Experiencing Complexity

A gaming approach for understanding infrastructure systems

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PREFACE

After six years, this thesis is finished. And by finishing it, it also means closing a part of my career, which I enjoyed from start to finish. Although it was great period, I am also glad it has become to an end. Many times, I have thought about this moment and what I could write in this preface. One of the main questions was how to characterize my PhD process. Many different metaphors came into my mind, like long distance running or travelling around the world. Both have comparable characteristics and experiences with doing PhD research, like starting with a lot of energy and motivation, which fluctuates over time, happy to see the finish line, meeting many people with different views and opinions and visiting many places. However, they are not really comparable. Maybe, the best description of my PhD is a combination of the following characteristics: challenging, a lot freedom within some boundaries, a clear final goal, which can be reached by many sub goals, interaction with a lot of people, and engaging... or briefly:

It looks like a game!

Although ultimately you have to write a dissertation alone, many people supported me during the process and I would like to thank them all for their support. To show my gratitude, some of them are mentioned in this preface.

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1. INTRODUCTION: UNDERSTANDING COMPLEX INFRASTRUCTURE SYSTEMS

Introduction

Our current society is highly dependent, both socially and economically, on well-functioning infrastructure systems. However, these infrastructures are increasingly difficult to manage, due to their high levels of interdependence. Furthermore, the development of new infrastructures faces challenges due to limited time and budget and social resistance (Flyvbjerg, 2007; Hertogh, Baker, Staal-Ong, & Westerveld, 2008; Priemus, 2007).

Each intervention in an infrastructure, be it small or large, affects the system behaviour, and the nature of these effects is uncertain. Direct effects of interventions can be more or less predicted. However, indirect effects, such as long-term or side effects, are unknown before implementation and are sometimes unexpected or undesired. In explaining these consequences, concepts such as self-organization, adaptation, feedback mechanisms and emergence are used. These concepts are all derived from complex systems thinking (Holland, 1995; Kauffman, 1993; Senge, 1990).

Before intervening, policy makers and designers of infrastructures try to reduce the uncertainties about the effects. In this way, they want to prevent making decisions that will lead to the worsening of the system's shortcomings or the emergence of undesired side effects. In theory, it is possible to implement interventions and observe the dynamics. However, for practical and financial reasons it is not advisable to simply test an intervention and remove it when the effects are different from those intended. Therefore, other methods are used to reduce these uncertainties.

If infrastructures can be considered to be complex systems, complexity theories can be used to explain the dynamics and patterns in infrastructures. However, theories cannot know the dynamics of a specific system in the future. Policy makers and designers use models and simulations to test alternatives and to analyse their possible physical and economic effects. One important element missing in these realistic simulations is the behaviour of individuals or organizations in the decision-making process and the use of infrastructure services. They are either not taken into account (Geurts & Vennix, 1989; Weijnen & Bouwmans, 2006) or they are simulated as ‘rational’ computer agents. A second disadvantage of models and simulations is that decision makers only see the outcomes of the simulation; they are in most cases not aware of the mechanisms within the model and how these can be influenced by the designers or by other individuals (Geurts & Vennix, 1989; Lee, 1994).

In order to gain better insight into system behaviour and consequences of interventions, another way needs to be found – a way in which policy makers and designers are part of the system. Serious gaming could be a possible solution, since it is a method that uses the advantages of computer simulations in a multi-actor setting where players become part of the system. In this dissertation, the use of serious gaming is explored as a means to increase our understanding of the dynamics of complex infrastructures.

Exploring planning decisions in the game SimCity

Let’s illustrate this new way of experiencing complexity of a system with gaming. We will use the example of the well-known game about urban development, SimCity, the first version of which was released in 1989 (Maxis Software Inc., 2003). Will Wright developed the game out of interest in city planning and computer modelling, and he was inspired by the work of Forrester (Forrester, 1969) on Urban Dynamics, Alexander (Alexander, 1965) on top-down models, and the colonial influences of Rybczynski (Rybczynski, 1995 in Lobo, 2007).

Building a city in an afternoon

On a rainy afternoon, I started my computer with the idea of developing my own perfect city. My goal was to build a city, with many detached houses, lots of green areas, less industry and no traffic jams. Of course, the city had to be financially healthy and the residents (called the Sims) had to be happy.

I started with an empty area; on the east side there was sea and on the north-west side, there were some mountains. That was a nice starting position to build my perfect city. Very soon, I recognized it was easier said than done. At the beginning, I did not only have to define zones for houses, but I also had to define industrial and agricultural areas. The city had to provide employment and enough food to become attractive for the Sims. I, as a mayor of the city, also had to build infrastructure systems, like power plants, water pumping systems and roads. All these activities polluted the air and water, which was against my first objectives.

When the number of Sims in the city grew, more requirements had to be fulfilled. In the first place, more space was needed for houses, industry and agriculture. Second, the capacity of the power plants and water supply systems had to grow, together with the demand. And third, new facilities had to be implemented, like educational institutes (schools, libraries, and museums) and other city facilities (fire department, police, recreation areas, treatment plants). Soon the capacity of the normal city roads was insufficient and the first traffic jams occurred, due to the growing number of Sims. One of my (computer-based) advisors told me to develop public transport (bus and metro system) and build highways; even harbours and airports belonged to the transportation possibilities. Unfortunately, the space of my area was limited and choices had to be made about what to be built and what not. On top of that, I also had to balance the finances. I could not spend more money than the income of the

taxes from the Sims.
At the end of the afternoon, I built a city, only not the city I would like to build. There was a lot of industry, there were capacity problems, and the green areas were used for other activities. Fortunately, it was only a game. Next time I can start again with an empty area.

Textbox 1-1 Personal experience of playing SimCity 4 (Maxis Software Inc., 2003)

Although SimCity is just a game, the dynamics show several patterns comparable with the development and use of real-world infrastructures. In the first place, SimCity shows the relevance of infrastructures for economic and social life. Second, the processes of the game demonstrate relations between different subsystems, like water, energy and road systems, in relation to urban planning. Third, the development of the city shows system effects. Multiple feedback loops can be found between the performances of different subsystems (Langley & Larsen, 1994). There are positive relations between recreational space and quality of the living environment and negative relations between industry and air quality. Furthermore, the system adapts to changes in the environment, based on the decisions of the player. The building of new roads or metro lines leads to an adapted flow of transportation of people. It is up to the player to find a balance between the available resources and the use of these resources. If the power plant or water supply is out of business due to lack of maintenance, the system has to find a new equilibrium, for example by moving people out of the city. The game also demonstrates the balancing process between economy and environment, the short- and long-term planning and how to deal with capacity problems. These are all subjects and dilemmas with which policy makers have to contend in the planning and design of real-world infrastructures.

Although many similarities between the game and reality can be observed, we have to be aware that the game also has limitations. The simulation is based on a number of unrealistic assumptions (Gaber, 2007); the city is built from scratch, decision making is based on economic driving forces, and the player has the full power to intervene. The player's interventions are not directly influenced by urban planners, pressure groups or residents. In reality, many actors make decisions with or without having knowledge of each other's actions; all decisions influence the system and its behaviour. Finally, important social and economic issues such as poverty and race are not taken into account. Until the latest version, SimCity Societies (Tilted Mill Entertainment, 2007), the city was a typical US-style city and did not take national differences into account.

Despite the limitations, the value of SimCity as a simulation of urban planning is recognized by urban planners and teachers. The game is used as a motivation tool in looking at urban dynamics in a city (Langley & Larsen, 1994) or as a way to make students aware of environmental issues (Nilsson, 2008). Despite the limitations, it offers possibilities to experience the consequences of different types of infrastructure decisions in a system context: on the one hand as simulation of a development of the city and on the other hand as an individual experience.

One could argue that this example of the SimCity gaming environment illustrates that games ‘simulate’ complex systems; using basic rules they show how complex system properties work, examples of these being system feedback, self-organizing power of individual people and emergent behaviour. The question is whether such gaming environments can also be used to improve insights into the complexity of infrastructure systems. If they *can* be used, what does this mean for purposes like planning, design and management of infrastructure projects?

Before describing the research done about the possibilities of games for understanding complex infrastructure systems, the main concepts behind this research need to be explained. What are infrastructures? What do we mean by complex systems? What do we mean by game environments and gaming? In the remainder of this introduction chapter, these questions will be addressed. Furthermore, it will be argued that games can fill a gap in the toolbox of managers and designers, allowing them to gain a better understanding of complex infrastructure systems. This leads to a general research question and several sub-questions, which can be found in Section 1.4.1.

1.1 Design of next generation infrastructures

This chapter started with the observation that infrastructures are important for our social and economic life, that interventions in infrastructures are difficult to design due to their complexity, and that the consequences of these interventions are difficult to predict. In this section we will take a closer look at the characteristics of infrastructures which make decision making and design difficult.

1.1.1 Next generation infrastructures

A general description of any infrastructure is ‘a system that is essential to the functioning of the economy’ (Hirschman, 1958 in Firth, Boersma, & Melody, 1998 p.24). As defined, infrastructures can be thought of as systems. However, the description gives no further clues about what infrastructures are. The US National Research Council gives a more functional description:

> ‘Infrastructures are facilities and their operations and the operating and management institutions that provide water, remove waste, facilitate movement of people and goods,

> and otherwise serve and support other economic and social activity or protect environmental quality (National Research Council, 1995, p.121).

This description shows that infrastructures are concerned with the transportation of matter (electricity, water, etc.), information and people. The educational system, waterworks, health and national defence (Stohler, 1977) and tourism, sports and cultural sector (Biehl, 1986) are also often considered as infrastructures. Consequently, infrastructure sectors are broad. In this research, we have looked at networked infrastructures that have a large physical and spatial impact, like cities, transport and transportation hubs (for example airports and sea ports) (Van Twist & Ten Heuvelhof, 1998).

Infrastructures must always be prepared for future generations. Therefore, infrastructures develop constantly so as to increase their capacity and satisfy the growing demand. Nowadays, infrastructure managers and designers have to search for more efficient and sustainable uses of infrastructures due to changing demands and social requirements. In this development, managers have to deal with technical, social and economic issues. Infrastructures use a physical network for the transportation of their goods or services, consisting of interconnected elements. These physical networks have a long lifespan and are expensive to build and modify. Therefore, infrastructures show network externalities (Noam, 1992), economies of scale and scope, and monopolistic characteristics. Infrastructures have a social function, so they need to be reliable, available and of high quality (Ten Heuvelhof, Koolstra, & Stout, 2001). Managers and designers of infrastructures have to deal with these requirements, which may conflict with each other. The interaction between the technical, social and economic characteristics makes infrastructures socio-technical systems (Herder, Bouwmans, Dijkema, Stikkelman, & Weijnen, 2008; Weijnen & Bouwmans, 2006).

Interventions in infrastructures are needed to safeguard their functioning while dealing with the dynamics in the environment. There are four trends in infrastructures identified (Weijnen & Bouwmans, 2006): 1) convergence, 2) internationalization, 3) demand for services and 4) institutional changes.

1. Technological developments make it possible for infrastructure systems to converge on the physical, organizational, market and spatial levels (Hansman, Magee, Neufville, Robins, & Roos, 2006). This leads to bundled networks, networks with multiple functions and multi-utility companies. This convergence has advantages for exchanging services and coupling different networks. For example, the development of the Internet Protocol structures the communication between computers. However, a consequence of this intense integration between different networks is that failures in one network affect the functioning of related networks. The effects of integration and

interaction make it difficult to find the cause of the problem and to identify responsibilities.

2. Infrastructures are today broadening to become international systems, leading to larger interconnected physical and social networks and to larger areas (i.e., not only local) being affected by system failures. This became clear when, on November 4th, 2006, Eon Netz closed a high-voltage cable. This action increased the voltage through other high-voltage cables to such a level that these cables disconnected (*Algemeen Dagblad*, January 31st, 2007)[1]. Consequently, millions of households in The Netherlands, France, Belgium, Italy, Portugal and Spain had no electricity for some time, despite the fact that they had providers other than Eon Netz. At the same time, there is a tendency to decentralize activities. This decentralization requires much coordination between different organizations. For example, individual wind turbines or solar collectors are small-scale energy producers connected to the network, and they influence the energy production of the large-scale producers. Another example of this coordination is related to the building of an off-shore wind farm. This farm needs a physical point at which it can connect to the power grid. The farm and its connection point are built by two different companies, and investment only becomes interesting after both activities are done.

3. There is a growing demand by consumers for services and flexibility (Hansman et al., 2006). The overall demand is increasing; however, the fluctuations in use over the course of a day are uncertain. Infrastructures have to become flexible, which is often done by means of technological innovations. These technology-driven changes make the infrastructure less dependent on human failure but more dependent on technology.

4. Due to a process of liberalization and privatization of public infrastructure companies, the institutional systems change. This is also known as a shift in paradigm (Hansman et al., 2006; Ten Heuvelhof et al., 2001; Weijnen, Ten Heuvelhof, Herder, & Kuit, 2003). Consequently, the number of actors increases as new players are defined and new actors enter the playing field (Weijnen & Bouwmans, 2006). These players have different roles and objectives, leading to a greater likelihood of strategic behaviour and information asymmetry (Trujillo, Quinet, & Estache, 2002). New actors and new roles mean new social and legal rules. Competition is encouraged in order to increase efficiency, and regulators are introduced so as to safeguard public values.

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[1] According to Eon, the problem was caused by a human mistake based on a wrong simulation (Trouw, November 17th, 2006), but the European Commission said it was caused by a lack of communication (NRC, December 13th, 2006). The internationalization gives more related subsystems and unclear responsibilities.

According to Hansman and others (Hansman et al., 2006; Ten Heuvelhof et al., 2001; Westerduin, 1998) all infrastructure sectors are facing these trends in varying degrees. The combinations of these trends give even more components, relations and unexpected behaviour, which make infrastructures even more complex. This increased complexity adds a further challenge to the planning and design of next generation infrastructures.

1.1.2 Planning and design of infrastructures

To adapt to the dynamic environment and maintain high quality, interventions are constantly being made in infrastructure systems. Interventions consist of the planning, design and construction of new subsystems. These interventions are often said to be ill-structured because of a lack of knowledge about the consequences of the interventions and the values of the directly or indirectly affected actors. These actors have different objectives and different views of the problem situation. Each actor would like to optimize his or her values, which can lead to conflicting situations. The consequences of the interventions are unknown and unpredictable, due to integrated and long-term effects.

Based on earlier experiences in infrastructure projects, three general dilemmas in the planning, design and construction of infrastructures projects can be observed: 1) short-term vs. long-term behaviour, 2) public vs. private interest, and 3) environmental vs. economic issues. These three points will be discussed in the following paragraphs.

Infrastructure projects have lengthy decision-making processes, and physical interventions have long lifetimes. This offers possibilities for self-organization and adaptation. Problems, values and solutions change over time due to the self-organizing properties of systems. Sometimes the magnitude of the problems decreases, making interventions unnecessary. When policy makers have to intervene, they must be aware that interventions directly change the variables. Yet the changes can also indirectly affect variables in other parts of the system (Senge, Roberts, & Ross, 1994; Weijnen & Bouwmans, 2006). It is possible that interventions in the short term move the system to the desired state, while in the long term undesired effects can be observed. For instance, building more roads solves the problem of traffic jams in the short term. However, fewer traffic jams increases the value of having a car, thus the number of cars increases and traffic jams return in the longer term. Examples of adaptation include using new technologies which become available during the project.

A second dilemma for designers of infrastructures is the discrepancy between public and private interests. Whereas private organizations want to make money and cost-effectiveness is an important criterion, public organizations aim at safeguarding public values like quality, safety and sustainability. On the one hand, defining clear objectives can be difficult because of conflicting criteria. On the other hand, this broad set of criteria assures that multiple system effects are taken into account. Designing infrastructures, such as developing new services or adaptations in the network, demands that these conflicting interests are dealt with.

Third, there are dilemmas between environmental and economic issues. Most infrastructure problems are initiated from an economic perspective. The extension of the Schiphol Airport, the Port of Rotterdam, the construction of the High-Speed Line or the *Betuwelijn*, are necessary to support the economic growth in The Netherlands. However, these and other infrastructures need space, and using them produces emissions, radiation and/or noise. Thus, aside from the expected potential economic effects, there are many unknown and uncertain environmental effects. Dutch regulation requires an Environmental Impact Assessment in these types of projects, where attention must be given to the future effects; nonetheless, this gives no certainty. In The Netherlands, as well as in many other countries, many infrastructure projects are delayed by environmental and other conflicting issues (Flyvbjerg, 2007). Although stakeholders are aware of the economic importance of infrastructure, policy makers have to balance the economic value against the social and environmental issues in a convincing way.

These dilemmas are not always clear at the start of a project or intervention. Consequently, many infrastructure projects exceed the initial budget and time planning. Several researches, like the Parliamentary Committee on Infrastructure Projects in 2004, show that this is caused by three reasons (Flyvbjerg, 2007; Priemus, 2007). The first is a delay due to technical shortcomings, such as imperfect forecasting, and inadequate data and changing designs resulting from the availability of new techniques or materials. The second reason is described as a psychological effect caused by planning fallacy and optimism bias. Third is a political-economic explanation. Planners and promoters overestimate benefits and underestimate costs. This is a strategic decision intended to increase the likelihood of gaining approval and funding (Flyvbjerg, 2007 p.583).

1.1.3 Lack of understanding about infrastructures

The observed dilemmas and consequences regarding the effects of the intervention, delays in implementation and higher costs are caused by the complexity of the system. Infrastructure systems can not be considered as a single technical aspect. It is not possible to design new infrastructures without the knowledge of both physical and social elements (Herder et al., 2008).

Due to the trends in infrastructures, infrastructures are becoming more integrated and more difficult to manage, and more and more dilemmas can be observed. In order to deal with these dilemmas, policy makers and designers need a better understanding of systems behaviour. To take the different issues into account, a holistic system perspective, including technical, social and economic elements, is needed in order to analyse the behaviour of the system.

1.2 Complex systems: on the edge between order and chaos

The lack of understanding about the dynamics and behaviour of infrastructures can be reduced by taking a systems perspective. A system is a set of elements in interrelation among themselves and with the environment (Von Bertalanffy, 1975 p.159). The elements interact to function as a whole (Maani & Cavana, 2000 p.6) and the total behaviour of the system is more than the sum of the individual behaviours (Senge, 1990; Waldrop, 1992). Or, in other words, complex systems have emergent properties (Holland, 1997).

1.2.1 Complex Adaptive Systems (CAS)

Within complex systems thinking, several fields analyse systems in different ways. For example, the following fields can be identified: General Systems Theory (Von Bertalanffy, 1968, 1975), Systems Thinking (Forrester, 1958; Senge, 1990; Sterman, 2000), Chaos Theory (Gleick, 1988), and Complex Adaptive Systems (Crutchfield, 1994a; Gell-Mann, 1994; Holland, 1995; Kauffman, 1993). Although these fields have several differences, they have in common that they describe systems consisting of heterogeneous interrelated elements which are dynamic and show emergent behaviour. Emergent behaviour is a logical consequence of the interaction in the system and the organizational structure of the system which gives the elements qualities that they could not have if they were isolated from the organizing whole (Morin, 1999 p. 118). Emergent behaviour is often observed in highly connected systems with moderate non-linear relations. Complex systems are open systems and have the ability to adapt to changes in the environment. Therefore, these systems are also called complex *adaptive* systems (CAS). CAS continuously balances between structuring the system and adapting to survive in a dynamic environment. These systems evolve naturally, without control, but not so much as to destroy the essential order and structure of the system and the balance on the edge between order and chaos. Characteristics of CAS and observable phenomena are further explained in Chapter 2.

1.2.2 Complicated and complex systems

Not all systems are considered to be complex. Systems are described as complex when there are: a) many elements or subsystems, b) when the elements have many interrelationships (Kauffman, 1993), c) when there is a certain ratio between the number of elements and the number of relationships each element has with other elements (Barabási, 2002 p.196; Wolfram, 1984) or d) when the system has a high degree of hierarchy (levels) (Lehn & Ball, 2000 p.349). Many complex systems meet multiple criteria of complexity. However, there is a subjective and an objective connotation of complex systems.

Systems with many elements and interrelationships are often related to complicated systems. Complicated systems are systems which are difficult to understand due to the *number of elements*. Complicated systems have a subjective connotation, because the degree of complexity depends on the observer of the system. A layman will describe a system as being more complicated than will an expert. Another description of complicated systems is the effort or perceived effort that is required to understand and cope with the system (Backlund, 2002 p.31). A way to increase the understanding of complicated systems is by defining understandable subsystems.

Another way of describing complex system is a composite system with different hierarchical layers. These systems cannot be understood by solely understanding the subsystems. Increasing complexity refers to the elaboration in organizational structure without necessarily increasing the number of components (Arthur, 1994; Hmelo-Silver & Azevedo, 2006). In contrast to the subjective connotation of 'complicatedness', 'complexity' is viewed as being more objective. This means that relatively easy to understand – or simple – systems, consisting of few components and links, can have features of complex systems (Sweeney & Meadows, 2001).

1.2.3 Infrastructures as complex adaptive systems

Based on the general characteristics of complexity, we can describe infrastructures as complex adaptive systems. Infrastructures consist of many different subsystems, like rails, stations, trains, passengers, traffic management systems and many more.

Because these subsystems could have technical and social characteristics they have to be considered as socio-technical systems. Each subsystem has its function in the total system, influences other subsystems and is necessary for the functioning of the system as a whole. Infrastructure systems are dynamic and exhibit non-linear behaviour. The performance of an infrastructure is an example of emergent behaviour, because it is a result of the interactions of the subsystems. Other examples of emergence are unforeseen power black-outs and traffic jams. Finally, infrastructures are open systems. They continuously adapt to changes in the demand, such as more traffic, and both short- and long-term requirements. For example, sustainability is becoming an important topic and will need to be integrated into many of our current systems. In Section 2.4, infrastructure systems are analysed as complex systems in more detail.

Next generation infrastructure *projects* take place within these complex systems. These projects intervene in the physical systems and are placed in a multi-actor context. The individual decision makers have their own motives for being involved and have their own priorities and objectives, as observed by Flyvbjerg (Flyvbjerg, 2007). The decision making is hampered because no objective information is available about the direct and indirect consequences in either the short- or long-term. This is also impossible if you take the non-linearity of the system into account.

Infrastructures contain common characteristics of complex adaptive systems. Therefore, a CAS perspective is used to support the understanding of the dynamics in a system. Because the human brain is limited in processing a large number of elements and feedback mechanisms, we need supporting tools. These tools can simulate system behaviour and contribute to our understanding of these complex infrastructure systems.

1.3 Tools for understanding complex systems

Policy makers and designers of infrastructures have to deal with many uncertainties during the design and decision-making process. In order to reduce the uncertainties, they use different supporting tools. A collection of these tools are models and simulations. These models and simulations are descriptive as well as normative and can be expressed verbally, symbolically or procedurally (Dunn, 1981 p.110-115). In general, models and simulations are used for problem structuring, for reducing knowledge gaps, for comparing alternative solutions and for forecasting. Shannon (1975) describes simulations as the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system. This section gives a short overview of the different types of tools and introduces gaming as one of them. In Chapter 3, the use of gaming for understanding complex infrastructures is analysed in more detail.

1.3.1 Modelling socio-technical systems

Much research is carried out on the physical effects of new designs through calculations of strengths, multi-criteria analyses, life cycle analyses, etc. However, to gain a holistic view of the dynamics within a system, scale models or simulations are used. The advantage of conceptual models and computer simulations is that they define the relevant elements and relations and can calculate long-term behaviour. Furthermore, computer simulations are capable of testing different designs in different scenarios. Researchers can use these simulations to search for sensitive parameters and unexpected behaviour and outcomes. Well-known models for simulating complex systems are System Dynamics models (Forrester, 2007), Cellular Automata and Agent-Based Models (Axelrod, 1997; Holland, 1995).

These simulations are useful; however, they have two important disadvantages. The first is that the political and positional rationality of social actors are not taken into account. If social actors are added to the computer model, they have to be formalized in mathematical symbols. In this process, the social rationality is excluded. The second limitation is that simulations are developed by modelling experts and these models are often black boxes for the policy makers and designers of infrastructures. Communication about simulations and the use of the simulation in the design process has proven to be difficult. This lack of using simulations is called the 'implementation gap' (Lee, 1973; Te Brömmelstroet & Bertolini, 2008).

Participatory modelling and group modelling are introduced to deal with this implementation gap (Anderson, Vennix, Richardson, & Rouwette, 2007). In this situation, policy and decision makers become part of the modelling process, which gives them more insight in the model. Furthermore, visualization of model output is improved, which makes the models easier to understand.

Although these types of modelling improve communication about the model and allow for a closer relation between policy makers and modellers, the social actors are still outside the boundaries of the model. To investigate the uncertainties and knowledge gaps in the social network, there are several other tools available. For example, a descriptive actor analysis can be done in which the relevant actors, their opinions, resources and power and the dependencies are taken into account (De Bruijn & Ten Heuvelhof, 2008). By continuously adapting the analysis to include the strategic behaviour of actors, new actors and additional information, insights about the dynamics in the network can be derived. Another way of investigating social networks is to simulate this network in a role play. In a role play, participants are asked to identify themselves with a given role. They receive a role description and a problem which has to be solved together with the other participants. In this process, the different values and objectives and possible conflicts can be observed and solved. A disadvantage of this approach is that there is no reality check of the outcome. Finally, people could come to consensus about a solution which could be technically impossible. Especially in socio-technical systems, like infrastructures, there have to be checks between the negotiated solutions and reality. To investigate the social network and the physical system together, simulations and role plays have to be combined. This can be done in simulation gaming.

1.3.2 Gaming: simulating socio-technical systems

To deal with technical and social systems together, multi-dimensional models have to be used. Simulation gaming is a method in which it is possible to take into account the simulated technical system and the simulated social system. Simulation games can be described as:

> A representation of a set of key relationships and structure elements of a particular issue or a problem environment, where the behaviour of actors and the effects of their decision are a direct result of the rules guiding the interaction between these actors (Wenzler, 2003).

Simulation gaming can offset the limitations of computer simulations. In the first place, players are an important element in simulation games. Players become part of the system by interacting with each other, supported by simulations of the physical system. Social elements do not have to be modelled with mathematical symbols; they are played by the social elements themselves. Second, by being part of the simulation, the players experience the consequences of their decisions and directly react to this. In this way, the black box of the simulation is opened. Simulation gaming also deals with the disadvantage of role play, by including the reality check in a simulation.

Gaming also has some limitations. One of the limitations is the impossibility to reproduce the game. Whereas computer simulations can be started many times, games are dependent on the availability and characteristics of the players (Geurts & Vennix, 1989). Secondly, the number of possible simulation runs is reduced by the fact that it takes longer to play a simulation game than it does for computers to run the simulations. Third, a game cannot be repeated with the same starting position. The game can be played multiple times; however, each time it is played there are either different participants, who will of course have their own interpretations and roles, or participants who have already played the game, which increases their knowledge and affects their responses in the new game.

Gaming has been used in understanding complex systems for a long time and for many topics, including urban planning, business, strategic management, social issues, etc. It is used in different steps in the design and decision-making process: communication, problem analyses, testing alternative solutions and forecasting. As Duke argued in 1974 (Duke, 1974), playing a multiplayer game starts discussions about the topic, the relations and the outcome of the game. Simulation games have proven to be an effective way to enhance social interplay and to create and learn about organization knowledge, as well as being good for increasing a shared holistic understanding of the work process (Forssén & Haho, 2001). Nonetheless, there is little scientific evidence that gaming works. In relation to understanding complex systems, games focus on making sense of reality in terms of processing meaning between the participants/actors. Especially in free-form games – games with multiple possible solutions – they are considered to be self-referential systems (Klabbers, 2006b).

1.3.3 Serious gaming

In gaming, computers were mainly used for simple calculations, like finance in business games, or for facilitation, presentation and communication, but not to improve the realism of simulated technical systems. The developments in the entertainment gaming industry and the availability of the source code have increased the attention that is being given to using these technologies in simulation games and simulating a more realistic world. This process has been further encouraged by the expectations about future policy makers, who are growing up in the digital era. The introduction of computer gaming technology leads to new possibilities and uses of simulation gaming, but also to new questions about the design and added value.

For the purpose of this research, these simulation games with the use of knowledge of the computer and entertainment game industry are called ‘serious games’. This term is derived from the entertainment industry, where entertainment games are sometimes used for serious purposes, as shown in the example of SimCity at the beginning of this chapter. Players take on the roles of managers of large technical projects. They have to deal with limited resources, time and emergent effects. For example, in Civilization (Firaxis Games, 2005), players have to manage communities and build a realm from scratch. To become a world leader, the players have to deal with constructing cities and thinking about politics, economics and knowledge creation.

Playing these games involves complex and important concepts which are relevant for real world projects, such as mathematics, science, history, sociology, economics and even urban and regional planning (Shaffer, 2006 p.169). In these building and strategy games, players have to train their strategic skills and think about the long-term consequences of their decisions. Aside from entertainment value, these games could also have an educational value. Kurt Squire (2004) found that the game Civilization III, when used for educational purposes, engaged each student in unique ways. He observed this in the different types of questions students asked, the different conceptual understandings during game play and different interpretations about history. His research supports the idea of using entertainment games for education, but also shows the significant, unsolved challenges of integrating entertainment games in classroom settings.

While low-tech role-playing games are still used and are effective in simulating social systems, with infrastructures the physical system has to be taken into account. Therefore, this research focuses on serious games. Starting from the idea that infrastructures are complex systems, their physical complexity can be simulated via computer simulation or a digital gaming environment.

1.3.4 Future policy makers

One of the underlying ideas behind exploring the use of serious games for policy and decision making is that the current generation of teenagers is growing up in an information and communication era. They use applications such as computers, mobile phones, Internet and other ICT-applications daily. These *Digital Natives* (Prensky, 2001) and *Netgeneration* (Tapscott, 1998) use this technology as a first language, and it is argued that this changes people’s cognitive learning styles (Prensky, 2001). Characteristics of this generation are that they are digitally literate, have a preference for structure and experiential learning, are social, goal-oriented, community-minded, connected, multi-taskers, have a preference for group work and have resistance against reading and text. Consequently, education has to be adapted to this new generation of students. Digital game-based learning fits this group (Prensky, 2001). Although this opinion is shared by many other researchers (Bergeron, 2006; Gee, 2003; Oblinger, 2004; Veen, 2006), there is hardly any empirical evidence for these claims. Bennett et al. (Bennett, Maton, & Kervin, 2008) go so far as to name the call for changing education ‘moral panic’.

Although empirical evidence is scarce and the differences among the digital natives are as large as between digital natives and other generations, the use of technology in education has changed. This will also necessarily pass through the policy- and decision-making processes when this next generation of policy makers start their careers. Although still undefined, serious games could play a role in this changing environment. Therefore, it is interesting to explore the possibilities of serious gaming for policy and decision making.

1.4 Gaming as a way to understand complex infrastructure systems

In the previous sections, three concepts were introduced: infrastructures (Section 1.1), complex systems (Section 1.2) and simulation gaming (Section 1.3). This chapter started with the dilemmas faced in the planning and construction phase of infrastructure projects. These dilemmas are caused by a lack of understanding of these socio-technical systems. It is argued that policy makers and designers need a holistic view of the systems on which they work. They can use a complex adaptive systems perspective as a frame of reference to analyse the dynamics in infrastructure systems. However, this perspective does not provide information about future system behaviour. Policy makers and designers use simulation tools to explore this future. Because of the socio-technical characteristics of infrastructures, serious gaming is proposed as a tool to gain more insights into the socio-technical behaviour of systems and to experience their complexity.

The combination of technology and game mechanics of the entertainment game industry and experiences from simulation gaming seems to become a strong partnership for understanding infrastructure systems from a complex systems perspective. It is expected that computer simulations can represent more complicated systems, can provide better visualisation of the consequences of the decisions and fit with the changing attitude of the next generation managers. This leads to the following hypothesis as a starting point of this research:

> Serious gaming is a useful tool to simulate complex socio-technical infrastructure systems and supports policy makers and designers in understanding the complexity of the planning and design of these systems.

To research this hypothesis, we have to further explore the relationships between the three concepts. We identify three relationships and define several questions about them. These relationships are visualized in Figure 1-1.

The first relationship is between the design of infrastructures and complex adaptive systems. CAS is used as an analysis framework for the understanding of infrastructure systems. Relevant research questions related to this relationship are: what are the characteristics of complex adaptive systems, and in what way can this framework increase the knowledge about infrastructure systems?

The second link is the relationship between serious games and complex adaptive systems. Games are considered to be a simulation or a representation of CAS. The questions about this relationship concern the circumstances under which games can simulate complex systems and the design criteria that have to be fulfilled.

Finally, there is a relationship between the designing of infrastructures and serious games. This relationship is about the use of gaming as a support tool for understanding the complexity of infrastructure systems. With a support tool is meant a tool or instrument which can contribute to the planning and design of infrastructures in different ways. Questions about this relationship are: in which way can gaming be used in the policy-making process, and what can be learned about the system?

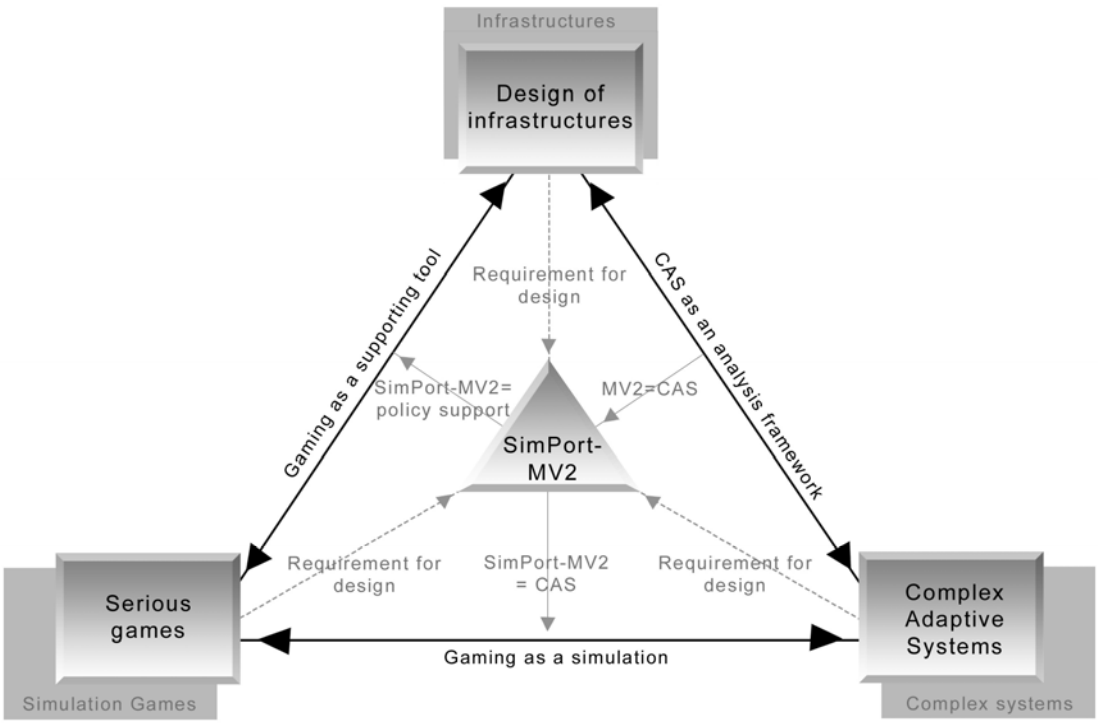

Figure 1-1. Research framework showing the relation between the key concepts and the function of the game SimPort-MV2

In the centre of Figure 1-1 is the game SimPort-MV2. This game, about the planning and design of the Second Maasvlakte in the Port of Rotterdam, is used for the analysis of the relationships in practice. This game is developed based on the requirements from the three concepts and is used to further explore the relationships between the concepts and to support the theoretical notions with empirical evidence.

1.4.1 Research questions

The objective of this research is to explore the use of serious gaming for infrastructure planning processes from a complex adaptive system perspective. This leads to the following main research questions of this dissertation:

> To what extent can serious gaming simulate complex infrastructure systems, and how can serious gaming be used in understanding complex infrastructure systems?

To answer these questions, several sub-questions are formulated, based on the relationships between the three concepts shown in Figure 1-1:

RQ1: What are complex systems, and in what way does complex systems theory contribute to the understanding of infrastructure systems? (Chapter 2)

RQ2: What properties make serious gaming suitable for simulating complex adaptive systems? (Chapter 3)

RQ3: In what way can serious gaming support the policy-relevant understanding of complex infrastructure systems? (Chapter 3)

The theory-based analysis leads to a framework, which is needed for analysing complex systems and games. This framework has to be specific enough to distinguish between simple and complex systems and broad enough to be used in the analysis of different infrastructures. Second, this analysis creates several requirements for serious game design. In the third place, it is investigated in which way serious gaming could contribute to the understanding of complex infrastructure systems, relevant for policy processes. This is done on two levels. The first is exploring the system behaviour of the simulated system, to get the ‘big picture’. The second is the individual understanding of the complexity of the system by the players. This individual understanding is based on increasing knowledge of the system and skills to be used in the policy process.

An empirical study of the development and use of serious gaming has been conducted in order to answer the following sub-questions:

RQ4: What are the lessons learned from the development of a serious game about complex infrastructure planning? (Chapter 6)

RQ5: What lessons learned about the complex system behaviour in gaming can help us to improve our understanding of complex infrastructure systems in reality? (Chapter 7)

RQ6: What knowledge and skills do players gain about complex infrastructure systems from being involved in and part of the system? (Chapter 8)

1.4.2 General research approach

This research links the concepts of infrastructures, complex adaptive systems and games. With these links, we contribute to the scientific and social community as explained below. Because this research is focused on the relation between these three concepts, clear boundaries and scope are defined. Finally, the general research approach is described. The approach followed for the empirical part of the study is discussed in more detail in Chapter 4.

Scientific and social relevance

This research contributes to the scientific community in several ways. The dissertation attempts to provide a generic framework to analyse complex systems in general and infrastructures in particular. With this framework, the discussion about complex systems can be structured. This framework also contributes to the discussion about using gaming to better understand complex systems. It is often mentioned that gaming can be used for understanding complexity; however, it is unclear what this means. Secondly, this research proposes a game research methodology. Although this method is tested for only one case, it is a starting point from which to structure the research of serious games and is a contribution to the game research field. Furthermore, this research provides empirical evidence as to if and why games give us an increased understanding of complexity.

In addition to the scientific value of this research, the research also makes a societal contribution. In this research, a new serious game about the policy-making process of Maasvlakte 2 is developed, tested and evaluated. This game is used within the Port of Rotterdam for policy support, and the game has been used as a learning tool in different educational settings. Further, this research contributes to the public discussion about serious games and foundations of the learning effects of gaming. The results can be used as a starting point for future research about the use of serious gaming in policy- and decision-making processes.

Focus and scope

This study of the use of gaming for understanding infrastructures demands several boundaries. As we already described, many different sectors can be considered as infrastructure and many different types of problems can be investigated. In this research, we have focused on urban and spatial infrastructures and especially the planning and design of these infrastructures. Furthermore, these infrastructures have been studied in a holistic way, which means that technical, economic and social parts were not studied in detail.

Based on the focus of planning and design, we mainly studied games which are categorized as building and strategic games. The objectives and behaviour in these games have similar characteristics as those found in the planning and design of infrastructures. The objectives of other types of games, like first person shooters, market games or sport games, generally are unrelated to systems construction or to strategic choices and long-term consequences. For example, first person training games are used for emergency training, like Levee Patroller (GeoDelft, 2006) or Hazmat Hotzone (Entertainment Technology Center & Carnegie Mellon University, 2007). Market games show the balancing process between demand and supply and are more related to business games. When necessary, other types of games have been used for explanation or to illustrate differences.

The third main boundary is to measure the general learning effects of individual players as well as system behaviour. General effects are measured, because of the exploratory character of the possibilities of using serious gaming. This means we did not focus on detailed learning effects, nor did we conduct a comparative study of effectiveness with other educational or policy-making tools.

Research approach

Gaming research balances between analytical and design science (Klabbers, 2006; Meijer, 2009). Both approaches are used together, often without the researcher knowing this (Klabbers, 2003, 2009a). We have chosen to follow design science with some elements from analytical science, because we want to know if games work. The main question is whether games can be used to improve the understanding of complex adaptive systems. We therefore focus on this rather than testing a hypothesis of a theory which relates to analytical science.

Within the design science, the design research approach is followed. This approach has its foundations in the Information Systems Research, but is also applied in other fields. The fundamental principle of design research is that knowledge and understanding of a design problem and its solution are acquired in building and application of the artefact (Hevner, 2007; Hevner, March, Park and Ram, 2004). Therefore, the design research approach combines the environment, the design research and the knowledge base. This is done in three design research cycles (Hevner, 2007). The first is the rigor cycle. This cycle provides the foundations and methods for the design. The results of the design approach contribute to the foundations. The second cycle is the relevance cycle, which links the application field with the design. Problems and questions of the application field are identified and the developed artefact can be used in the application field. The third cycle is the design cycle consisting of the development and evaluation of the artefact.

The rigor cycle in this research discusses theories about gaming and complex adaptive systems. The objective of the rigor cycle is to get a better understanding of what complex adaptive systems are and why gaming can support the understanding of these systems. Therefore, the research started with a literature study and the development of a framework for understanding infrastructure systems. Literature about gaming was used to analyse whether games can be used to simulate complex adaptive systems, and if so, under which conditions. This leads to a set of criteria for choosing a serious game and developing a serious game about complex adaptive systems.

In the relevance cycle, the Maasvlakte 2 case is further studied to identify the questions of The Port of Rotterdam Authority. They want to synchronize the building and exploitation process in such way that no empty spaces are left open in this area. They would like to know what long-term consequences this 'building on demand' could have and where bottlenecks could emerge. The reason for using gaming was to be able to gain more insights into these processes. After development, the game was evaluated on the system level. The question explored was whether it is possible to identify patterns of complex system behaviour. Secondly, the game was evaluated on the level of the individual player. The main question was: did the players improve their understanding of complex systems and Maasvlakte 2? In answering these questions, analytical methods were used, based on simulation outputs and surveys.

The design cycles consist of the development and evaluation of a serious game, called SimPort-MV2. This game is about the development of a new port area, Maasvlakte 2, in the Port of Rotterdam, The Netherlands. In the development the questions of the relevance cycle and the foundations and criteria of the rigor cycle have to be taken into account, in the development as well as in the evaluation of the serious game.

1.5 Outline of the dissertation

In Chapter 2, we further elaborate on the complexity of infrastructure systems. A complex adaptive system framework is developed, which is used for a descriptive analysis of infrastructures. In the third chapter, the relationships between serious games and CAS and between serious games and infrastructures are further explored. The objective of Chapter 3 is to argue under what conditions serious games can simulate complex adaptive systems and in which way games can be used as supporting tools to increase the understanding of infrastructures. A distinction is made between individual and system understanding.

These ideas are tested and further explored with the development and evaluation of a game. There is no single approach to researching games; game research uses methodologies from different fields. Consequently, before starting the empirical exploration, a research approach had to be designed. The discussion about the design research approach followed, together with the used methods and the way of analyzing the data, can be found in Chapter 4.

The increased individual and system understanding are tested in a case about the extension of the port area in Rotterdam, the Second Maasvlakte (MV2). Chapter 5 describes MV2 as a complex system. The design of the game SimPort-MV2 and the validation can be read in Chapter 6.

Chapter 7 describes the analysis of the game outcome and relates this behaviour in the game with the real-world system. These patterns can be used in the decision-making process of the Port of Rotterdam about the design and management of MV2. Additionally, the game mechanisms provide relevant information to support the theory about complex adaptive systems. Chapter 8 gives the results of the session from the players' perspective, or the individual's understanding. The game is played with professionals of the Port of Rotterdam, other professionals in the field of port planning, students at the Delft University of Technology and others. Observations, debriefing and surveys provide information about the players' learning about MV2.

The final answers to the main research questions can be found in Chapter 9. This chapter gives the conclusions and recommendations about the use of serious gaming in improving our understanding of complex infrastructure systems.

2. TOWARDS A FRAMEWORK FOR UNDERSTANDING INFRASTRUCTURES

Introduction

In Chapter 1, infrastructures were introduced as complex socio-technical systems relevant for the functioning of society. The design, planning and building of infrastructures were described as ill-structured problems within complex systems. Improving this design and building process requires a better understanding of these complex infrastructure systems.

The objective of this chapter is to explore the complexity of infrastructure design and management. This means that we have to take a closer look at characteristics of infrastructures based on the properties of a Complex Adaptive System (CAS) (Figure 2-1). The first step is to elaborate more on the characteristics of infrastructures, the relevant physical and social elements and the problems managers of infrastructures observe (see Section 2.1). Because the range of infrastructure types is broad, it was decided to focus on network-bounded infrastructures that have large physical and spatial impact, like cities and main ports.

In Section 2.2 several systems-thinking perspectives are introduced. CAS is chosen as the most appropriate for understanding infrastructures. Before infrastructures can be described from a CAS perspective, it is necessary to develop a framework containing the observable properties of CAS. This CAS framework, consisting of three conceptual levels, is based on a literature study. The conceptual levels show three different perspectives to describe and analyse complex systems. This chapter answers the questions of what the properties of complex systems are and in what way these contribute to the understanding of infrastructure systems.

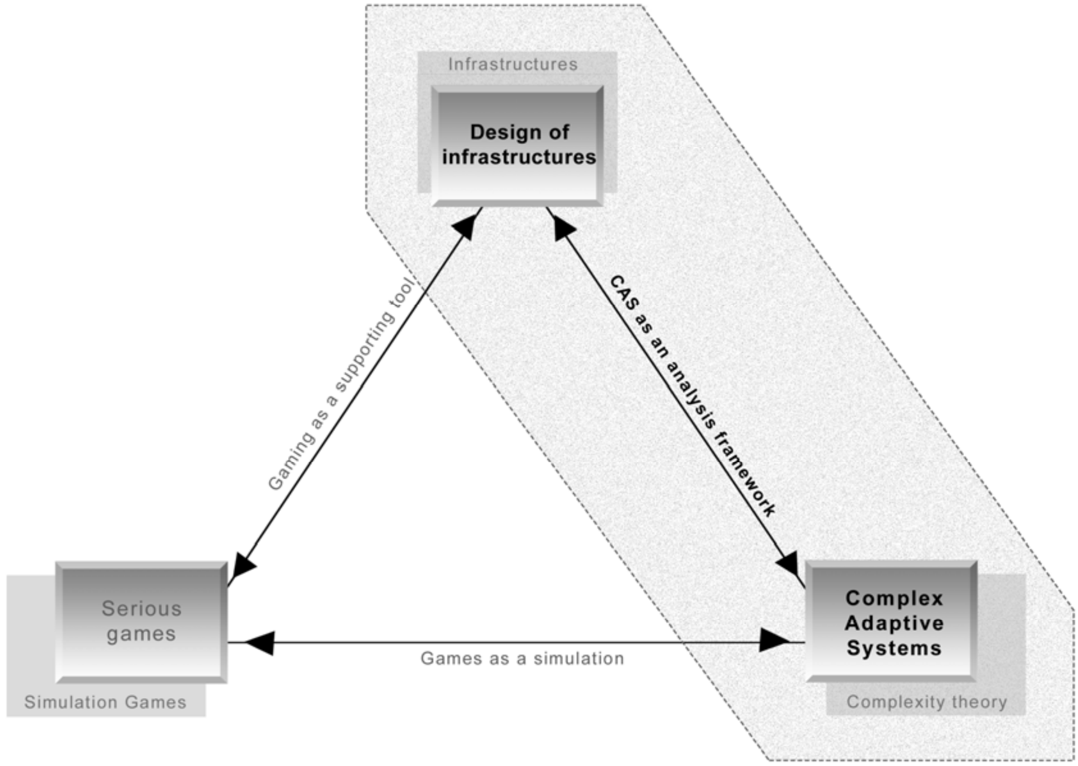

Figure 2-1. This chapter focuses on the relation between infrastructures and complex systems.

2.1 Socio-technical infrastructure systems

Infrastructures are essential systems for the economy and contain technical, social and economic characteristics. These infrastructures are increasingly becoming more complex due to convergence, internationalization, change in demand for service, and institutional changes (Weijnen & Bouwmans, 2006). This increasing complexity has consequences for the design and management of infrastructure systems. Intervening in an infrastructure has many effects on the existing system in question and on the output of that system. These effects are unknown and uncertain. To increase the understanding of these systems and the success of interventions, we need to further explore the characteristics of infrastructures and the consequences of interventions in the system.

2.1.1 Characteristics of infrastructures

Infrastructures exist in many shapes and forms. The sectors included and the system boundaries are ambiguous and flexible over time (Moteff & Parfomak, 2004). They have in common that they facilitate the transportation of matter, people and information and that they support economic and social life. The components of an infrastructure system are also similar: physical network, services over the network, rules and incentives of the system, and the social network around the system.

Physical network: Infrastructures are network-bounded systems, often consisting of large networks. This physical network consists of components of producing, transporting and using the services over the network. For example, electricity networks begin with a production plant; the produced electricity is transported over high-voltage and low-voltage cables towards the consumers, for the purposes of computer, lights, television, etc. These infrastructures are indivisible, because production is not separate from distribution and consumption (Herder & Verwater-Lukszo, 2006). Other characteristics are the costly construction of physical infrastructures and their long lifetimes. Therefore, physical infrastructures show network externalities (Noam, 1992), economies of scale and scope and monopolistic characteristics.

Services over the network: Each infrastructure network has a function in society. The relevance of the networks requires that these networks be reliable, available and of high quality (Ten Heuvelhof, Koolstra, & Stout, 2001). Some networks can provide multiple functions, like combined telephone and Internet services. The capacity of the network determines the amount of service available. When the demand for services increases, then the physical network has to be extended.

Rules and incentives: To attain high quality in the services and the network, many rules and norms are secured via laws or agreements. For example, in The Netherlands we have the Electricity Law of 1998, Gas Law, Telecommunications Law and Water Board Law. These laws describe the inspection and quality of the different products. Especially after the liberalization of several infrastructure markets, these laws became important not only to stimulate competition but also to ensure quality. In addition to the rules, government uses incentives like subsidies to make infrastructures sustainable.

Actor network around infrastructures: These physical systems, the services and the rules and incentives are all influenced by – and in turn influence – a large network of actors. These actors can be on the production side, the consumption side or even both simultaneously. In this network, there are also regulators, government, service providers and more organizations, which all have a stake in the use and development of infrastructures. Indirectly, this actor network also includes the actors who are negatively affected by the construction and use of infrastructures.

We see that infrastructures are large systems having many physical, social and economic elements, all relevant at the same time and all being highly dependent on the proper functioning of the infrastructure as a whole. Now it is time to unravel these tangled infrastructures.

2.1.2 Unravelling infrastructure systems

The first step in improving the understanding of infrastructures is to research the elements and structure of a system. Infrastructures contain technical and social subsystems. Each subsystem consists of different elements and is bounded to different type of rules. Apart from the complexity of these subsystems, on the interface between these systems additional relationships emerge, making them socio-technical systems.

Technical systems

Infrastructures are the physical resource systems made by humans for public consumption purposes (Frischmann, 2005). The physical or technical infrastructure system consists of physical elements, such as cables, switches, roads and cars. Examples of more or less purely technical systems are chemical plants, energy networks and railway systems. The relationships between the elements are determined by laws of nature and are related to the conversion of energy. Therefore, Gharajedaghi (1999 p.12) called these physical systems 'energy-bonded systems'. The function of a technical system is often the transportation or transformation of matter or information.

The convergence in infrastructures is based on connecting different technical systems, where systems arise with multiple functions and bundled networks. This connection is only possible when the laws of nature allow for this combination. Therefore, these heterogeneous systems are standardized, which leads to large-scale standardized coupled systems (De Bruijne, 2006).

The designers of new or additional technical systems have to deal with the physical restrictions; the intervention has to fit with the existing infrastructure. Developing large-scale infrastructures is based on related historical actions and involves large investments, large sunk costs and long life-times of the physical structures. These consequences make it vital that there be a careful decision-making process.

Social systems

On the other hand, infrastructure systems are designed, developed and used by social elements or actors, which can be people, subgroups, organizations, and communities (Wasserman & Faust, 1994 p. 36-37). Each actor is unique, based on the history, values and objectives of the actor. An actor is autonomous and capable of calculation and manipulation, can adapt himself and invent responses depending on the circumstances and the manoeuvres of his partners (Crozier & Friedberg, 1980 p.19). The relationships among the actors are based on social rules, and these differ from network to network (Klijn & Koppenjan, 2006). These interdependent relations are dynamic (De Bruijn & Ten Heuvelhof, 2008 p.12). Therefore, social networks are called socio-cultural systems (Gharajedaghi, 1999 p.12,13).

From the history of infrastructures, several clear changes in social networks can be observed. Infrastructure systems were developed by private companies (Stout & De Jong, 2005). However, to ensure public values, like easy accessibility at reasonable costs, governments have bought the infrastructures and have become (semi-) public organizations (Ten Heuvelhof et al., 2001). Since the 1980s, the opposite process has been observed: the process of liberalization, privatization and deregulation (Hansman, Magee, Neufville, Robins, & Roos, 2006). Organizations gained new functions, new organizations entered the field or the social network, and new interactions arose (Weijnen & Bouwmans, 2006).

In the design of new infrastructures, actors with a stake will become part of the social network and will try to safeguard their values and achieve their objectives. Final design decisions will be based on the interaction and negotiation of this group of actors (De Bruijn & Herder, 2009).

Socio-technical systems

Hughes (1987) analysed large technological systems and concluded that technological systems contain messy, complex, problem-solving components. He showed that the engineer has to simultaneously keep in mind technological matters (such as the design of a lamp), economic matters (for example, the price of electricity must be competitive with that of gas) and political matters (including legislative frameworks). Policy makers and designer of today's infrastructure projects, too, have to deal with these aspects of the technical construction, the economic consequences and the values in the social network (De Bruijn & Herder, 2009). Geels (2004) defines socio-technical systems as 'a somewhat abstract, functional sense as the linkage between elements necessary to fulfil societal functions. As technology is a crucial element (…) to fulfil those functions, it makes sense to distinguish the production, distribution and use of technologies as sub-functions.'

Figure 2-2 is a schematic representation of socio-technical systems consisting of actors and physical elements. Within socio-technical systems three types of relationships can be found: the relation between actors, according to the laws of social sciences; the relationships between the physical elements, based on the laws of nature; and the relationships between physical elements and actors. There are no clear laws to describe the relationships between physical elements and actors. The interface between social elements and physical elements are poorly understood, and the relationship between the elements is inadequately managed (Hansman et al., 2006). Therefore, especially the interrelation between these technical and social elements is interesting for research.

For many purposes it is possible to analyse both types of systems in isolation of each other. Researching the overall function and developments of infrastructures requires a socio-technical system. On the one hand, a technical analysis could lead to an optimal technical system. On the other hand, the outcome of the negotiation process, without reality checks, could lead to negotiated nonsense, an accepted decision but in conflict with technical feasibility (Van de Riet, 2003). The social system and technical system cannot be taken separately when the overall effects of a system are relevant and highly influence the outcome (De Bruijn & Herder, 2009).

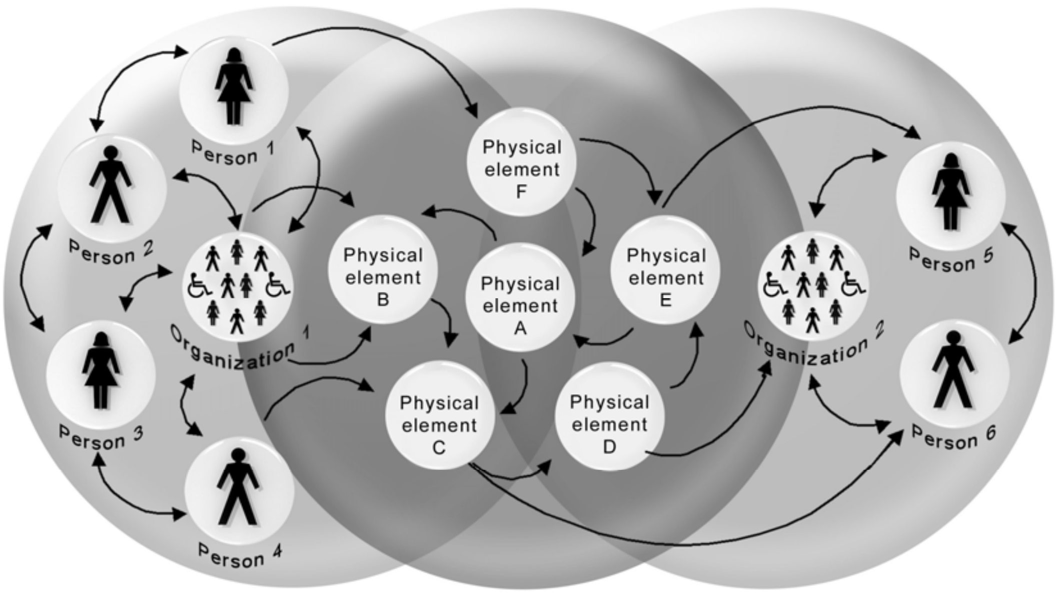

Figure 2-2. Schematic socio-technical system, where social and physical elements interact with each other and therefore influence the behaviour of the independent elements

2.1.3 Conflicting values and uncertain behaviour

The interaction between the physical infrastructure and the social environment increases the complexity of the already complex systems and makes it more difficult to understand the system behaviour.

Managers and designers of infrastructures have to deal with this uncertain behaviour and effect. In addition, they are part of a social network consisting of actors with conflicting values. These conflicting values and uncertain behaviour in infrastructures are clearly observable in the discussions about, for example, the construction of the *Betuwelijn* (the railroad from the Port of Rotterdam to Germany for cargo transport), the High Speed Railway (from Amsterdam to Belgium) or the enlargement of the Mainports Schiphol and Rotterdam. Opponents of these projects claim that the investments are too high and revenues too uncertain. Environmental issues also play a role, because consequences for environmental quality and safety are uncertain and difficult to predict. Consequently, the planning and design of these projects takes decades, and even then research on effects does not provide clear answers about future consequences. Despite the difficult and long discussions, these projects are built to increase the capacity for future demand, while dealing with issues of sustainability and efficiency.

Managers and designers have to deal with uncertainty and conflicts about the knowledge of the system and uncertainty and conflicts about the seriousness of the problem. Based on these two sources of uncertainty and conflicts, four types of problems can be derived (Dunn, 1981; Hoppe, 1989; Koppenjan & Klijn, 2004). The first group of problems are problems where there is substantial knowledge about the problem and the environment and there is a substantial agreement on the objectives, effects and solutions. These problems are called 'tame' problems or issues, since causes of the problems are relatively easy to find and can be solved efficiently. A second group of problems are the 'untamed technical problems', where there is consensus about the size of the problem but uncertainties about the substantial knowledge or effects of solutions. In the third group, 'untamed political problems', the technical solutions are available, but there is a social conflict. Finally, there are situations where there is little consensus about the standards and little knowledge about the system and solutions and future consequences. These are called 'wicked' problems.

Infrastructure problems cannot be defined in a clear problem statement accepted by all actors in the network. On the contrary, infrastructure problems are characterized by incomplete, contradictory and changing requirements and solutions. Large-scale infrastructure projects, as mentioned earlier, fall within this group of wicked problems (De Bruijn & Ten Heuvelhof, 2008). Managers and designers have to deal with conflicting values between economics, technical limitations and social issues (like environmental, political and security issues).

In order to deal with these wicked and ill-structured problems and find a solution, designers have to try to reach consensus about the standards and/or increase their knowledge about the system. In practice, both ways are difficult or even impossible to achieve. Values and objectives in a multi-actor network are contradictory, which makes reaching consensus difficult, and the complexity of the system and lack of information avoids predicting future consequences of interventions.

2.1.4 Social and technical complexity of infrastructures

The design and planning of large infrastructure systems requires that the designers deal with both the technical complexity and the social-political complexity. The technical complexity is caused by many interdependent quantifiable factors and a lack of useful information about the values of the factors and relationships between these factors. The political and social complexity is grounded in many interdependent, loosely-coupled stakeholders. The outcome of decisions is the outcome of a negotiation and cannot be predicted from clearly defined rules.

In both systems, the design of infrastructures has different objectives. In technical systems, designers are looking for the 'best' solution that is the most feasible or (cost-) efficient one; in social systems, designers search for the most 'accepted' solution. Designers have different tools which they can use to reach one or both objectives. There are models and simulations to increase the knowledge about the technical system, and there are participatory or interactive decision tools like open forums to discuss the values and norms and negotiate about the decisions.

These objectives and tools have to be combined in the design process of large-scale infrastructures. The design has to be feasible within a limited budget, and at the same time the design has to be accepted by the stakeholders. Consequently, the design and management of large-scale infrastructures is even more complicated because designers have to deal with the social and technical questions together. New relationships arise, causing other dynamics and uncertainties, which makes designing and forecasting long-term consequences even more difficult.

To conclude, infrastructures are highly complex, and therefore the effects of social and/or physical interventions are difficult to predict. However, to be prepared for the future, we need to maintain and extend our infrastructure systems. Therefore, it is necessary to gain more insights into the complexity of the system and the causes of the interventions. The world of 'complex systems' could help us in increasing our understanding of this complexity.

2.2 Different perspectives on systems

In this section, different perspectives of complex systems are introduced. Again, a differentiation in technical and multi-actor systems is observed. The two system types use different vocabularies to explain behaviour: technical systems use the vocabulary of the natural sciences, and social systems need the language of social sciences. Therefore, a framework has been developed which translates these languages.

As a reaction to the mechanistic world view, with the assumption that people can understand systems by analysing the elements separately (Ackoff, 1981), people started to analyse systems as a whole. This resulted in thinking in terms of systems. 'Systems thinking' is a framework for seeing non-linear relationships rather than linear cause-and-effect relationships, and for seeing patterns of change rather then static snapshots (Senge, 1990). This way of thinking is used in many different research fields, like General Systems Theory (Von Bertalanffy, 1968, 1975), Systems Thinking (Forrester, 1958; Senge, 1990; Sterman, 2000), Chaos Theory (Gleick, 1988), and Complex Adaptive Systems (Crutchfield, 1994a; Gell-Mann, 1994; Holland, 1995; Kauffman, 1993). Also in the field of policy and management, thinking along the lines of networks and systems is becoming common (De Bruijn & Ten Heuvelhof, 2008; Koppenjan & Klijn, 2004; Teisman, 2005).

2.2.1 A brief overview of Systems Thinking

Since the 1950, researchers have been thinking in terms of systems. The biologist Von Bertalanffy was the first to introduce a General Systems Theory. He presented his theory in 1937 at a conference in Chicago, in the article *An Outline of General Systems Theory* in The British Journal for the Philosophy of Science (Von Bertalanffy, 1950) and in the first translated edition of the book *General System Theory: Foundations, Development, Applications* in 1968 (Von Bertalanffy, 1968). His desire was to describe the common principles of systems in general. The General Systems Theory focuses on patterns which hold for all systems, and therefore it was not applicable for real-world situations. But these ideas of thinking were nonetheless used in later theories.

At the same time, Cybernetics emerged from the engineering fields. The mathematician Robert Wiener was the first to introduce the idea of Cybernetics, in his book *Cybernetics: Or the Control and Communication in the Animal and the Machine* (Wiener, 1948). The essential goal of Cybernetics is to understand systems that have goals and feedback mechanisms in order to make them more efficient and effective. Cybernetics introduced the ideas of feedback mechanisms and of communication and control, but they did not open the black box of the system.

In reaction, Jay Forrester started the System Dynamics Group at the MIT Sloan School of Management in 1957. The first publication of System Dynamics and systems thinking was published in 1958 (Forrester, 1958). The idea behind the method is the recognition that the structure of any system is often just as important in determining its behaviour as the individual components themselves. In the first period, the models were related to industrial dynamics, but in 1968 system dynamics broadened to include social systems. The model of Urban Dynamics, about urban problems in US cities, is an example. A couple of years later, system dynamics were used for the famous models World Dynamics (1971) and Limits to Growth (1972) used by the Club of Rome (Forrester 2007). Since the 1980s system dynamics has been used in a variety of fields, like project management, energy systems and sustainable development. This growth was mainly facilitated by the emergence of user-friendly simulation programs.

Systems Thinking and related fields like system analysis and system engineering give insight into the long-term behaviour patterns of the system. However, in the beginning they did not recognize the dynamic environment nor the self-organizing capabilities of the system. Several researchers observe that the system itself is adaptive to the environment and has the capability to self-organize (Crutchfield, 1994a; Gell-Mann, 1994; Holland, 1995; Kauffman, 1993). The theory of Complex Adaptive Systems (CAS) emerges with the objective to create a unifying and comprehensive vision on complex systems. CAS is dynamic; it grows and evolves and is adaptive to the environment in order to survive. Examples of these systems are immune systems, ecosystems and cities. Not all complex systems are adaptive; examples of non-adaptive systems are galaxies and snow flakes (Jacobson, 2001).

From the socio-technical perspective of infrastructures, a CAS perspective seems a nice fit. In the first place, this is because CAS analyses the dynamics of physical systems. In the second place, social systems contain reflective actors who adapt to the changes in their environment. CAS is the only perspective which can deal with this adaptive characteristic of actors.

2.2.2 Complex adaptive systems: an evolutionary perspective

Because it is expected that the CAS perspective is to become a valuable means of analysing infrastructures, it is worth further exploring what is meant by CAS. In the first section, CAS is related to fixed and chaotic systems. Second, several characteristics of CAS are derived.

Classifications of systems

In Chapter 1, a distinction was made between subjective and objective descriptions of complex systems. However, this does not yet give a very clear picture of complex and non-complex systems.

Different attempts have been made to make a clear distinction between classifications of systems. The biologist Stuart Alan Kauffman (1991) discovered that the overall behaviour of a NK network[2] is almost entirely dependent on K; the number of relationships (K) a subsystem has with other systems. When the number of relationships is low or much lower than the number of subsystems (N), the system is not complex. When, on the other extreme, K is approximately equal to N, the system is chaotic. In between, the system is defined as complex. This discovery explains why small systems with a low number of elements can show patterns of complex behaviour.

With the use of cellular automata, Wolfram (1984) distinguished four classes of systems, based on behaviour: I) fixed, II) periodic, III) chaotic, and IV) complex. Class-I systems evolve to one unique homogenous state, independent of the initial values. Class-II systems generate simple structural behaviours, stable or periodic, from a particular initial sequence of values. The evolution of the Class-III systems to a finite state follows an non-period pattern from most of the initial states and is most unpredictable. These systems, which are highly dependent on initial conditions, are studied in Chaos Theory (Gleick, 1988). The behaviour of a Class-IV system is essentially unpredictable. Even given complete initial information, the behaviour of the system may essentially be found only by explicitly running it (Wolfram, 1984).

Langton (1990) also studied the behaviour of systems with cellular automata and developed a measure to define the type of system. The parameter, called Lambda (λ), is the chance that a cell survives in the next generation in a cellular automata model. Langton came with four situations, which can be associated with the Wolfram classes. For example, for Conway's Game of Life, when $\lambda \approx 0$, then the system becomes fixed (Class I); in the situation $0 < \lambda < 0.273$, the behaviour can be classified as periodic (Class II); when $0.273 < \lambda < 1$, the system is chaotic (Class III); and in the situation $\lambda \approx 0.273$, the system shows complex behaviour (Gardner, 1979).

From these theoretical classifications, we learn that complex systems are systems in between chaotic and periodic systems; these complex systems are also called 'critical' or 'on the edge of chaos'. The behaviour of a complex adaptive system is non-linear and cannot be written down in a closed manner. On the other hand, the behaviour is not random. CAS shows patterns of behaviour which can be considered as archetypal. The classifications are based on cellular automata, which are simple representations of a system. For real-world systems with a large number of diverse subsystems, the relation between N and K (or the calculation of λ) is difficult to determine. Therefore, other observable indicators are needed in order to identify a system as complex and to analyse the complexity of the system.

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[2] An NK network is a network which consists of a number of subsystems (N) and each subsystem has a number of relations with other subsystems (K). Based on these numbers, several characteristics can be derived, for example the categorization of complexity or the characteristics of growth.

Characteristics of complex adaptive systems

The distinction made above is relevant when comparing different types of systems based on the number of subsystems and relationships. In theory, they are useful in supporting the understanding of the complexity and the behaviour of systems. But they give little insight into observable characteristics of real-world systems. John Holland (in Waldrop, 1992) provides an operational definition of what a CAS is.

> ‘A Complex Adaptive System (CAS) is a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behaviour in the system, it has to arise from competition and cooperation among the agents themselves. The overall behaviour of the system is the result of a huge number of decisions made every moment by many individual agents.’

Within this definition, Holland describes the elements in the system as agents; these agents interact, and the system behaviour is based on parallel decisions of many individual agents and not on top-down control. Holland emphasizes the hierarchy that can be found in complex adaptive systems, which means that the system behaviour cannot be explained from the sum of the subsystems.

> ‘… Interactions among the components that are non-linear, such that the global behaviour of the system cannot be compositionally deduced from the components’ behaviour.’ (Holland, 1995)

Based on the literature, three characteristics of CAS can be derived, among others: 1) adaptive agents, 2) co-evolution and 3) emergent behaviour (Center for the Study of Complex Systems, 2009; Choi, Dooley, & Rungtusanatham, 2001; Holland, 1995).

1. A complex adaptive system consists of many interacting adaptive agents. In this perspective actors can be seen as one type of agent. Each agent has an internal mechanism, which defines the signals the agent receives, how this signal influences the state of the agent and what decision or outcome the agent sends to the environment. The behaviour of agents is not static, agents adapt to their environment by receiving feedback of their actions and learning. Therefore, their behaviour is based on past interactions. In case of a long-term process (relative to the adaptation time of the agent), the internal models of the agents change.
2. The structure of a CAS co-evolves. Co-evolution means that the evolution of one domain or entity is partially dependent on the evolution of other related domains or entities. Co-evolution emphasizes the evolution of the interactions or the structure of the system. Therefore, the structure in complex adaptive systems is not constant over time. This is caused by the self-organizational mechanism of complex adaptive systems (Mitleton-Kelly, 2003). The

development of systems is established by chosen or accidental interactions. An example of a co-evolving network is the evolution from a monoculture to a rain forest or the growing of the Internet.

3. The behaviour of CAS is (intrinsically) emergent (Crutchfield, 1994a). Emergence is the process by which new characteristics arise once the system is constituted (Crutchfield, 1994b; Morin, 1999). This cannot be explained by decomposition of the components. Self-organization is an example of emergence. The structure, patterns and properties arise without influences from the environment, and there is also no single agent that determines which agents interact with each other (Kay, 2002; Prigogine & Stengers, 1984).

2.2.3 Social networks and complex adaptive systems

Most of the characteristics of CAS are derived from physical or natural systems. In order to deal with socio-technical characteristics of systems, a relationship has to be made with the complexity of a social system. Public administration and organization science study the complexity of actor networks (Ackoff, 1981; De Bruijn & Ten Heuvelhof, 2008; Kickert, Klijn, & Koppenjan, 1997; Klijn & Koppenjan, 2006; Koppenjan & Klijn, 2004; Luhmann, 1995; Teisman, 1992, 2005). Within an actor network, the behaviour is dependent on the interacting actors. Therefore, several researchers link the characteristics of complex adaptive systems to the characteristics of social actor networks (Axelrod & Cohen, 2001; Teisman, 2005).

Classification of social networks

Just as in natural sciences, there are different classifications to describe social systems. These systems exist between and within organizations, have similar characteristics and are described as hierarchical or as a network.

Organizations are seen as social systems which use the notion of membership as one of the boundary-formation principles (Brans & Rossbach, 1997 p.422). Just as physical systems, organizations are designed with a special purpose (Machado & Burns, 1998). There are also interactions between organizations. These network organizations with different core values are related, like public organizations, private companies and semi-public organizations (De Bruijn & Ten Heuvelhof, 2008; Teisman, 2005).

In public administration a conceptual distinction is made between hierarchies on the one hand and chains and networks on the other (De Bruijn & Ten Heuvelhof, 2008; Kickert et al., 1997 p.5; Powell, 1990). A hierarchy is seen as a conventional organizational steering model. Structuring organizations in a hierarchy is a way to create order in a chaotic world of complex relationships. Agents in hierarchies are characterized as having uniform perspectives, being subject to directed dependencies and following the orders of superior agents (De Bruijn & Ten Heuvelhof, 2008). Further, the links between actors in a hierarchy are stable and so the whole system can be considered as stable. This stability is a central value. Changes are only possible after the agreement of the top of the organization. The hierarchy and rules are needed to safeguard the contribution of the subsystems to the total system performance (Teisman, 2005).

On the other hand, it has been noted that relationships emerge between different departments and organizations apart from the hierarchical structure (Teisman, 2005 p.78). It has also been observed that due to professionalization, globalization, public-private relationships and information technology, dependencies between organizations increases (De Bruijn & Ten Heuvelhof, 2008). These new interactions change the structure of the organization from hierarchical to that of a chain or network. Actors in networks are characterized as having 'pluriform' perspectives, being subject to undirected dependencies and being relatively insensitive to orders of actors higher up in the formal hierarchy. De Bruijn and Ten Heuvelhof (2008) describe networks as:

> 'a number of actors with different goals and interests and different resources who depend on each other for the realization of their goals'.

Interactions between actors can emerge spontaneously, without intervention from outside. The consequence of undirected dependencies in networks is that actors are interdependent. That is, actors can not attain their goals by themselves but rather need the resources of other actors to do so (Kickert et al., 1997 p.6). Although relationships between actors are different than in a hierarchy, this does not mean there are no rules. The rules are based on social manners. Furthermore, networks are dynamic, as insignificant agents can suddenly acquire an important position. The power of agents in networks is also dynamic, as new links are formed and/or old links disappear.

In reality, a combination of those structures can be found. On the one hand, organizations are structured according to a hierarchy. By having rules and procedures, the dynamics are more or less stabilized. On the other hand, organizations and departments within organizations are aware that they are part of a network and that this network is adapting to changes in the environment. This characteristic gives opportunities to become more efficient on a higher level or to become innovative. When the fear for chaos increases, managers start reorganizations and introduce new regulations. At the same time, the aversion to bureaucratic mechanisms increases and there is a demand for self-organization, new relationships and renewal (Teisman, 2005). Managers of these intra- and inter-organizational networks have to balance between creating structure and order and being flexible and adaptive. In other words, managers are part of a complex social system.

Characteristics of complex social networks

According to Teisman (2005), social networks also balance between order and chaos. Order leads to the efficient execution of goal-directed actions and possibility of steering. Yet this order becomes inert when effectiveness decreases. Chaos leads to new interconnections and provides opportunities for innovation and adaptation to new circumstances, but it can become aimless and inefficient.

This complexity can be explained from the characteristics of social networks. The networks consist of many interacting actors, who aim to realize their objectives, and these networks show properties of self-organization and evolution. The outcome of a negotiation can be considered to be an emergent outcome based on the individual contributions of the actors in the network. That means that social networks have the same three characteristics of complexity as described with CAS.

1. A social network consists of interacting agents. Actors are mostly individuals, coalitions or organizations which follow social rules, but they have the freedom to deviate from these rules in a not necessarily rational or logical way. Each actor aims for a complex combination of self-interest and shared values (Teisman, 2005). These preferences, problems and solutions change over time, because actors are adaptive (Kickert et al., 1997 p.16). Axelrod and Cohen (2001) found a tendency toward variation, for example by task division and specialization. The rules of the system organize specific actor roles vis-à-vis one another and define their rights and obligations (Machado & Burns, 1998 p.359).
2. The systems evolve over time due to stable causality and accidental interrelations. These changes can take place within as well as between the actors. Axelrod (Axelrod, 1984) compares the evolution of actors with the evolution of species. However, there is a clear difference between evolution in ecology and between actors. In ecology, variation arises from mutations and mistakes, while variation between actors arises from competition. The competition in ecology leads to the extinction of species. When multiple actors adapt to changes of the other, Axelrod and Cohen talk about a co-evolutionary process (Axelrod & Cohen, 2001 p.20). Teisman (2005 p.28) describes co-evolution as a concurrency of circumstances and events. Co-evolution also causes changes in the directions of the interaction in the long term. In the short term, the neighbourhood determines the type of house buyers; in the long term, the house buyers make the neighbourhood (Axelrod & Cohen, 2001).
3. Organizational networks develop and exist because of interdependencies and repetitiveness of interaction that leads to stable patterns in social networks

> (Koppenjan & Klijn, 2004; Teisman, 2005). Social organizations have heterogeneous modes of organizing, combining different types of relationships like administration, market relations and democratic associations (Machado & Burns, 1998 p.356). These relationships and modes of organizing are designed for a certain purpose of the organization as a whole. Combinations of steering and spontaneous interactions provide that systems develop non-linearly, resulting in emergent behaviour. Social systems have self-organizational and self-steering power. Developments and interactions arise spontaneously where they are not expected. Interactions on lower levels influence the interactions on higher levels within the organization and *vice versa*. Lower-level units – something we called 'lower-level agents', live their own lives and make independent decisions. Social systems also interact with the environment (Luhmann, 1970 p. 39-40 in Brans & Rossbach, 1997).

Thus, the characteristics of complex social networks are diverse actors, evolving processes and emergent behaviour.

2.2.4 Complex adaptive systems in a multi-actor context

As the management and design of infrastructures requires a socio-technical system approach, this means the complexity of both types of systems has to be taken into account. The complexity increases due to the interactions between the physical and social systems. With the use of the characteristics of complex adaptive systems and complex social networks, the following description is used for complex adaptive systems in a multi-actor context.

> Complex adaptive systems are open, adaptive systems, situated in a dynamic environment, consisting of heterogeneous agents and actors, which are related in a network structure and consequently the result of these networked interactions is the observed system behaviour.

Different perspectives have to be combined and notions shared in order to describe these complex socio-technical systems. In the next section a conceptual framework is introduced which tries to develop a combined perspective on complex adaptive systems in a multi-actor context. This framework is used as a starting point for describing the complexity of infrastructure systems so as to gain a better understanding of their behaviour.

2.3 Framework for complex adaptive systems[3]

Complex adaptive systems studies systems 'at the edge of order and chaos.' These systems are physical or biological systems (Holland, 1995; Kauffman, 1993) as well as social actor systems (Axelrod & Cohen, 2001; Teisman, 2005). Researchers in these fields all study the same phenomenon of complex systems but are likely to use different 'terms' to describe properties of complex systems. In this section we combine the different characteristics into a generic framework which can be used to observe and analyze complex adaptive systems in general and infrastructures specifically. This framework gives three conceptual levels of looking at complex systems and the properties of complexity which can be observed on these levels. These conceptual levels do not exist *per se* but are useful when observing, describing, and modelling complex adaptive systems. Figure 2-3 shows a representation of these levels in their environment.

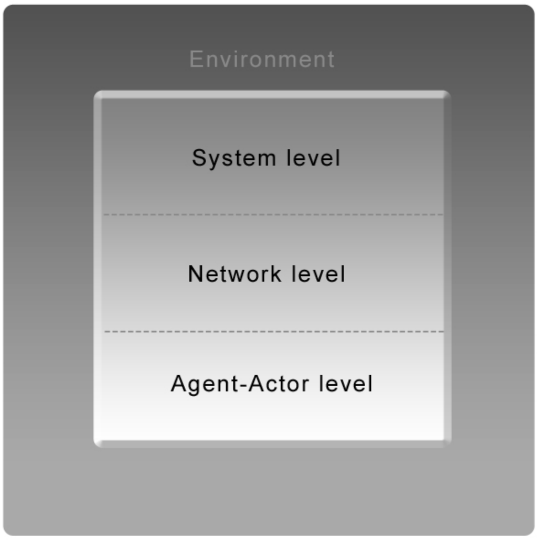

Figure 2-3. Complex adaptive system represented in three conceptual levels

On the first level we find the agents. Agents are constructs and can be cells, species, individuals, firms or nations (Holland, 1995), people, artefacts or technology (Miser & Quade, 1985), social structures, portions of nature, equipment or organizations

[3] Large parts of this section are published in Telli Van der Lei, Geertje Bekebrede, Igor Nikolic (accepted) Critical Infrastructures: a review from a Complex Systems perspective, International Journal of Critical Infrastructures (forthcoming)

(Walker, 2000) or actors (De Bruijn & Ten Heuvelhof, 2008). Notice that the defined agent and actor can be a complex system in itself when described on another hierarchical level.

The second level describes the structure of interactions between the agents. When observing the system at this level, we perceive the way in which agent interaction is organized in networks. Networks are a natural abstraction for describing elements and their relationships. The relationship can be an exchange of information, matter or people and has different rules and strengths.

The third level describes how the aggregate system behaves, which is a result of the behaviour of the individual actions of the agents, the interaction between the agents and input from the environment.

In the next sections, the environment and these three levels are further explained. On each conceptual level, elements and properties are defined which support the analysis and understanding of Complex Adaptive Systems.

2.3.1 System environment

Complex Adaptive Systems are open systems (Kay, 2002; Miser & Quade, 1985); they are constantly influenced by the environment. In contrast, closed systems are not affected by the environment. According to the Second Law of Thermodynamics, closed systems move towards a state where the entropy, a measure of disorder, is as high as possible. In that situation, the system state is fixed; the overall behaviour does not change. While in open systems, the system itself searches towards an ordered situation, but changes in the environment lead to adaptations and new equilibriums. Therefore, open systems does not have to reach a steady state. CAS maintain order but have to be able to adapt according to changes in their environment or ones internal to the system (Holland, 1995).

The environment has two extreme states: perfect randomness and perfect order. In perfect randomness, there is no causality between any two events: things ‘just happen’. In a perfectly ordered environment, each event is perfectly predictable from the previous ones. CAS experience an environment that is a mix of these two extremes (Crutchfield, 1994a).

2.3.2 Agent level

On the lowest conceptual level, the agents of the system can be found. We consider an individual agent to consist out of: input, state and rules, and output. Agents have three dominant properties: adaptivity, internal diversity, and interface and protocol similarity (See Figure 2-4).

For the discussion on the agent level, the field of artificial intelligence (AI) is used as a starting point, because this community formally describes agents and their properties. An agent, in the AI field, is a self-contained problem-solving system capable of autonomous, reactive, pro-active social behaviour (Wooldridge, 1997; Wooldridge & Jennings, 1995; Wooldridge & Jennings, 1998). In a narrow definition agents are described as computer elements. However, we will use the concept of agent in its broadest sense according to the definition of Wooldridge, which also includes actors. Actors are a specific type of agents, because actors are reflective. This means that they display strategic behaviour, learn how to neutralize the interventions of other actors and understand the process of interaction (De Bruijn & Herder, 2009).

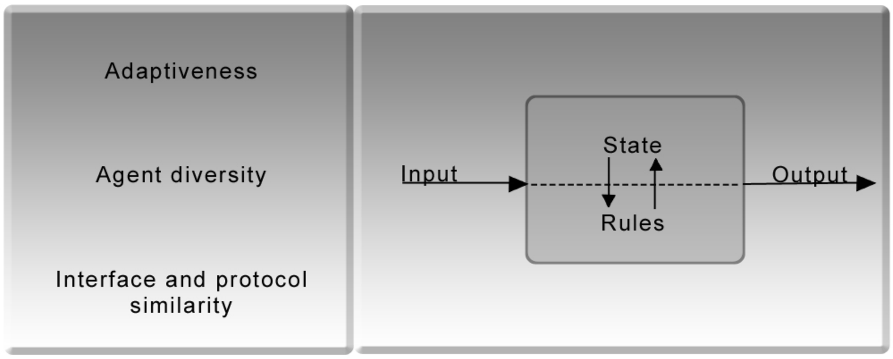

Figure 2-4. Agent level characteristics and visualization. While the whole agent level consists of numerous agents, a single agent is visualized on the right side of this picture.

Agents

The state of an agent is a specification of the particular collection of parameters that defines an agent (e.g. Wooldridge & Jennings, 1995 p.116). It is a snapshot containing all the relevant information about the state. States can be observable or unobservable. Unobservable states are hidden or private states. The hidden agenda of actors is an example of an unobservable state. However, they are relevant, because they influence the behaviour of the agent.

Rules describe how the different inputs and internal states are translated to outputs and new states. Holland (1995) calls these rules the 'internal models' of agents. Human DNA is an example of a set of rules. Rules can differ in different situations, and people have different behavioural rules in different societal contexts (Scharpf, 1997). Because these rules are usually private and unobservable, prediction of behaviour is difficult. Some agents, for example actors, have a memory. Actions of these agents will be partly determined by their past actions.

An agent receives inputs from the outputs of other agents and stimulus from the environment. The agent's reactions are its outputs, which affect the environment and other agents. Gharajedaghi (1999 p. 36) distinguishes three types of agent outputs: reaction as a necessary behaviour to maintain his state; response to a difference between the system state and goals of the system; and action, which is a self-determined event, or autonomous behaviour, correlated with purposeful systems.

A relationship between the output of agent 1 and the input of agent 2 is an example of interaction. This interaction can be further specified. We define all interactions to consist of three elements: interface, protocol, and message. The horizontal arrows in Figure 2-4 represent the directionality of the interaction.

Agents must have a common interface in order to interact. Agents quite literally need to be able to speak the same language. Language in this case must be understood in an abstract sense – that is, information or effects must be exchanged in a way that all interacting parties can make sense of the messages (Wooldridge & Jennings, 1995 p.116). For example, in an English-speaking debating group a person who speaks only Chinese will not be able to join the debate. In a more physical sense, flowers interact with butterflies through scents and colours that butterflies can perceive. The flower's colour and scent is compatible with the butterfly's vision and scent organs.

The protocol is the set of rules that describes the format of the message. It can be seen as the grammar of the message. In order for interaction to take place, agents must also have some degree of protocol similarity. Examples of protocols are the Hypertext Transfer Protocol (HTTP) or '*Het groene boekje*', a book that describes the rules of the Dutch language.

The message is the content of the arrows depicted as input and output. A message is everything that flows through the interface that can be picked up, like warnings of an approaching car or an attractive flower. Depending on the protocol, messages can consist of words, light, energy, etc. An integrated example of the elements that make up interaction is the connection of an electrical appliance. The socket in which a plug is placed forms an interface, the 220 Volts across the interface is the protocol, and the actual movement of electrons is the message.

Important properties on the agent level

Three main properties are relevant at this level: adaptation, agent diversity and interface and protocol similarity. The first is a property of agents themselves, and the latter two are properties of the agents relative to each other. We will elaborate on these properties and show how the different fields describe these properties.

Adaptation: Influenced by the surroundings or internal states, an agent can change its rules; this is called adaptation (Holland, 1995; Kauffman, 1993; Levin, 1998). It is the ability of an agent to change towards a more 'optimal' or 'fit' state. For example, the body's immune system becomes stronger after it has been frequently exposed to pathogens. The evolution of species is another example of adaptation, in which species adapt to survive. Learning (Argyris & Schon, 1996) is a specific form of adaptation. A manager of a business learns through the feedback he receives on the work done. Learning requires an agent to have a memory. The state and dynamics of an agent, therefore, also depend on its previous states and dynamics. The manager in our example has a memory; DNA in a species does not, but is a memory itself.

Agent diversity: Complex systems exhibit large internal diversity of agents. Internal diversity means that agents have their own states and rules that may differ from agent to agent. Agent diversity is responsible for behaviour at higher levels of the system (Kauffman, 1995, 2000; Waldrop, 1992). The field of Public Administration and Management Science refers to the diversity in an actor system as 'variety' (De Bruijn & Ten Heuvelhof, 2008) or 'variation' (Axelrod & Cohen, 2001). If there were to be too much diversity, one could not speak about a complex system, because little to no relationships between agents would exist.

Interface and protocol similarity: All agents of a system share a common interface and protocol. Agents must be similar enough in interface and protocol to be able to interact. In many situations, people respond to financial incentives like environmental subsidies and taxes. Ottens, Franssen et al. (2006) refer to regulation and rules as being the common interface humans have agreed upon. Jargon or rules about codes are languages used by specialists. They understand each other, but people outside the community do not. Mobile phones share the same data protocol, and ships use the same containers to transport different goods in.

2.3.3 Network level

All definitions of complex systems contain the notion of structured interactions. In some of the definitions these interactions are specifically seen as networks. We use the network concept to describe the structured interactions of complex systems. The field that studies networks extensively is graph theory. In the field of graph theory a network is described as:

> '… a set of items, which we will call vertices or sometimes nodes, with connections between them called edges' (Newman, 2003 p.2).

Graph theory is based on the abstraction that everything can be described as one of the two components that make up a network: a node and a link or edge (Gross, 2004). We choose to speak of nodes as abstractions of agents and links as abstractions of the interaction between the agents (See Figure 2-5). However, it is important to realize that in graph theory it is a matter of choice as to what to label as a node or link.

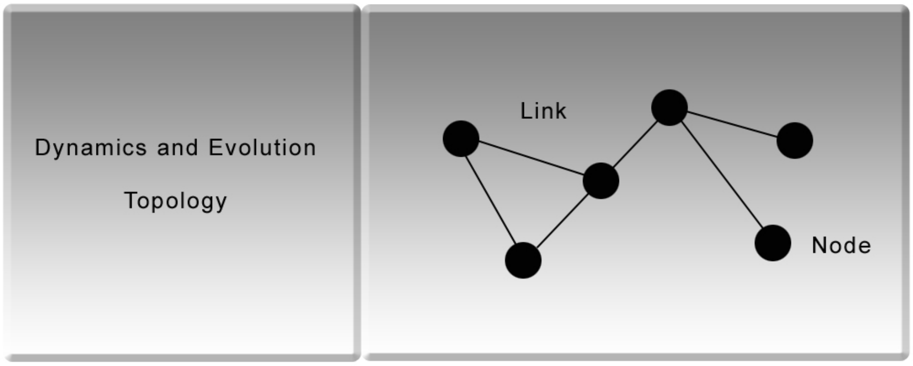

Figure 2-5. Network-level properties and visualization

Network

When considering networks in a strictly graph-theoretical perspective, the only difference between nodes is the number and weight of their links and the identity of the nodes connected to them. However, the numerous diverse examples of agents and interactions between them show the limitations of Graph Theory. Therefore, Graph Theory is not able to handle networks of complex systems, which consist of a variety of nodes and links. Still, the graph theoretical representation of networks in nodes and links makes it possible to compare and talk about different networks.

Nodes can have more than one link connecting to them. Links are realized the moment agents interact. Links can be abstract and non-material, such as information exchange, or they can be very real and physical, such as the flow of electricity or water. In a physical network, cables, roads or pipelines can be considered as links. In a social network these links are based on social rules, informal power, and norms. In economics, relationships are represented as the exchange of goods, services and money.

Links can have a one-way or two-way direction, also called ‘directed’ or ‘undirected’. Water in pipes always flows from the area of high pressure to an area of low pressure and is therefore a directed link. A telephone connection or Internet connection is undirected, as it allows for two-way interaction. Links between nodes can have different weights. This weight may refer to the size of the flow across the link or its importance. An example is a road network with highways, provincial roads and back roads. Highways have a higher weight, because the intensity of the traffic is higher on them than on the other roads.

Important properties at the network level

The important properties at the network level are the network dynamics and evolution, and network topology.

Network Dynamics and Evolution: Networks are not static. The flows through the network (of mass, energy, information, etc.) can vary and change in size. This is often referred to as 'network dynamics'. Examples of network dynamics are variable energy flows through the power grid, signals travelling through nerve cells during motion and the intensity changes in friendships during life.

The network structure is also subject to change: new nodes are added to or removed from the network and/or new links emerge or disappear between existing nodes. This is referred to as 'network evolution'. Examples of network evolution are the addition of more cell phones to the network (nodes) that lead to more and different calls being made (links). Another example is the broadening of a person's social network by introducing friends to other friends. Well-known network evolution models are the network growth model by Barabási and Albert (1999), who first used the concept of preferential attachment, and the probabilistic 'NK growth model' of Kauffman and Weinberger (1991) that is based on an energy distribution model.

Network topology: The structure of a network can be defined as its topology. There are two main types of networks: these are networks with either an exponential or a random structure. The type of network is determined by the connectivity distribution, i.e., the probability that a node is connected to K other nodes (Albert, Jeong, & Barabási, 2000). Another characteristic is the average path length of the shortest path between any two nodes in the network, which is a measure of the interconnectedness of the network. Networks with a very large number of nodes can have a small shortest average path length, for example a social network. In the global population any two persons can be connected by six to ten acquaintances (Milgram, 1967).

Scale-free networks are inhomogeneous networks, like the World Wide Web. These networks have a node-degree distribution that follows a power law. In these networks typically 20% of the nodes have 80% of the links. The shortest average path length between any two nodes increases only very weakly with the number of nodes (Dijkstra, 1959). The network grows according to preferential attachments. Examples are the random graphs model and small world models (Watts, 1999). Exponential networks are homogeneous networks in which each node has approximately the same number of links. In these networks, the shortest average path length between nodes becomes longer when the number of nodes increases, as the degree distribution is far more even.

The topology of a network determines its sensitivity of network to node failure. Scale-free networks, such as airline routes, are fairly insensitive to random node failure. The average path length does not decrease drastically. So, if an airport is disabled, there is one nearby. However, when one considers directed attack, it is very easy to disable the global airline system by targeting a few of the main hubs (Albert et al., 2000).

The organization literature also has several modes of organizations, comparable to a topology, such as hierarchy or bureaucracy, markets and networks (Machado & Burns, 1998), with administrative, market and network relationships. These modes differentiate on the underlying social relationships, based on the dimensions degree of boundedness, formalization and hierarchization (Machado & Burns, 1998 p.360).

2.3.4 System level

All definitions of complex systems contain notions of overall system behaviour. In this subsection we will examine system properties and behaviour at the system level. The system level describes the whole system: a human, the world, a species, etc. The system-level conceptualization has a structure similar to that of the agent level: input, rules and output (see Figure 2-6). The difference is that at the agent level there are multiple agents and the system level can be seen as a 'single agent'. The properties we define at this level are: emergent behaviour, self-organization, path dependency, robustness and instability. We use the vocabulary of non-linear dynamics (Prigogine & Stengers, 1984). This field has established a tradition of formally describing overall system behaviour.

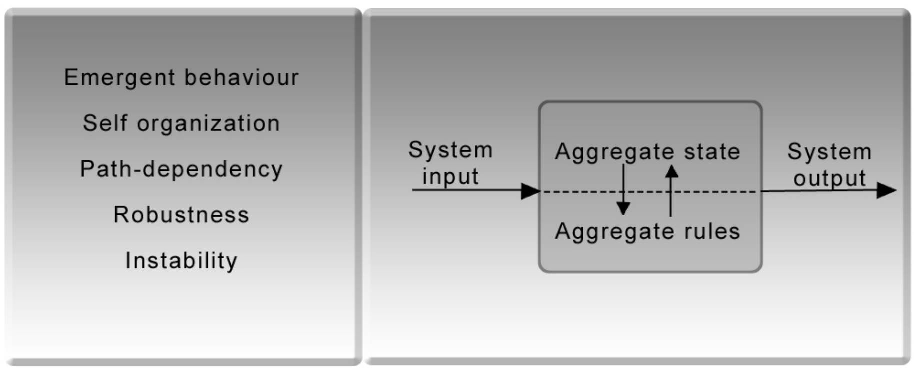

Figure 2-6. System level properties and visualization

System

The system *input* comes from within the system and from the environment. From within the system it is the aggregate input from all agent interactions. For example, as assuming the arm to be a system, the brain sends an electric pulse to the arm to raise it. The system input is an electrical signal to the muscle, which consists of countless muscle cells, and the system output is movement of the arm, caused by the contraction of the cells simultaneously.

A characteristic of the system output is the attractor. An attractor is the area where the system output 'wants' to go. That is, the system output has structure (Holland, 1997). Usually, the system output contains multiple attractors and the system itself is sensitive for initial parameter values (system inputs). Slight changes in parameter value may lead it to another attractor. This extreme sensitivity to initial parameter conditions leads to chaotic behaviour.

Important properties of the system level

We identify five important properties at the system level: emergent behaviour, self-organization, path dependency, robustness and instability. These properties are properties of the whole system. However, self-organization and path dependencies can also be observed at the agent level, but then within their internal model.

Emergent behaviour: The behaviour shown by the system as a whole – the system's output – is called 'emergent' behaviour. Emergence occurs in systems that are generated: the systems are composed of copies of a relatively small number of components that obey simple laws (Holland, 1997). Emergence is the process by which new characteristics arise once the system is constituted (Crutchfield, 1994b; Morin, 1999). Or, as Jennings (2000) puts it: emergent behaviour is the behavioural phenomena that cannot be deconstructed *solely* in terms of the behaviour of the individual agents, because the interactions between agents are non-linear. Newman (2003) understands emergent behaviour as being processes on networks.

It is important to realize that emergence is 'no magic'. Emergent behaviour is a logical consequence of the interaction in the system and the organizational structure of the system, which gives the parts qualities that they could not have if they were isolated from the organizing whole (Morin, 1999 p. 118). Emergent behaviour is simpler to understand, and more insightful, than the collection of processes that cause it. However, this behaviour is not always predictable or obvious. Examples of emergent behaviour are flocks of birds, hurricanes, termite mounds and bankruptcy.

Emergent behaviour has also been observed in the economic literature. Externalities are considered to be emergent properties. These externalities can be positive: the lovely garden of the neighbours that adds value to your house, or negative: sitting next to a person who is smoking. Emergence in social systems is the meaning given to information (Gharajedaghi, 1999). Emergent properties are the spontaneous outcome of ongoing processes (Gharajedaghi, 1999 p.48), such as happiness, success and development (p.56). The outcome of policy processes, which are unpredictable due to incomplete information and unclear values, can be considered as emergent.

The behaviour can be explained by the interaction between agents, the adaptations of the agents and the attractors of the system. Meadows et al. (Meadows, Meadows, & Randers, 1992 in Ehrenfeld, 2000) describe four characteristic behaviours of complex systems: exponential growth, logistic pattern, overshoot and collapse, and oscillation. Another explanation for emergence is the feedback loops in the system. The feedbacks can cause positive effects when they strengthen the outcome, called the 'success of the successful' (Senge, 1990 p.385), or negative effects when the feedback nullifies the changes: 'limits to growth' (p. 379).

Self-organization: Self-organization is specific type of emergent behaviour. It is a process by which a system achieves a different output through internal processes, without any external input (Kay, 2002; Prigogine & Stengers, 1984). For example, the morphogenesis (construction of shape) of embryos, a fully functional organism self-assembles from a single fertilized cell (Campbell & Reece, 2002). With autopoiesis (self-steering), for example, society self-organizes in a way that limits the amount of individual choice, thereby providing a self-steering and a more predictable system (Luhmann, 1995).

Social networks are also self-organizing systems (Kickert et al., 1997 p.xiii). A certain design of an organization or the implementation of new rules and regulations work for a short while. Agents in the systems will try to avoid these rules or use them wisely, which could lead to unintended outcomes or perverse effects (Innes & Booher, 1999). It is important to note that self-organization is different from adaptation, as self-organization originates from the system itself, whereas adaptation is a reaction of the agents to the changing environment. Self-organization and adaptation can be present at the same time.

Path dependency: Path dependency has two conceptions. The informal conception is that 'history matters' (Buchanan, 2000): an accidental choice determines a certain path. A more formal conception is that there is a reinforcing effect; institutions, for example, are self-reinforcing. In economics, the term 'path dependency' is also known (Economides, 1996). Production and consumption decisions are based on sizes of an installed base and on expectations of its increases over time. Path dependency in economics lasts because of the high switching costs involved. This is, for example, the case with our current infrastructures. We cannot change to an all-hydrogen economy overnight. Path dependency can also be found in politics. Once a political party chooses a statement, it is difficult to change; only when a new leader comes or elections are held can the statements be changed.

Robustness: A system displays robustness (Callaway, Newman, Strogatz, & Watts, 2000) when it is close to an attractor. Changes in certain parameters cannot cause a deviation from the path to the attractor. Robustness is a relative concept, as a parameter change, no matter how large, cannot make the system deviate from its path to an attractor; other slight changes might. The system is therefore robust for certain parameters.

With the term 'robustness' we mean the resilience of the system. It is a measure of how the system performs under stress when it is confronted with extreme inputs or with shocks from the environment for particular variables. Crash zones in cars enhance the cars' robustness and help save people's lives. The Internet is another example of a robust system. It is designed to function even if large parts of it are destroyed. The economic situation of lock-in, on the other hand, in which a customer is so dependent on a supplier for products and services that he or she cannot switch to another supplier without substantial costs (real and/or perceived) is an example of a system that is not robust. The resilience in social networks is the ability to improvise or the ability to bounce back to the stable state. However, in this framework these two characteristics are split. The ability to improvise is related to the adaptivity of the agents, where the ability to bounce back is related to robustness. Robustness can also be found in policy networks: if a conflict between parties escalates, the network structure (the ruling parties) should not immediately break down and these networks should be able to recover from damage caused by conflicts (Kickert et al., 1997).

Instability: Instability is the capability to suddenly change over to another attractor with minimal parameter changes. Instability can be seen as the opposite of robustness. We do not call robustness 'stability' since both robustness and instability are present in the system at the same time. The terms stability and instability would make the properties sound mutually exclusive. The extreme sensitivity of a complex system to parameters values can be illustrated with the example of the exploded space shuttle Challenger. A difference of 13 degrees at the landing pad caused the Challenger to explode. The rubber sealing rings of the fuel tank cracked at this temperature[4]. Large crowds can also be instable, as they can suddenly turn to riots. Other examples of robust systems that become instable are: the human body, in which a tumour can become life threatening when it grows and presses into other organs; or the mobile phone network that periodically overloads on New Year's Eve.

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[4] Presidential Commission on the Space Shuttle Challenger Accident (1986) Report of the Presidential Commission on the Space Shuttle Challenger Accident. Washington D.C.

2.3.5 Connecting the levels into a framework

The framework represents the different conceptual levels and properties of complex adaptive systems in a multi-actor context. On the left side of Figure 2-7, the properties of each level are presented, while on the right side a visualization of the level is presented. It should be noted again that these levels are conceptual distinctions, used for a better understanding of the systems, and that they do not exist as such on top of each other.

For clarity, the framework is described as a separate system within an environment with a clear boundary. We have to be aware that this boundary is not this clear in reality; agents can be part of multiple systems, and the observed system is part of other systems.

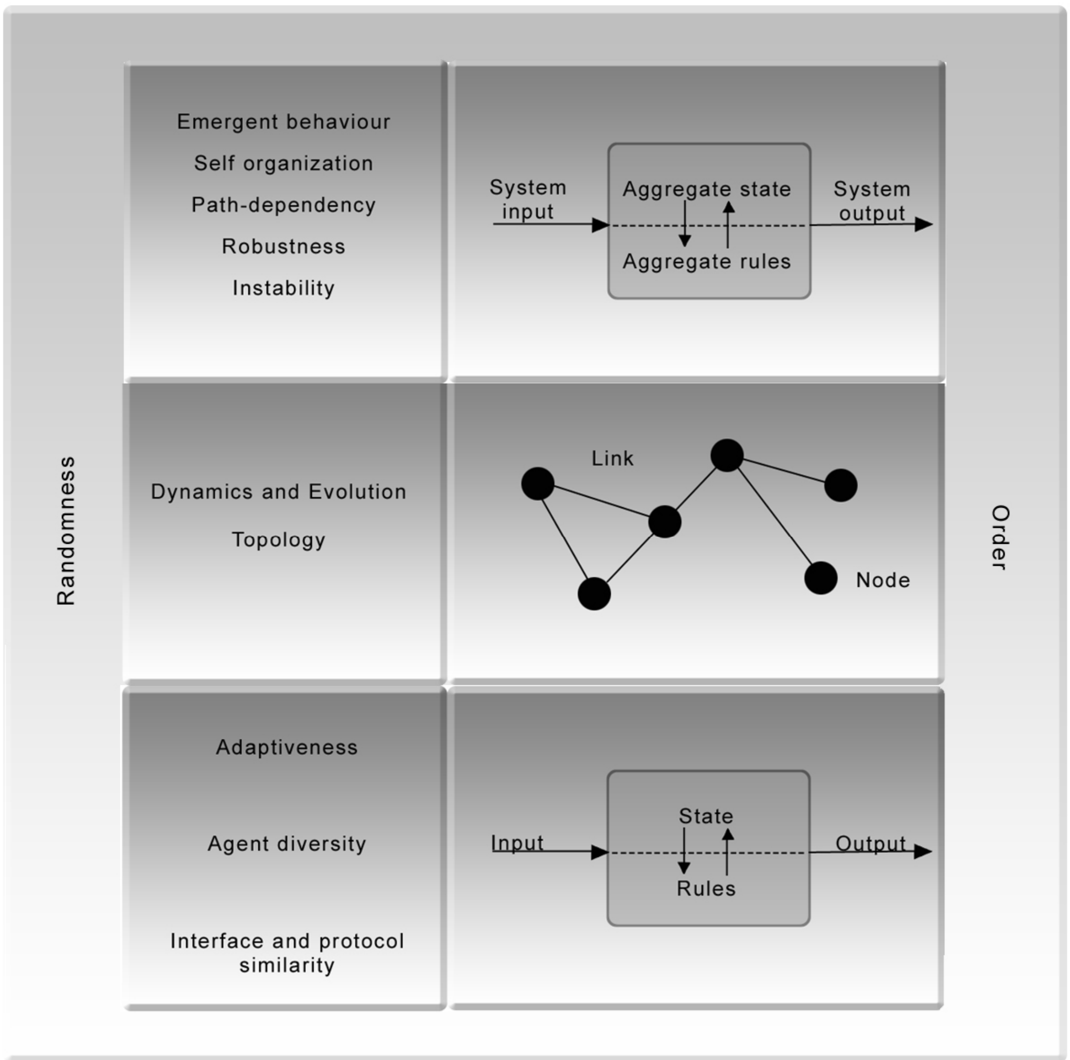

Figure 2-7. Conceptual framework of complex adaptive systems

Observer dependency

When the framework is applied, the choice of system decomposition is dependent on the system's observer. Each observer chooses a certain perspective when interacting with a system. For example, a chair is a social, physical and chemical entity. It depends on the interests and questions of the observer as to which of these perspectives will be used to construct the conceptual model of the chair. The observer dependency is especially apparent when considering system behaviour over time. An observer studying the plate tectonics of a region will not be able to make meaningful observations within a time scope of minutes or hours.

The observer also chooses the system's aggregation level. By aggregation we mean that many agents with the same or similar kind of behaviour can be generalized into an aggregated, larger group. If one wants to compare the behaviour of soccer supporters of different countries, one does not consider all the individuals separately but aggregates them into a homogeneous group, e.g. the Dutch supporters and the French supporters. Aggregation is used to decrease the number of agents and to simplify the system so that the observer can effectively determine the smallest component in the system.

2.4 Infrastructures as complex adaptive systems

The framework of complex adaptive systems can be used to analyse infrastructure systems. In order to explain the complexity of infrastructure systems, we have to compare the properties of infrastructures with the properties of complex adaptive systems.

In this section, urban and spatial infrastructures are analysed as complex adaptive systems based on the framework. As a leading example, we take the growth of an urban area. Urban areas can be considered as network-bounded infrastructures, and many other infrastructures are part of this system. Furthermore, cities are also used by others as an illustration of properties of complex adaptive systems (Holland, 1995; Portugali, 1997). Examples of other infrastructures like energy and transportation are used for a broader explanation.

2.4.1 The framework applied to infrastructures

Cities are networks that evolve over time and space. These networks emerge from the interaction between a huge number of people, and nobody has full control. Cities are open systems adapting to the environment. For cities, as also for infrastructure systems, it is difficult to define clear boundaries of the system. Cities are connected to other cities in different ways and different intensities.

A city is built of several subsystems, such as a transportation system, energy system, housing system, market system, government, etc. These systems are highly integrated and make the city what it is. The observer does not only have to define the boundaries of the city, he also has to define which level in the hierarchy is relevant.

The development of cities is based on the interactions between social elements and the physical environment. Both elements are highly interwoven. Therefore, both types of systems have to be considered integrally.

Under the following headers, the complexity of cities is described based on the properties of complex adaptive systems.

Infrastructure agents

Within cities, many agents (including traffic lights, streets and bridges) and actors (like buyers and sellers) can be found (Holland, 1995). Between the city as a whole and the individual agents, subsystems can be found: for example, the transportation system, the energy system, the market systems and governmental system (see text box).

> Several examples of different subsystems and their agents:
> Transportation system: busses, bus Stations, passengers, drivers, roads, cars, bicycles, pedestrians and traffic lights
> Energy system: cables, switches, street lights, computers, power plants, etc.
> Housing system: flats, villas, houses, streets, inhabitants, public services
> Market system: shopping malls, retail business, buyers, money, information
> Government: mayor, aldermen, citizen, councillor, action groups, elections.

A process which increases the diversity between agents is specialization. Specialization allows for more diversity of function in the system among and within organizations and leads to a more efficient division of tasks. However, due to specialization, information is unequally divided over the agents. This information inequality can be found in infrastructures after liberalization and privatization. The network companies have more knowledge of the operating system than do the regulators. Consequently, agents are dependent on information from each other to be able to operate in a proper manner. Sometimes they use this asymmetric division of information strategically. Several notions which describe agent behaviour are ‘bluffing’, ‘cheating’, ‘adverse selection’ and ‘moral hazard’ (Ten Heuvelhof, De Jong, Kuit, & Stout, 2003).

Agents and subsystems observe changes in their surroundings and adapt to these accordingly. They change their state or behaviour, creating dynamics in the system. Interaction between agents depends on the type of agents: people interact by talking with each other, while physical elements are bounded by the laws of nature. Finally, actors react to the environment based on functions and visibility and influence the environment by design and use.

To conclude, cities and infrastructures consist of many diverse adaptive agents. These agents have a common interface in which to interact. City planners or managers have to reckon with these different agents. Changing a system provokes a reaction of the adaptive agents, which could be to return the system to its previous state or to deal with it in another way as expected or intended.

Infrastructure networks

The interaction between agents leads to network structures. Physical networks of roads, electricity cables and sewage pipes, as well as social networks like an educational or cultural system exist within a city. These networks have different topologies; a road system is mostly undirected, while the electricity network and sewage system can be considered as directed graphs. This structure influences the choice of where to intervene or connect new elements.

The development of cities and infrastructures follows a long-term co-evolutionary process. The city grows physically by developing new areas or reconstruction areas. Movement of people and recomposition of different groups of people also change the structure of a city. In other infrastructure systems like electricity or gas, the process of liberalization causes large changes in the networks. Finally, networks evolve through combining different systems, like combined communication systems (VoIP, Internet on the cell phone), Internet via electricity cables, or the use of communication technology in the health-care system.

Cities and other infrastructures have different types of network structures and levels of hierarchy. These structures are not static; they evolve by means of human interventions. Introducing new projects or predictions of problems will start a dynamic of opposite plans and solutions. These become part of the system and change the structure. Dealing with these systems requires insights into the structure and knowing where to intervene for the highest effect, while at the same time being aware that the intervention directly means a change in the structure.

Infrastructure system behaviour

Cities and infrastructures are robust systems; they do not collapse after small changes. Gradual growth of inhabitants, for example, is a process that can easily be accommodated, as long as the system has enough time to adapt. On the other hand, these systems can be instable for other parameters, like a flooding or power black-out.

The structure of the city shows emergent behaviour, the value of the whole is more than the sum of the parts. The functions and dynamics of the city itself are emergent in the sense that the state emerges from the interacting elements. More specifically, the combination of different services surrounding a living area increases the value of both elements. Traffic jams are also observable emergent behaviour, just as the division of people over the city during the day.

Infrastructure systems also show self-organization. They adapt to new rules, changed in the systems. An example which shows the self-organizational property of the agents in a system is the development of slums, for example in South America. The people build their own areas; create their own economies and build their governance without support from the central government (De Soto, 1989).

In the development of infrastructures, path-dependency is evident. Cities slightly grow and adapt to the changing environment. Each new project starts from the existing system.

Complex adaptive infrastructures

Cities and infrastructures are complex in two ways. In the first place, they consist of many interacting elements, which show adaptive and non-linear behaviour. In the second place, these systems have both physical and social elements and have to be considered as socio-technical systems. The consequences of the design and planning of future development is not predictable because of the complex, non-linear, self-organizing properties of the system (Portugali, 2008). Portugali (2008) even argues that cities are dual self-organizing systems; although the physical elements are rather simple, they already lead to emergent behaviour. The same holds for the human system, only the elements in the human system – the humans – are complex themselves. They learn, plan, think and make decisions based on earlier experiences. Therefore, urban planning can be seen as an ongoing interaction between planners and their plans when none of them can fully determine the final form and structure.

The changes in infrastructures (see Section 1.1), due to the convergence of networks and functions, specialization and globalization, together with changing social needs, lead to a larger network with more interdependencies between actors and other elements. Consequently, more non-transparent and non-linear relationships emerge, which become observable in the self-organizing capacity of cities and emergent behaviour. Other infrastructures show self-organization and emergence as well. The chain of production, transportation and use of energy is an example of emergent output of the energy system, because it cannot be reached by each individual part. More often, emergence in infrastructures is characterized by poor performance, missed opportunities and the inability to serve smaller user communities.

2.4.2 Understanding infrastructure complexity in terms of design

Based on the CAS-framework, power black-outs, traffic jams and the evolution of cities can be better understood and explained. Changes in the environment can be absorbed and the system returns to its original behaviour. However, when a sensitive factor is changed in the environment, like the presence of many cars in a row, the behaviour of the system can totally change, i.e., a traffic jam occurs. The CAS-framework provides no insights into the prevention of malfunctioning or the consequences of intervening in the system.

Changes in complex adaptive systems

A system's state is somewhere in an attractor field. These attractors move the system towards equilibrium, the state where, according to the law of thermodynamics, entropy is the highest. However, this is only the case in closed systems which are not influenced by the surroundings. Complex adaptive systems are open systems. Therefore, their optimum states differ according to their changing environments (Mitleton-Kelly, 2003). Because a complex system is situated in a dynamic environment, the system is always adapting and changing. These dynamics, caused by the system, we call 'normal change'. On the other hand, managers would like to steer the system to a desired state. Because the desired state is not caused by normal change, managers intervene in the system to bring the system into another attractor field.

Normal change: The possible states of the system in the environment can be represented as a fitness landscape. The highest point in the landscape can be considered as the optimal state of the system. When the system is on a certain peak, the system will change to this highest point or local optimum, which is not necessarily the global system optimum.

The behaviour of an agent is also an autonomous process. Actors make choices when they act. Teisman (2005) speaks of path dependency and bifurcation. He assumes that human agents walk down a fixed path. Path dependency then means that a human agent's behaviour is based on the position of the agent and that this position is based on the path taken earlier. The system could come to rest in a lock-in situation, where there is no switching possibility. However, when the environment changes, new opportunities appear and old goals become less important. Then human agents do have the option to change their direction; this is called bifurcation. This choice depends on the internal mechanisms of the human agent. This behaviour shapes the structure, which determines the overall behaviour of the system. The aggregate system output in turn affects the inputs that the agents receive. So, any change in any component or level of the system can affect the whole system.

Intervention: The second way to change the system is by intervention. In an abstract sense this means one wants to switch the systems from one attractor to another, more desired, attractor. When the system is in the desired part, less energy is needed to stay there. This seems easy, but several problems can be identified with this process. The first is that we have to know what the state diagram looks like, if there is more than one attractor and where the other attractors are. Complex systems have multiple possible operating states, attractors or critical points and may shift or diverge suddenly from any one of them (Kay, 2002). This is caused by the chaotic characteristics of the system and the dynamics in the environment.

Intervening in the system can be done in several ways: changing the internal rules and behaviour of the agents, changing the type and number of agents, and changing the structure of the network. This can be done respectively by learning about the system, by adding new elements or people, or by changing the rules.

According to Axelrod and Cohen (2001), designers or managers have to find the right balance between variety and uniformity. They have to choose between exploitation, to make the most of existing ideas, and exploration, which means searching for new solutions. The challenge for managers of complex systems is to put the right changes in the agents or the structure and to search for the windows of opportunities. This challenge can be made easier when they have a better understanding of the system.

Theoretically, this means that managers and designers of infrastructures have two options: 'wait and see' and 'intervene'. With the 'wait and see' approach, the system moves to the desired state, by normal change. The attractor is either at the desired state, or other mechanisms within the system change in such way to make the attractor change. Intervention to change this process is not necessary, except when the attractor of the system is not at the desired state. The second option is 'intervening in the system'. There are interventions that can change the internal models of agents, such as learning or rewriting rules. Another option for an intervention is to change the number or type of agents by replacing persons or elements in the system. Third, interventions can be used to change the interaction between agents and therefore the rules and relationships of the network.

Intervening in the system

Managers and designers of infrastructures can intervene based on a physical or a social approach. Both approaches have to be taken into account in socio-technical systems.

Physical approach: A way of describing the direction of the behaviour of the system is by attractors. A system is somewhere in an attractor field. An attractor state is the point where the system finds some stability and attractors are the characteristic dynamic semi-stable patterns of behaviour the system goes to (the peak in a fitness landscape). The moment that the system is situated on an unstable peak in a fitness landscape, the system could be sensitive to certain parameters. A small change in the environment could start a flow of change until a new quasi-equilibrium is found. A well-known example of Per Bak (1996) is to drop one grain of sand at a time onto a sand pile. The system grows and becomes higher until at one point a new grain of sand disturbs the equilibrium and the hill caves in. This caving-in process continues until a new equilibrium is reached, which is again a sand pile, only lower and wider. The point in which the system is sensitive to certain parameters is called the 'bifurcation point'. Bifurcation is the tendency to split into alternative solutions when there are two or more options (Mitleton-Kelly, 2003).

In simple systems, we can observe such behaviour and draw those attractor fields. Take, for example, a swing with one connection point. If we move the swing away from its equilibrium and let it go, then the swing will oscillate around its equilibrium. The deviation from the lowest point will decrease due to friction, and finally the swing will stop oscillating. This process is well-known: there are equations that simulate this movement and the phase diagram can be drawn. From these equations, we know in which direction the system goes and what we can do if that is not the desired situation. For the example of the swing, the upward position is an unstable point in the phase diagram, where it is easiest to change the course of the system in time. Of course, this is a simple and imaginable example, but for complex systems the approach is not different. Only, with many variables and relationships this is difficult; we cannot simply use some equations and draw pictures as we could do with the example of a swing. Secondly, if we were to be able to draw such a field, we would have to know where the system is at a certain moment; this, too, is impossible to know. When the attractors are known and the state of the system is known, then the best time for intervention can be chosen. The best time is when the distance between two attractor fields is small and the effort to change into another field is relatively low. An example from the social sciences is the streams model of Kingdon (1984), where this moment is called the 'window of opportunity'. This is when the stream of solutions, problems and politics come together. At this moment the system is ready for change.

Social approach: Complex systems are difficult to steer with top-down rules. Complex systems are living systems and adapt, change, grow and create new interactions. Interventions from top-down managers have fewer effects. Self-steering is more important in these systems, and the steering has to be adapted to this process

(Teisman, 2005). Steering can be possible if the limitations are taken into account: for example, incentives can be used to give a spectrum of options instead of prescribe specific actions (Teubner, 1993 in Brans & Rossbach, 1997 p.433). In complex systems where hierarchical and network structures exist at the same time, a conflict can emerge between hierarchical and network management strategies.

According to Lindblom and Cohen (1979) an outcome or a decision emerges from the interaction among decision makers. They also describe the process as ‘muddling through’. Cohen, March and Olsen (1972) state that ‘a decision is an outcome or an interpretation of several relatively interdependent “streams” within an organization’. De Bruijn and Ten Heuvelhof (2008 p.23) describe this process as the ‘dancing table’, where all the actors are pulling and pushing the table to bring it to a certain corner in the room. Finally, the table sways through the room and lands at some place nobody expected or is satisfied with. The characteristics of complex networks make policy processes unpredictable.

In many situations there is a solution or an attractor to which the system goes, due to new information or interactions the solution suddenly changes in the environment and the system follows a path to another attractor. Boin (2006) discussed three laws of complexity: 1) a complex system tends towards a situation of order; the system is looking for structures and general behaviour, 2) the development of a complex system inclines to a critical point (the edge of chaos or the tipping point), and 3) this optimal (critical) point is very vulnerable; small changes can bring the system out of equilibrium, thus creating changes in the behaviour. He concludes that these laws enrich insights into the dynamics of social systems. Complexity gives an explanation as to why there can be sudden radical changes in apparent stable systems and to the powerlessness of policy makers.

Chaos and order support or halt the development of a system (Teisman, 2005 p.39). Order in a system leads to the efficient execution of a task, but when order becomes inert, the effects of actions are limited. Chaos, on the other hand, is aimless and inefficient but leads to adaptation and innovation. A social system has to be efficient in order to execute its task, but also flexible enough to adapt and innovate.

The framework explains why it is hardly possible to bring the system to the desired optimal state. There is no stable end state and no single possible outcome. The system is dynamic, and interventions will lead to new dynamics. This is also observed in infrastructure projects. In these project, decision makers focus on one solution (Priemus, 2007). They are not able or willing to adapt to other ideas proposed by other actors in the system. Project managers have to be aware that the first solution is a way to go, but not necessarily the outcome. A complication in this decision-making process is that the dynamic processes do not stop after building but continue for a long time. For example, in the short term the intervention has a positive effect by solving the problem. Yet in the long term or at other places in the system, negative externalities could occur. These dynamics are difficult to predict and to act on at the start of a project. According to Innes and Booher (1999), more adaptive strategies have to be used for metropolitan development, and this requires three elements: consensus building, indicators for feedback, and new leadership style. Boin (2006) proposes two ways of dealing with complexity: improving the adaptation of the system and increasing the resilience of the system. And Roos et al. (Roos, De Neufville, Moavenzadeh, & Connors, 2004) argued that next generation infrastructures have to be adaptable and flexible in order to be able to respond to unanticipated events.

Simulating future system behaviour

A framework gives only a static view of a situation. Therefore, framework can be used to comprehend and explain the dynamic social phenomena (Waldrop, 1992) or to learn that complex systems require a feasible combination of stabilized order and developed dynamics (Teisman, 2005). However, it is not possible to simulate the dynamics of the complex system and to understand possible future behaviour.

In order to explore possible future situations or the effects of interventions on the system, dynamic tools or instruments are needed. To research aggregate behaviour we need the support of computer-based exploration (Holland, 1997). These computer-based explorations can have different functions: to show the correctness of the prediction of the world, to demonstrate that something is possible, or to suggest new ideas about complex situations (Holland, 1997). Further, managers need tools for practicing their management competence to be able to switch between getting order and dealing with chaos. The computer-based tools have two objectives: 1) to provide insights of possible future behaviour caused by the characteristics of the system and 2) to train managers about the complexity and the role of the actors in the system.

There are different types of simulation models used for the understanding of complex systems. For example, Systems Dynamics (Forrester, 1958), which is based on systems thinking, studies the behaviour of systems and shows how policies, structures and delays are interrelated and influence growth and stability. Systems Dynamics opens a black box of input and output systems and provides more insights into the feedback mechanisms of a system.

Another type is the use of agent-based modelling (ABM) (Axelrod, 1997; Briassoulis, 2008; Epstein, 1999). The idea behind ABM stems from Von Neumann in the 1940s, but it took until the 1990s before ABM was widely used to solve business and technological problems. An ABM is built of relatively abstract agents with decision-making rules. These rules form the internal model of an agent and determine the reaction of inputs from other agents. The aggregated behaviour is based on the relationships between the agents and is computed from the bottom up. Agent-based models can explain the emergence of higher order patterns or observations at the system level.

There are also many other types of simulations, often computer-based, like Cellular Automata, and Discrete Event Simulations. These all could have different functions in urban planning and design. Without going into detail, these simulations and models become more complicated and are used for multiple functions. There is also a tendency to combine different models to provide multidisciplinary functions. Based on the outcomes of the models, which represent future behaviour, complex systems properties can be derived and explained.

Still, there are two limitations of the use of these computer simulations for understanding infrastructure systems. The first has to do with the socio-technical characteristics. Empirical research (De Bruijn & Ten Heuvelhof, 1999) has shown that the policy- and decision-making process also depends on the political context. Many policy makers with different interpretation frames are also involved and introduce new ‘facts’, values and argumentations. The policy and the effects of policy are the result of the complex interactions between the different stakeholders (De Bruijn & Ten Heuvelhof, 1999). Computer simulations do not take these values and interactions into account, though there have been attempts to develop socially intelligent agents (Hogg & Jennings, 2001).

The second limitation is the gap between modellers and policy makers (Brewer, 1975; Lee, 1973; Te Brömmelstroet & Bertolini, 2008). The simulations become too complex for a policy maker to understand (Lee, 1973; Yewlett, 2001). Research into the effects of large-scale urban simulations showed that the best learning effects reached were the increased understanding of model building and the relationship to policy analysis.

Gaming simulation is introduced as a way to deal with both of these limitations (Duke & Geurts, 2004; Geurts & Vennix, 1989). The players of the game bring values and interactions into the simulation, and the policy makers can become players and thus experience the dynamics of the simulation while playing. In Chapter 3, the role of gaming in understanding complex adaptive systems is analysed in detail.

2.5 Conclusion

The central question in this chapter was what the properties of complex systems are and in which way these contribute to the understanding of infrastructure systems. To answer this question, a framework was developed based on Complex Adaptive Systems.

Managers and designers are faced with complex infrastructures, because they have to reckon with physical requirements and a variety of social values. However, this is not the reason that infrastructure systems are complex. This is caused by the large number of interacting agents, the uncertainty of the consequences of the decisions in the long term, the unknown reaction of the system and therefore the unpredictable results of the intervention.

For the explanation of the system behaviour, several theories of complex systems are introduced (General System Theory, Cybernetics, Systems Thinking and Complex Adaptive Systems). Complex Adaptive Systems was selected as being the most suitable approach for explaining the behaviour of complex infrastructure systems. To relate the concepts of Complex Adaptive Systems to characteristics of social networks, literature form Public Administration and Managements were used[5]. Several researchers have tried to explore the possibility of using notions of CAS to describe and explain the behaviour of social systems (Axelrod & Cohen, 2001; Boin, 2006; Teisman, 2005). This led to the following description of complex adaptive systems: Complex adaptive systems are open, adaptive systems, situated in a dynamic environment, consisting of heterogeneous agents and actors, which are related in a network structure, and the result of these networked interactions is the observed system behaviour.

The notions of complex adaptive systems and social networks are combined in a complex adaptive system framework. This framework provides a way of thinking or a way of seeing the world and is not a methodology or a set of tools. The framework consists of three levels (agent, network and system), and each level contains several properties. This makes a system complex. With the use of the framework, the complexity of infrastructures can be explained and understood. This framework is useful to describe the complexity; however, this does not solve the problem of being able to understand the dynamics and analyse the consequences of different policies.

For the exploration of complex system behaviour based on the interacting diverse agents, dynamic tools or instruments are needed. There are many different computer models and simulations that are useful for simulating the physical and technical behaviour of the system. However, these do not take social elements into account, and these models and simulations are too complicated for managers to be able to use them effectively to increase their understanding of the system. In the next chapter,

[5] Recently, other fields have also tried to apply concepts of CAS in their research, like ecology/natural resource management and urban planning (Innes & Booher, 1999; Portugali, 1997, 2008).

gaming simulation is introduced and analysed as a tool that deals with these limitations and increases the understanding of complex adaptive systems.

3. GAMING COMPLEX SYSTEMS AS A WAY OF UNDERSTANDING INFRASTRUCTURES

Playing a game is a learning experience, because playing a game is an activity of improving skills to overcome challenges (Juul, 2005).

Introduction

The understanding of complex infrastructure projects can be improved by considering them as complex adaptive systems (CAS). As concluded in Chapter 2, the developed complexity framework supports the explanation of complex system behaviour retroactively; it is not a method for exploring future behaviour. In this chapter, gaming is introduced as a simulation of CAS and as a supporting tool for understanding infrastructure systems (Figure 3-1).

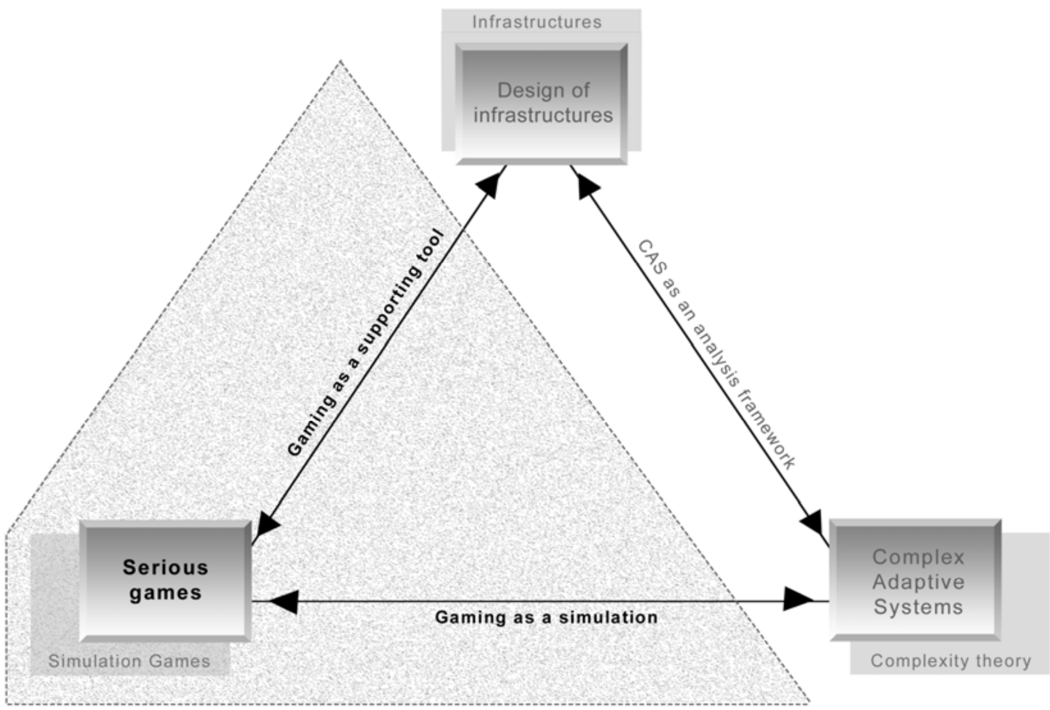

Figure 3-1. Focus of this chapter in relation to the framework

Gaming in itself is not new; it has already been used to explore various scenarios (Bots & Van Daalen, 2007; Duke & Geurts, 2004). However, developments in the video game industry provide new possibilities for gaming as a policy support. This leads to a re-introduction of the concept of serious gaming. After analysing the added value of serious gaming, the question arises as to the way in which serious games can simulate CAS. This is explored by considering serious games as a CAS. In Section 3.2, games are divided into players, rules and behaviour, which can be compared with the functions of agent, interaction and system behaviour. Based on this analysis, several requirements are derived for the use of serious gaming as a CAS.

Considering games only as CAS is not sufficient to increase the understanding of these systems. Therefore, we have to answer the question of the way in which serious gaming supports the understanding of the complexity of infrastructure systems. In order to answer this question, we will take two perspectives on increasing knowledge about the system. The first perspective is the increased understanding of system behaviour, where the dynamics in the game contribute to an understanding of the dynamics of the real-world system. The second perspective is the increased understanding of the game participants. By playing the game, they become part of the system and experience its complexity.

This chapter ends with several expectations of the use of serious games as a simulation of CAS and as a supporting tool toward a better understanding of infrastructure systems. Furthermore, several design requirements are defined which have to be fulfilled to be able to develop a successful gaming intervention.

3.1 Serious gaming: a new look at simulation games

If you ask developers or hard-core gamers what is meant with serious gaming, the answer will be that all games are serious. They consider the development and game play as serious business and spend a lot of time playing, discussing and reflecting. On the other hand, the concept of *serious games* seems like a contradiction. Gaming is related to play, pleasure and fun. How can that be serious? Nevertheless, the term *serious games* is used by many people. So, what characteristics make a game a serious game?

Since the re-introduction of serious games in 2002 (Sawyer, 2002) there have been many discussions about the use of this concept, and many definitions of serious games have emerged. Without intending to define serious games as a whole, it is necessary to give a description of what is meant by serious gaming in this dissertation. This description is grounded in the ideas of simulation games, used as a starting point for this research.

3.1.1 From games to serious games

Games

Games and playing are well-known concepts, but a generally accepted definition of games does not exist. Below, there are two definitions of games, provided by Klabbers (2006b) and Juul (2005). These definitions have several characteristics in common. They both describe rules, outcomes and players as game elements. Juul further emphasizes the emotional attachment of the players with the outcome. Klabbers emphasizes the competition element, caused by constraints and resources.

> Games are rule-based systems with variable and quantifiable outcomes, in which different outcomes are assigned to different values, the player exerts an effort in order to influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable (Juul, 2005).

> A game is a form of play. It is an activity involving one or more players who assume roles while trying to achieve a goal. Rules determine what the players are permitted to do, or define constraints on allowable actions, which impact the available resources and therefore influence the state of the game space. Games deal with well-defined subject matter (content and context) (Klabbers, 2006b, p.20).

Other researchers describe similar game characteristics: elements, actors, rules, resources, players, competition, challenge and game state (Armstrong & Hobson, 1975; Crawford, 1984; Huizinga, 1952).

Another important element of games is that they are separated from the real world. There is a permeable boundary, the so-called 'magic circle', which separates the game world from reality (Copier, 2007; Klabbers, 2006b; Prensky, 2001). Within this boundary, the rules and roles in the game are valid and the outcomes of the activities within this boundary do not have consequences for the real world. On the other hand, this boundary is open to transfers between game and reality. Recently, Copier (2007) concluded in her dissertation that the influence and networks surrounding games go beyond the magic circle. Game play is influenced by the cultural and social backgrounds of the players, and players acquire new knowledge and skills which can be used in reality.

Simulation games

There are different perspectives from which games can be viewed. Games can be considered as an artistic medium which is more interactive than books and video

(Michael & Chen, 2006). On the other hand, games can be considered as simulations. Duke and Geurts describe gaming simulation as ‘a special type of model that uses gaming techniques to model and simulate a system A gaming simulation is an operating model of real-life system in which actors in roles partially recreate the behaviour of the system’ (Duke & Geurts, 2004). Simulation games or policy exercises are described as representations of sets of key relationships and structural elements of a particular issue or problem environment, where the behaviour of actors and the effects of their decisions are direct results of the rules guiding the interaction between these actors” (Wenzler, 2003). Gaming simulation emphasizes that human participants play a role in the simulated reality.

The first simulation games were found in the military industry in the late 18th century (Armstrong & Hobson, 1975). These war games were used for the exploration, planning, testing and training of military strategies, tactics and operations in a simulated, highly interactive environment (Brewer & Shubik, 1979; Shubik, 1975). Military games are still successfully used today (Bohemia Interactive Australia, 2007; US Army, 2009).

Since WWII, games also have been used in the public sector to support policy- and decision-making processes (Becker & Goudappel, 1972; De Caluwé, Geurts, & Buis, 1996; Duke, 1998; Duke & Geurts, 2004) and for business processes (Faria, 1987, 2001). Forty years of experience shows that simulation games have educational, training, policy and research purposes. Games have proven useful for experimentation and learning (Mayer, 2009). Duke and Geurts summarized multiple objectives of policy games, which they divide into the 5 C’s: improving Communication, the need for Consensus, Commitment to action, stimulating Creativity and understanding Complexity (Duke & Geurts, 2004).

Improving communication: Communication between actors in policy processes is important. Gaming creates a setting in which multiple stakeholders can communicate together. This makes gaming a valuable method for supporting the communication and learning processes (Van der Meer & Geurts, 1995) and structuring the debate between stakeholders (Geurts & Joldersma, 2001).

Need for consensus: Duke and Geurts (2004) describe three perspectives beyond this function: reaching consensus, conflict mediation and collaboration. A game can explore whether or to what extent a conflict between actors’ perceptions exists. By learning from the perceptions of other stakeholders, the proposed solutions can be considered from multiple perspectives.

Commitment to action: Gaming can be used to introduce or test new policies or interventions; to convince the participants of the need for the intervention; to introduce the intervention approach; and to show the roles of the participants in the intervention. Examples of games used for these purposes are games for organizational change (De Caluwé et al., 1996) and 'a day in the life' simulations (Wenzler, 2002).

Stimulating creativity: Games can be considered as a laboratory for developing and practicing policy interventions. By stepping into a game setting, players leave behind their routines. This new environment encourages creativity. In addition to experimenting with policy processes and researching future development, games are used in researching difficult or unacceptable situations (Geurts & Vennix, 1989).

Understanding complexity: By 'understanding complexity', Duke and Geurts (2004) mean understanding the problem situations of macro problems. They describe macro problems as problems in dynamic environments, with many variables and actors; these actors have different objectives and values, and the outcomes are uncertain and unpredictable (Duke & Geurts, 2004). The objective is to use simulation games to gain a holistic view of the system. Gaming contributes to the problem solving of complex managerial, social or policy problems (Geurts, 1993). But most of all, gaming should be seen as a 'language of complexity' (Duke, 1974; Vennix & Geurts, 1987).

Urban planning games

One of the fields in which gaming has taken on an important role and relevant for the focus of this research is urban planning. Without calling it a game, in the late 1950s Duke developed an exercise for students to help them understand and communicate about the complex urban environment (Duke, 2000). In this exercise, the participants had to deal with economic, social, spatial and other issues integrally relevant for urban planning. Based on this success, Duke developed the simulation game METROPOLIS, a game about the various decision-making roles affecting community development and urban growth. In the period since then many more planning games were developed, played once or twice and never published (Mayer, 2009). These games were about a wide range of topics, had different geographical scales and different objectives.

Inspired by the upcoming computer possibilities in 1964, Duke developed a computer-supported simulation game METRO (Duke, 2000). Although the game was a success, Duke was disappointed with the value of the computer simulation and returned to the low-tech simulation games. Duke was not the only one who was disappointed in the use of computer models for urban planning. Lee, too, wrote about several shortcomings of large-scale models for modelling and planning (Lee, 1973, 1994).

Nowadays, there is a renewed interest in urban gaming simulation (Cecchini & Rizzi, 2001). It can be successful if we use new models, new paradigms, new tools and new goals, or new forms of planning such as analysing urban planning from a complex system approach, and if we use new gaming elements and techniques. Instead of using games to find the optimal solution, games should be used to explore different possible paths.

Serious games

Recently, serious games were re-introduced by Ben Sawyer (2002). Sawyer was not the first to use serious games. Clark C. Abt already used this concept in 1968 as the title of his book *Serious Games*. He used the following definitions of games and serious games:

> A game is an activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context (p.6). Serious games have a thought-out educational purpose and are not intended primarily for amusement (Abt, 1970, p.9).

Today's concept of gaming comes from the video game industry. Games originally created for entertainment purposes are now additionally used for serious purposes. SimCity, used for research and education, is an example of this. The re-introduction of the concept of serious games meant that digital entertainment games were now used for serious purposes. The scope of serious games was broadened when not only existing entertainment games were used for serious purposes, but new games were developed specifically for education, training, health and public policy, using the knowledge gained from experience with entertainment computer games. This leads to the following description of serious games:

> Serious games are games which use the knowledge from the entertainment computer games for education, training, health and public policy (www.seriousgames.org).

Since the introduction of the concept in 1968, there has been discussion about terminology. For example, Stadsklev (1979) commented that Abt uses serious games as advertisement. Based on the ideas of Huizinga (Huizinga, 1952), it is said that all games can be considered to be serious. Klabbers (2009b) argues that if there is a distinction of serious games, there must also be non-serious games, though what is meant by this is unclear. If non-serious games are the same as entertainment games and players are seriously involved, the concept is confusing (p.16). In our opinion, 'serious' relates to the outcome or purpose of the game and not to the intention of playing. In that sense, there is a difference between serious games and those used for entertainment.

If we follow the description of Michael and Chen of serious games – 'Serious games are games that use the artistic medium of games to deliver a message, teach a lesson, or provide an experience' (Michael & Chen, 2006) – then all simulation games and urban games can be considered to be serious games. The question remains as to what the difference is between simulation games and serious games. Simulation games focus particularly on education and policy making and try to simulate a part of the reality. These games can be found in large variety from non-digital games to digital games. Furthermore, less attention is given in their design to entertainment aspects; it is more important to have a valid representation of the real world system. On the other hand, serious games are derived from the entertainment industry and have a larger focus on entertainment elements. Also, the serious objectives are broader in the sense that they also focus on advertising and political statements.

This means that a large overlap exists between simulation games and serious games, as represented in Figure 3-2. In this overlapping area, which does not have clear boundaries because these are related to the perspective of the developer, games can be found which focus on policy making and education, try to represent parts of real-world systems, and use the technology and entertaining elements of entertainment gaming industry. The game SimCity, developed for the entertainment industry, can be considered as a serious game when used in an educational context. Taking into account the limitations behind the model used, the game simulates the development of a city and therefore can be placed in the overlapping part.

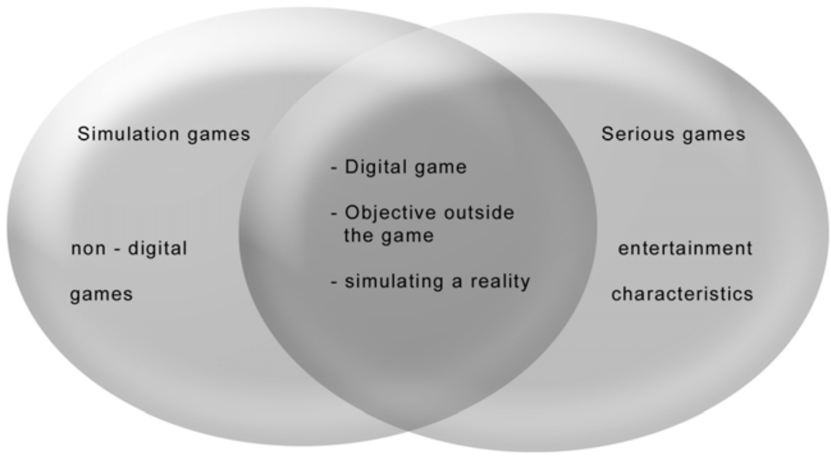

Figure 3-2. Overlap between simulation games and serious games

In this research we look at serious games, which focus on topics comparable with simulation games. On other words, this research focuses on games which fall into the overlapping part: games with an objective outside the game, with the use of digital technology, and a simulation of the reality. While low-tech role-playing games are still used and are effective for the simulation of social systems, in infrastructures the physical system has to be taken into account. Starting from the idea that infrastructures are complex systems, the physical complexity can be simulated via a computer simulation or a digital gaming environment.

3.1.2 Opportunities for serious gaming

Serious gaming has several characteristics that provide opportunities for gaming in relation to complex adaptive systems and design of infrastructures. In the first place, serious gaming simulates a socio-technical system in which there is a strong interaction between the decisions of an actor network and the simulated environment (Mayer, Bekebrede, Van Bilsen, & Zhou, 2009). The knowledge of simulations can increase the validity of the dynamics in the physical system. In the second place, serious games can use design principles from the entertainment industry, which makes dealing with large simulations models more understandable.

Dealing with socio-technical systems

As discussed in Chapter 2, infrastructure systems are socio-technical systems, which means that dynamics in the social system affect the dynamics in the physical system and vice versa. Studying the complex system behaviour not only requires a holistic view of a technical system but must also integrate this technical system with a social system.

Designers and managers of complex infrastructure systems can use many tools and methods to improve their understanding of this complexity. These tools differ in function and focus on different perspectives of a system; some tools focus on the static situation of social interactions, for instance actor analysis, while others focus on the dynamics of the physical system, as do computer simulations. In order to deal with complex systems, Muller (2004) concluded that multi-agent systems are the preferred method with which to model and design complex systems. However, in agent-based models, just as in other pure computer simulations, the social complexity can only be taken into account to a limited degree. Social actors can be simulated with the use of artificial intelligence; however, simulations cannot fully take into account the different viewpoints of the stakeholders (Barreteau, 2003).

Gaming is a way to deal integrally with social and physical characteristics of complex systems. Games reproduce a social system in terms of a laboratory (or computer) model (Druckman, 1971; Geurts & Joldersma, 2001). The different actors or stakeholders can be translated into different roles in the game. If people play these roles together, the social network is incorporated in the simulation of a real-world system. The subjective elements of the system, caused by the different values of actors, are modifiable by the players and are therefore taken into account in the dynamics of the simulation.

Virtual environments, as used in the video game industry, simulate the dynamics of physical systems, based on the decisions of the players. The advantage of using virtual environments, which do not necessarily have to be 3-D or have high fidelity, is that the changes in the environment can be based on a simulation with time delays and feedback. The representation of the physical dynamics is more realistic than what can be reached with board or card games. Of course, the value is related to the objectives and subject of the game, but for the simulation of socio-technical systems this visualization is valuable.

Integrating large-scale computer simulations with games

Developments in the computer industry have made it possible to develop larger and more complicated computer simulations of complex real-world systems. For example, in the 1950s, large-scale urban simulations emerged in the field of urban planning. Although these models were useful, they had two limitations: 1) validation of the model and 2) dissemination and implementation of the outcomes (Geurts & Joldersma, 2001). The simulations became too complex for policy makers to understand (Lee, 1973; Yewlett, 2001).

These limitations could not be disregarded; model builders had to adapt their way of modelling (Geurts & Vennix, 1989). For instance, in order to reduce the gap between modellers and policy makers, simulations now receive an interactive interface, which improves the communication abilities and usability of the models. Another solution was to involve policy makers in the modelling process. This led to the introduction of group modelling or participatory modelling (Anderson, Vennix, Richardson, & Rouwette, 2007; Rouwette, 2003; Vennix, 1996).

Gaming is another way of dealing with these limitations (Vennix & Geurts, 1987). Players deal with the models and increase their understanding of the dynamics of simulation, and they do this together with other players. To disseminate the message of systems thinking and feedback mechanisms, Meadows and others developed games to show some characteristics of system dynamics. Famous examples are *Harvest* and *Fish Banks*; other examples can be found in *The Systems Thinking Playbook* of Sweeney and Meadows (2001). Still, a discrepancy between the model builders and the decision makers exists (Lee, 1994; Te Brömmelstroet & Bertolini, 2008).

The re-introduction of serious games offers new opportunities for using simulations without increasing the gap between model builders and decision makers. In the video game industry, there is a tendency to develop large-scale, complicated simulations. At the same time, the game developers are able to successfully deal with the transfer of the complexity in the game. Players of, for example, SimCity (Maxis Software Inc., 2003) and Civilization (Firaxis Games, 2005) build cities and civilizations, both examples of highly complex systems. Players are challenged to deal with this complexity, to increase their understanding of the model behind the game and in this way improve their performances. If the players do not manage it in one go, they are motivated enough to try again.

There are two design principles which could explain the success of these games. The first is related to the usability of the interfaces. Much time is spent on developing interfaces which are intuitive and informative for the players. The second principle is the introduction of levels. A player starts with easy assignments, which increases motivation and hones the skills needed for playing. Step by step the complexity of the assignment increases throughout the game. This gives a continuous challenge to reach objectives and further explore the gaming system.

By learning from the video game industry about design principles used in games about complex systems, games for policy making can be brought to another level. In the first place, simulations can be used to calculate multiple alternatives on a broad number of criteria. In the second place, it is possible to visualize the dynamics of the system in an understandable and intuitive way, which is then used for interpreting the outcomes of the game.

3.1.3 Serious gaming in planning and design processes

Serious games have a serious purpose outside the game which makes use of the availability of technology and concepts developed in the video game industry. Serious games can be considered as a sub-group of simulation games, alongside interactive simulations, board games, card games, etc. On the other hand, serious games are also broader than simulation games. Also games for health, advertising, religion and many more fall within the category of serious games.

Gaming is known by its characteristic of creating a safe environment within which one can experiment or explore paths into the future. Serious gaming is not new in that sense. The advantage of serious games is that they can simulate and visualize these situations more realistically and immerse the players fully in the experience. This gives new opportunities for the use of gaming in urban and infrastructure planning processes. Gaming simulates the interaction between the social decisions and physical consequences and vice versa. Computer-based simulations can be more advanced as long as the outcome can be explained based on the decisions of the players. The visualization of changes in the physical environment can increase motivation, the feeling for the consequences of actions, and communication.

3.2 Serious games as complex adaptive systems

In the previous section, we argued that serious games simulate socio-technical systems. However, this is not equal to simulating complex adaptive systems (CAS). If the objective is to simulate a CAS, the game has to contain CAS properties. In this section, we analyse the relationship between serious games and CAS. This is done by considering a game as a CAS and by deriving the characteristics a game should have to simulate a CAS.

According to Klabbers (2006b), a game consists of three interrelated building blocks: actors, rules and resources (p.41). If the actors are left out and a system consists of rules and resources, then this system is a representation of feedback systems or agent-based models (p.43). When the resources are left out, then it represents a role-playing game (p.43). These building blocks of a game define the input of the model and the interaction in the model. The combination of these blocks over time leads to a game state. The game state is the outcome of the interaction between players and resources based on the rules of the system. Depending on the number of actors and resources, type of rules, structure of the game, and objectives and outcome of the game, a game can have different levels of complexity. This means that not all games simulate a complex system or even an open and adaptive complex system.

3.2.1 The game world as a complex adaptive system

In Chapter 2, complex adaptive systems were described as:

> … open, adaptive systems, situated in a dynamic environment, consisting of heterogeneous agents and actors which are related in a network structure, and consequently the result of these networked interactions is the observed behaviour at the system level.

The elements of games, like the magic circle, roles, resources, rules and the game state, can be linked in the same way. Namely, the game world is situated within a magic circle, consisting of roles and resources, which are related by rules, and the results of the interactions are observed by the game state.

As a result of this, the structure of a game can be represented by three levels in a game world (see Figure 3-3). Games consist of players and other agents on the lowest conceptual level. The second level consists of rules and interaction, and the third conceptual level is the system behaviour represented by the game state. The game operates in an environment, the game world, which is bounded with a 'magic circle'.

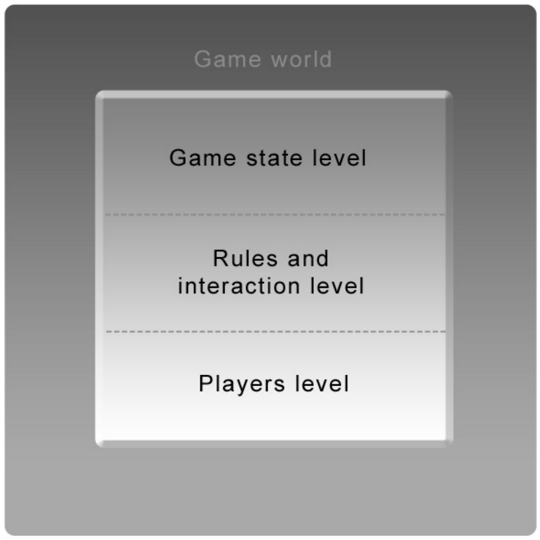

Figure 3-3. Games represented in three levels in a game world

At this level of abstraction, the conceptual representation of games is comparable with the levels of the framework of CAS (See Figure 3-4). The players of the game, who are the decision makers, are comparable with the agents in CAS. Games and CAS are both structured based on rules. Furthermore, games and systems produce an outcome or behaviour based on the individual actions of the player/agent and the rules. Finally, both systems are open and situated in an environment.

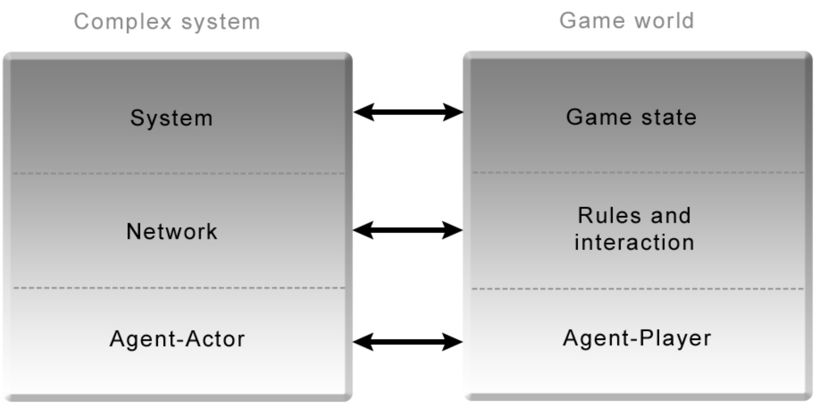

Figure 3-4. Comparison of a complex system with the game world. Both are conceptual representations, and neither exists separately from each other. Systems as well as games are situated in an environment and are therefore open systems.

The variety of games is large, and not all games will simulate a complex adaptive system. Based on the properties of CAS, we deconstruct the game characteristics which could make the game a simulator of a CAS. This analysis starts on the player level.

3.2.2 Player level

In order to represent a CAS, the conceptual level of the players has to consist of elements and properties comparable to that of the agent level of CAS. These elements have to be adaptive, similar enough to communicate and diverse (see Chapter 2). As in CAS, these elements are described as agents and actors; in games these elements are roles, played by participants, computer agents, facilitators and resources. As we talk about simulation games, these roles and resources are representations of agents and actors of the real-world system.

The most influential roles are played by the participants of the game, the players, who make the important decisions in a game. These decisions are based on the input the player receives from the game environment and his internal rules, including the strategy and allowed actions. The player can make numerous actions, like moving, collecting resources, fighting or collaboration, and all of them are made to reach the individual or group goals. Players have an observable and a hidden state. The observable state is how other players see the player, for example the place in the game and the actions the player makes. However, each player also has a hidden state: the hidden objectives, hidden resources or hidden strategies. The players use this hidden state in the game for bluffing, diplomacy or negotiation.

Other roles are played by the facilitator. The facilitator is generally reactive and will only respond to what happens in the game. The facilitator can have different roles: a referee to control the rules of the game; a game master or dungeon master in a role play, where he prepares the game, initiates the storyline and counts the scores and simulates the non-playing characters during the game; and a supporter of the learning process. However, this last role lies outside the system and is further explained in Section 3.3.3.

In computer games it is also possible to simulate several roles through agents called ‘bots’, which are competitors or supporters. More advanced bots can show emergent behaviour if they are able to act in ways that go beyond that which they have been explicitly programmed to do (Murray, 1997). This gives opportunities to develop realistic agents for serious games.

Finally, the player level consists of resources, all with a special meaning for game play (Björk & Holopainen, 2005). There are resources which represent the players, from pieces of different colours in board games to personalized avatars in computer games. There are also resources like health points, coins, money, weapons and time. These resources can be collected, exchanged and used in a game. The value of the resources is game dependent, just as the possibilities of using them. Entertainment games often make use of non-realistic elements, like fairytale figures or poisons and a deviating currency system. In realistic serious games, these formats of the resources are more similar to reality.

Properties at the player level

The elements of the player level have to contain the following properties: they must be adaptive, diverse, and similar enough to communicate, because these are the properties given to agents and actors in complex adaptive systems (see Chapter 2).

Players fulfil all these requirements. They have a diverse internal model, based on the background of the player, references to other games and real-world systems. This diversity can be reinforced by giving players different assignments and resources, which encourages collaboration and negotiation. Although the players are unique, there is interface and protocol similarity. There has to be agreement about the game language, meaning and value of the resources and rules of the game. When there are discussions about the meaning and rules, engagement is sometimes reduced. On the other hand, these discussions are valuable when the objective of the game is to show the different values and meanings. By playing, participants learn about the game; they gain more knowledge about the world and how to deal with the rules, they collect more resources, and they become more skilled. Players also develop strategies for surviving and adapting to the continuously changing situation. In other words, the state and behaviour of the player adapt by means of the experiences.

Other elements, too, show diversity and have some interface similarity. These elements have different values and have a function in the game. Most static elements will not have adaptive properties. By adding computer agents or bots, these elements can become adaptive, which increases the complexity of the simulated system.

The player level versus the agent level

The properties of the agent level of CAS can be found in the player level of games. This is especially caused by the characteristics of human players. Players have an observable state as well as hidden states and internal rules. These internal rules determine the decisions made by a player at certain moments in the game. Comparable with the internal rules in complex adaptive systems, these rules are initiated by input from the environment. Their different backgrounds make the players unique and different from each other. Still, they share the same game world and game rules in order to play together. The players also adapt to changing situations in the game. A player in a winning position could expect less collaboration from others. Players also adapt strategies by playing the game several times; they learn to deal with the system behaviour.

3.2.3 Rules and interaction level

The second conceptual level is the level of rules and interactions between the elements, which is comparable with the network level of a CAS. In games these relationships are based on the rules of the game. The rules set the boundaries of the game and define the possible interactions between the players and the game world. There are many different types of rules, e.g. operational rules, constitutive rules and implicit rules (Salen & Zimmerman, 2004 p.130). There are also rules of consequence, which determine the effects of the players' decisions (Salen & Zimmerman, 2004).

The operational rules or rules of play describe what is allowed and what is forbidden. These rules do not only give limitations but also affordances to the players; they give meaning to the actions of players (Juul, 2005 p.58). These operational rules have to be unambiguous and clear for every player and written down in a manual or game description. Because players hardly read these rules, especially in video games, learning these rules is part of the game play via tutorials or simple introduction levels. The number of rules differs per game from just a couple of lines to a booklet of rule descriptions.

The formal or constitutive rules structure the game in a logical and mathematical way (Salen & Zimmerman, 2004). These formal rules can be found in simulation models and game codes. The formal rules in the game code are the actions and the decisions of the players and the consequences of these events. Not all game codes are part of the formal rules. The codes about storage memory or the interface is not part of the rules (Salen & Zimmerman, 2004 p. 142 - 143).

The interaction between players is based on social rules. Part of the interaction possibilities are described in the formal rules. Because the rules for interaction are also implicitly made, they are also called implicit rules (Salen & Zimmerman, 2004).

Properties at the level of rules and interaction

The properties of a CAS at the network level are network dynamics and network topology. At the rules and interaction level of games, we observe dynamics and a topology of the game. This topology is not based on random or scale-free networks but on progression and emergence game play.

The dynamics in the game are caused by the actions of the players, autonomous physical changes and the rules of consequences. These rules influence elements and interactions between elements. The social relations between the players are open to change; coalitions can be formed or conflicts emerge. Physical elements are also affected by players' actions. When a computer game environment simulates the physical state of the environment, it is even possible to calculate multiple integrated effects of decisions. Removing or building objects in this world have multiple consequences for the environment and the following steps. The shape and stability of the game world will change and can be observed by the players. Visualization possibilities can even enhance this experience.

The structure of the game is based on progression and emergence (Juul, 2005). In a progression game, the challenges or sub-goals are serial. The player follows a linear process of challenges until the game is finished. In emergence games, the rules give many combinations of game outcomes and give endless possibilities of playing the game. Emergence games have many feedback processes. Players can go back to earlier visited places and observe new elements based on earlier actions, or players can make the same kinds of decisions again and experience changes in game outcome. Progression and emergence games are two extreme situations. Many games use both principles in combination, for example by progression via levels and feedback processes and emergence within the levels. This combination can also be used in serious games to simulate path-dependency and feedback processes.

Rules level versus network level

The rules define the game logic, the relation between players and system, and therefore structure the game outcome. The structure of the game contributes to the behaviour of the game state. The types of rules are comparable with the rules in a complex system, where there are legislative, social and physical links. In the game, these are formal rules, social rules and rules of consequence, respectively.

The rules and, consequently, the structure in the game are dynamic. New rules can be added to the game, or existing rules can be changed. In complex adaptive systems, the topology of a complex network can be defined in terms of random graphs or scale-free graphs. In games, the rules define a progression or an emergence structure.

Rules are not the same as the experience of the game. The experience is related to the game output or the strategies of the players, which are in turn based on the players' internal rules. In addition, the aesthetics or representational quality is not part of the rules of the game. The format of the pieces, the avatars and the surroundings do not change the goals or the rules and, consequently, neither do they change the strategies of game play (Salen & Zimmerman, 2004). For example, chess as board game is similar to chess as computer game. Although not important for strategies or game play, the representation can improve immersion and game experience.

3.2.4 System state level

At the third conceptual level, we compare the game state with the system state. The game state level is the situation of the game at a certain moment in time (Holland, 1997 p.33). The game state is the result of the individual actions of the players and the rules of the game.

The performance indicators of the game provide the value of the game state. In general, three different game outcomes can be observed: a win-win situation, a win-lose situation or a lose-lose situation. Win-lose situations are the outcomes of competitive games. Competitive games require players to form strategies that directly oppose the other players in the game. Cooperative games have a win-lose end situation. In cooperative games, there are two or more individuals with interests that are neither completely opposed nor completely coincident. Players can use anti-collaborative practices like free-riding and backstabbing (Zagal, Rick et al. 2006) to win or thwart the game. Win-win games and lose-lose games are normally collaborative games. In a collaborative game all participants work together as team, sharing the pay-offs and outcomes; if the team wins or loses, everyone wins or loses.

Based on the interaction, the game outcome is more than the actions of the individual players (Klabbers, 2006b p.86), thus leading to emergent behaviour. Emergence in games is the higher-level pattern arising from parallel complex interaction between local agents (Salen & Zimmerman, 2004). Emergence in games has different variations: emergence as variation, as patterns, as reducibility and as novelty or surprise (Juul, 2005 p.80). Emergence as variation is the variation of possible states and behaviour as results of the individual actions and the rules of the system. The second type is emergence as pattern. These patterns cannot be explained by the rules but are strategies to play the game. A strategy is the way of acting in a certain game state. Some of these patterns or strategies and their consequences, like the prisoner's dilemma and the tragedy of the commons, are already well-known in the game theory. The third type is emergence as irreducibility. Irreducibility means on the one hand that there is no shortcut to playing the game, and on the other hand it means path-dependency. The last type of emergence is that of novelty or surprise. Emergence as surprise is when several rules and objects are combined in unseen ways, surprising the player.

Another form of emergence, which is not in the game itself, is the emergent game play. Emergent game play means that the players play the game differently than the designer intended. This process can lead to new rules or totally new games consisting of the same elements. This emergence is interesting when games are used for experimenting with different policy options. With emergent game play, observations can be made about how people deal with new situations and whether this leads to the undesired actions of players. This emergence can only occur when the rules are flexible and the game has an open-ended state.

Properties at the game state level

Although the variety of states and behaviour is in general limited, the same properties can be observed as in complex adaptive systems. Once the game is started, the game play will be self-organizing; decisions of players will influence the state of the game, which is then the input for the next decisions. No influence of the outside world is needed to keep the game going. Most of the actions made in the game cannot be undone. And because the next action is based on the history of actions, games have the characteristic of path dependency.

The outcome of the game depends on the decisions of the players. In an open game, where the solutions space is broad, this outcome can be highly or hardly influenced by a decision. In other words, the game outcome can be robust for certain decisions or strategies while instable for other decisions and strategies.

Game state level versus system level

At the system level and the game state level, many similarities are found. Just as in complex systems, the observation of the game is a state at a certain moment in time and behaviour over time. Both levels are the results of the combined effects of the state of the agents and the rules. The possible states and behaviour of a large complex system are at a much higher level than the possible states and behaviour in a game. This is caused by the relatively bounded system of the game. On the other hand, this limitation lends more attention to certain aspects and makes it easier to show cause and effects. In cases where the game outcome is open and the solution space is broad, properties like self-organization, path-dependency, robustness and instability can emerge.

3.2.5 The game world

The above-mentioned layers construct the game world. The game world is a bounded system, where elements have their own meaning, constructed by the players and the rules. Huizinga (Huizinga, 1952) used the term ‘magic circle’ to set a boundary between game space and reality. The players, who become part of this world, have to accept the game rules.

This game world is architectural, a man-made construction. Game spaces consist of spatial and encyclopaedic properties (Murray, 1997). Spatial properties are the objects and physical rules players observe. It is up to the designer to develop a realistic or abstract metaphoric environment. Even in realistic games, the game developers have to decide which objects are necessary for game play. They have to simplify movements and constructions to practically reduce the calculation time but also to exclude distractions. In the video game industry, a trend towards more realistic environments and dynamics can be observed, due to the increasing processing capacity. The encyclopaedic properties constitute the content and the information of the game. The game designers also need to find a balance between what information is necessary, nice-to-know and unimportant. Too much worthless information distracts the player from the game play. The spatial and encyclopaedic properties make the world immersive. This immersion influences the involvement in the game play.

Another important aspect of the game world is the game time. The time in a computer game does not have to be equal to real time. The possibility of playing with the time of the game is useful when long-term processes are simulated or to slow down fast processes to improve the game play. Some games can also be paused, for example, to emphasize the reaching of the goal. Other games have a save button so the player can stop playing for a while without losing information.

Input from the real-world environment

Games are a subset of the real-world environment. Not only can games be based on a real-world system, there is also input from the real-world system during game play. Participants follow the rules of the game but also bring their experiences and skills into the game. For example, cultural backgrounds influence which games are accepted and which not. The freedom regarding social rules differs between different cultures (Hofstede, 2008). Another element is the knowledge about a certain subject. Unintentionally, players with more knowledge about the subject will use this in their decisions in the game. This could lead to discussions which are not necessary for the game play itself but worthwhile for the learning experience. Third, the game is influenced by the social skills of the participants, which are relevant in multi-player games, and computer skills, relevant for playing computer games.

3.2.6 Complex adaptive serious games

From the analysis of the deconstruction of games, several characteristics of complex adaptive systems are observed. However, this does not mean that each game has this ability or that all games are suitable to improve the understanding of complex infrastructures. Of course, games are far simpler than reality; however, their characteristics and simulations of real-world phenomena are interesting for the purposes of improving the understanding of complex real-world systems.

To be a complex game, a game must have the properties of what is described as a complex adaptive system. Games with one or just a few adaptive agents, with linear relations and rules are not considered to be games which simulate complex adaptive systems. In the first place, games have to consist of multiple diverse elements. Because players bring their own history into the game, multi-player games have this characteristic. A multi-player game can also be used to simulate the multi-actor network in complex adaptive systems. Artificial intelligence agents are also used to bring the multi-agent component into the game. Secondly, each game has rules which structure the interaction and which show evolution and adaptation in the game; these rules and interactions have to be flexible to allow change. Third, to simulate complex adaptive systems, the final state has to represent the consequences of players' decisions and of emerging processes. Complex adaptive serious games have to be so-called open games or emergence games (Juul, 2005).

3.3 Serious gaming as a way of understanding infrastructures

The main objective of this section is to define different functions of serious gaming in order to gain a better understanding of infrastructure systems, which could in turn support policy-making processes. We start by defining some general characteristics of gaming which make them suitable as a supporting tool. Next, two different ways of using gaming are further explored. The first is using gaming as a simulation of a complex adaptive system and exploring the system behaviour, or the observer perspective. The second way is using gaming as an experience space in which participants can experience the complexity themselves and increase their understanding of the system, i.e. the player perspective. We chose two different perspectives because they each have a different view on the simulated system (Klabbers, 2006b) and because they have different contributions to understanding complex infrastructure systems.

3.3.1 Gaming as a supportive tool

Games have been used for many years already, particularly war games and business games. War games are an abstract representation of military confrontations (Stoop, 2008) and are used to evaluate military tactics, equipment and procedures (Duke &

Geurts, 2004; Shubik, 1975), team tactics, decision making, conflict resolution and strategy (Egenfeldt-Nielsen, 2005). Business games teach a variety of business-related topics, including the general operations of a company, the management of a specialized business or specialized parts of the business area (Egenfeldt-Nielsen, 2005).

Games are also used as metaphors to describe policy-making processes by using concepts and emotions related to gaming. For example, De Bruijn and Ten Heuvelhof (2008) explain mechanisms in network management with concepts as winners and losers, game rules and win-win situations. Koppenjan and Klijn (2004) talk about problem solving as strategic gaming and use the metaphor of a policy game in rounds to describe policy processes. Klijn and Teisman even argue that policy-making processes can best be analysed when thought of as games (Klijn & Teisman, 1997; Teisman, 1992). Ideas of competition, cooperation and collaboration are also observed in the policy- and decision-making process. On the other hand, games are used to change our perspective on the real world. Games with an agenda, news games, political games, realistic games and core competence games are used to communicate a serious problem or a statement (Bergeron, 2006).

In other words, games contain characteristics which are recognized in the policy-making process. Together with the simulation value as described in Section 3.2, this makes serious games an interesting tool for the support of policy- and decision-making processes. There are also several other reasons why gaming receives attention as a supporting tool: games are motivating, games are a safe environment in which to experiment, and games result in a high level of retention.

Motivation

One of the characteristics of a good game is that it is motivating. Players are attracted to the game and will play for a long time. This motivation means that players are more concentrated, more involved, and spend more time on their tasks (Garris, Ahlers, & Driskell, 2002). This is also one of the reasons why teachers use gaming in their education. A research of Futurelab showed that 53% of British teachers use games for motivational reasons (Sandford, Ulicsak, Facer, & Rudd, 2006).

The motivation of the players increases in two ways: internal motivation, which is caused by the activity itself; and external motivation, which is caused by the reward of doing the activity. The internal motivation is stimulated by the game design, by trying to get the player immersed in the game. Several game characteristics have been seen to increase this immersion: fantasy (Amory, Naicker, Vincent, & Adams, 1999), curiosity, challenge (Malone, 1981), social interaction (Kirriemuir & McFarlane, 2004) and control (Wilson et al., 2009). Fantasy in games refers to the ‘mental images of physical or social situations that do not exist’ (Malone & Lepper, 1987). Fantasy can be used to develop a safe environment or as a metaphor for real-world problems.

According to Garris et al. (Garris et al., 2002), curiosity is stimulated by an information gap in our existing knowledge that is intermediate. Curiosity can be caused by the novel sensations in the game as well as the quest to obtain more knowledge. Third, a challenge is an activity that is not too easy and not too difficult. This can be reached by dividing a game into sub-goals, tasks or levels. Social, communication and peer activities are also characteristics which increase immersion (Kirriemuir & McFarlane, 2004). Social pressure causes competition in games, and competition and cooperation stimulate the processes of sharing knowledge and experiences. Finally, the player has to be in control. Goals and activities have to be meaningful for the player; they have to be linked to valued personal competences (Garris et al., 2002). Performance feedback and scores can be used to keep players on track toward achieving the objectives.

When players are totally immersed in the game, they have the optimal experience because they are in a flow (Csikszentmihalyi, 1991). This can be seen in the following:

> Concentration is so intense that there is no attention left over to think about anything irrelevant or to worry about problems. Self-consciousness disappears, and the sense of time becomes distorted. (Csikszentmihalyi, 1991 p.71)
> And the performance of a task, a sense of enjoyment and control, where an individual's skills are matched to the challenges faced (Garris et al., 2002).

Flow is important for serious gaming because it makes the situation more enjoyable and builds the self-confidence of players that allows them to develop skills. Furthermore, flow pushes the person to a higher level of performance (Csikszentmihalyi, 1991 p.74). The state of flow occurs spontaneously when the right internal and external conditions exist. The internal conditions are related to the individual's ability to restructure consciousness so as to make flow possible. It is outside the scope of this research to further explore these internal conditions; for more information see Csikszentmihalyi, 1975 and 1991. The external conditions are related to the game play and include the clarity of the goals, feedback from the game and the feeling of control and challenge.

In studies into reasons why people play games, characteristics like fun, challenge, social experience and entertainment are regularly mentioned (Kirriemuir & McFarlane, 2004 p.9). These studies also show differences between children and adults. Children like games because of their visual representations, graphics, design structure, the type of activity and challenges which games offer (Ellis, Heppell, Kirriemuir, Krotoski, & McFarlane, 2006). Older players also cite innovation and depth of story of character as being important to their playing experience (Ellis et al., 2006).

Serious gaming has the added value over simulation games of visual representation. Although visualization supports motivation, this is not the only aspect. Egenfeldt-Nielsen (2005) showed that edutainment and computer-assisted learning did not have the expected learning effects because they were still based on drill-and-practice. Such games use nice visualizations but lack important characteristics like challenge, social interaction and control over the situation.

Safe environment

The second reason why gaming is attractive for serious purposes is that games create an experiential learning environment (Duke, 1998; Mayer & Veeneman, 2002; Tsuchiya & Tsuchiya, 2000 pp.524-525). Game environments are safe in two ways: consequences do not have any effect in the real-world system, and games can replace expensive or dangerous experiments.

Because decisions made in the game only effect in the simulated game world and do not have consequences in the real world (Geurts & Vennix, 1989), players can experiment freely (Duke, 1998; Mayer & Veeneman, 2002). For example, students can run a business for a couple of hours or weeks and learn about their mistakes. However, research and experiences also shows that players may feel insecure because their actions are public to other players and observers (Hijmans, Peters, Van de Westelaken, Heldens, & Van Gils, 2008).

Games are quasi-experimental environments which can be used to enlarge problems, to analyze problems or to convince that there is or will be a problem. This is useful when actual testing is too expensive or too risky (Abt, 1970; Kirriemuir, 2002). It offers an opportunity to train for crisis situations, which cannot be done in reality (Crichton, Flin, & Rattray, 2000). Still, games cannot totally replace real-world training because games rarely can simulate every nuance of a real-world situation (Kirriemuir & McFarlane, 2004). Real-world practice is still needed, but basics can be done in a controllable and cheaper environment (Kirriemuir, 2002).

The role of more complicated and realistic models and dynamic simulations in serious games increase the validity and realism of feedback in this experimental environment.

Retention

Highly related to motivation, the expectation is that actively involved players are more conscious about their decisions and consequences thereof, and that they have a higher retention of their experience. From a constructivist approach, the players construct their knowledge through meaningful experience and through the transfer of this knowledge. When games are played in a collaborative context, this results in higher achievement, greater long-term retention of material, higher-level reasoning, creative thinking, transfer of learning from one situation to another and more positive attitudes towards the task (Johnson & Johnson, 2004 in Lobel, 2005).

Research also suggests that learning improves as the quality of cognitive engagement increases and that greater engagement during learning leads to a longer retention of information (Hannafin & Hooper, 1993 in Garris et al., 2002 p.453). Empirical research has shown higher learning retention of students who play games in the classroom in relation to students who do not (Egenfeldt-Nielsen, 2005). Direct measurement of the results of a factual test did not show a difference in learning between the two groups, but the test five months after the course showed higher learning retention in the gaming group.

These three positive aspects contribute to the use of games for serious purposes in general. The safe environment makes it possible to simulate future situations in a short period, and decisions which in reality lead to path dependency can be made in a game situation in order to observe the long-term effects. The motivational aspects influence the involvement of the players and how they play their roles. The expectations of higher retention increases the possibilities that lessons learned will be used in corresponding real-world situations. In the next sections we explain what this means in terms of understanding complex infrastructure systems. As mentioned in the introduction of this chapter, there are two perspectives: 1) system understanding of the observer outside the system and 2) individual understanding of the player as part of the system.

3.3.2 Understanding infrastructures: the observer perspective

The first way of using serious gaming is to increase the understanding of the dynamics and behaviour of the simulated system. The difference with the player perspective is that the observer is not part of the game and therefore has an overview of the socio-technical relations. From this observer perspective, the dynamics and the system behaviour are observed from a holistic view instead of being just an element in the system (Duke & Geurts, 2004; Geurts & Vennix, 1989). Based on these observations, several possible future development paths can be explored and analysed. Outcomes of this analysis can be used in subsequent steps in the policy-making process. From this perspective, serious games are used as a quasi-experimental environment.

The observations can be analysed in different ways depending on the questions behind the game. For this dissertation, the questions are related to increasing the understanding of infrastructure systems and exploring the consequences of interventions. Because we assume that infrastructures are complex adaptive systems and that games are simplified representations of a CAS, the complexity framework can be used for the analysis of the dynamics and system behaviour in the game. Thus, game dynamics can be analysed on three levels: agent behaviour, network dynamics and system behaviour.

Understanding agent behaviour

The first type of question which can be observed is that of how agents behave in the system and how they adapt to a changing environment. The game is played by the participants, who are all unique. Although the game has been developed for a certain group of players, they have their own experiences and social behaviours which they bring into the system.

Because each individual agent contributes to the system behaviour, one of the objectives of the observer is to recognize different strategies and behaviours of game play. From the observations of the individual players, it is possible to search for patterns of behaviour: for example, different roles in the system or different opinions about the subject. The games having the objectives of clarifying values and arguments, democratizing, mediating and strategically advising (Bots & Van Daalen, 2007) all have in common that they hope to increase insights about the different opinions and strategies of the different actors in the system. In games in which the players experience freely, these hidden values can become visible.

Understanding dynamics of relations

The second level of observations focuses on the network level. The players start with a reference situation. During the game, the relations of the system change. The network of interactions grows because more elements are added to the system, which is done in building games like SimCity or Civilization. Furthermore, the interactions between the elements can change. For example, in negotiation games pre-existing relations become stronger (Meijer, Hofstede, Beers, & Omta, 2006). Different type of structures can also become dominant, as Meijer et al. showed in their research of network structure in the Trust and Tracing game, where the trader's behaviour follows a market structure and the consumers follow a network structure (Meijer, Hofstede, Omta, & Beers, 2008).

The objective for the observer is to analyse the evolution of the network and the changing flows over the network, both for the physical network as well as for the social actor network. These observations of the evolving network can provide insights into the scope of the problem, for example, whether a problem is local or region-wide. It can also give insights into the speed of the processes and what part of the process frustrates the development.

Understanding system behaviour

The third level of observing complex infrastructure systems is the system behaviour. These observations are most surprising, because system behaviour cannot be designed by the game designer. The behaviour emerges from the rules and the actions of the players, giving a holistic view of the system in the middle- and long-term.

The objective of the observer is to determine the boundaries of the solution space, to search for patterns of behaviour and to explain the behaviour based on the players and the rules. The variety between the different game outcomes can give an indication of the solution space. It also gives insights regarding the parameters to which the system is sensitive or robust. This information is relevant in the design and management of real-world projects. Further, it gives insights into the bottlenecks that can be expected in future situations. Especially the games about researching and analysing and about designing and recommending (Bots & Van Daalen, 2007) focus on the dynamics and outcomes of the system.

Observer objectives for understanding infrastructures

As serious games can simulate complex adaptive systems, this perspective can be used to analyse the system simulated in the game. Each game session provides information about one possible path through the solution space of the system. Complex adaptive systems, consisting of many different elements and rules, have many different paths and solutions. Each individual session adds insights into the dynamics. However, to analyse the dynamics and the dominant system behaviour, multiple sessions have to be played.

Related to the different perspectives on describing and analysing a complex adaptive system, three different levels of observations and analyses are defined. The first level of observation is the behaviour of the different elements in the game, and especially the hidden values of the players and strategic decision making of different roles. The second level of observations is related to the evolution of the network and the network-wide dynamics. The third level of observations and analysis is the system behaviour and solution space of the system.

Achieving a better understanding of the system contributes to policy making in different ways. Knowing more about the system and its behaviour can be used to define or explain (future) problems in the system, to explore alternative interventions or to prepare and train for the use of new interventions.

3.3.3 Understanding infrastructures: the player perspective

The second contribution of serious games to the understanding of infrastructures is that players experience and interact with the system. Games have many different educational values, from increasing knowledge to behavioural change. Garris et al. (Garris et al., 2002) analysed different learning outcomes of games. Based on the cognitive, affective and psychomotor domain of educational activities as described by Bloom (Bloom, Engelhart, Furst, Hill, & Kratwhohl, 1964), they show that games can be used for learning objectives within all three domains (skill-based learning, cognitive learning and affective outcomes). However, these broad educational effects do not answer the question as to the way in which games can be used for understanding complex infrastructure systems how they can support the decision-making process.

The understanding of complex infrastructure systems is strongly related to learning within the cognitive domain. The focus of understanding is that a person increases his knowledge about the system and its dynamics, becomes aware of the consequences of certain system behaviour and learns how to deal with this system. Although the other learning domains (psychomotor and affective) could be useful, they do not directly contribute to the *understanding* of these complex systems. Based on the division of the cognitive learning domain of Bloom, where he described cognitive knowledge as a recognition of facts, creation of procedural patterns and development of intellectual ability, Garris made a distinction between declarative, procedural and strategic knowledge as cognitive learning objectives of playing games (Garris et al., 2002). These three sub-groups of learning objectives are the starting point from which to search for possible learning objectives related to understanding complex infrastructure systems. But before looking at the learning objectives of infrastructures, an explanation will be given about the learning process in games.

Experiential learning

Although many learning theories are linked to the use of games in educational settings, such as active learning (Gee, 2004; Niemi, 2002), situated learning (Lave & Wenger, 1991; Leemkuil, 2006), authentic learning (Maharg, 2004) and collaborative learning (Kirriemuir, 2002; Kriz, 2003 p.496), the concept of experiential learning is mentioned most often and fits best with the intended use of serious games for the understanding of infrastructures (De Caluwé et al., 1996; Egenfeldt-Nielsen, 2005; Kolb, 1984).

The idea behind learning by playing games is that it follows the basics of learning, namely learning by experience. According to Dewey (Dewey, 1938 in Kolb, 1984 p.35), experience is the interaction between humans and their environment, including thinking, feeling, seeing, handling and doing. This way of learning, called experiential learning, is further researched by David Kolb (Kolb, 1984). According to his theory, learning takes place on the basis of trial and error and is an experiential cycle of action, concrete experience, reflective observations and theory construction, and back to action again.

While gaming, participants learn on two levels. The first level of learning is about how to play the game. The player has to become familiar with the rules of the game, the relationship between actions and reactions and the game's structure. The second level is related to understanding the mechanics behind the game. For example, the 'aha'-effect when players become aware of the consequences of their actions or theories become clear. The player can use their growing awareness and increasing skills in reality as well as in playing other games.

Experiential learning is only possible when the learner has a basic knowledge of the concepts as well as the motivation and skills for observation and reflection. According to Garris (Garris et al. 2002), it is accepted that games in and of themselves are not enough for learning. Or as Thiagaranjan puts it: 'People don't learn from experience (including simulation experience); they learn by reflection on their experience' (Thiagarajan, 1994 p.532). Feedback is an important aspect of reflection and may be central to most effective learning experiences (Jarvis & De Freitas, 2009). This means that learning needs to be facilitated by the game leader. Research has been done to improve the educational value of games by including reflection in them (cf. Leemkuil, 2006). It seems that games with more complicated learning objectives have to be played in an educational context and must include a debriefing.

In games where players act, receive feedback and are rewarded for their efforts, the game leader has an important role in transferring the knowledge learned in the game to real-world issues. The game leader is also needed to correct or complete the player's relevant learning experience. As Garris proposes, the experiential learning cycle should be embedded in the game (Garris et al., 2002) – not just in the introduction and debriefing but throughout the different rounds or levels of the game.

The facilitator has four different roles in supporting the player's learning. All of these are related to sharing knowledge and competences (Mayer, Jager, & Bekebrede, 2007). Scientific and practical knowledge is needed to translate gaming experiences into generally abstract concepts, and vice versa to translate these abstract concepts into concrete starting points for actions in the game. Practical and reflexive competences are needed in order to be able to interpret and reflect on these experiences. The facilitator can share his experiences by direct transfer before and after the game, through facilitation during the game and during assessment after the game. This gives the following enriched model of experiential learning (see Figure 3-5).

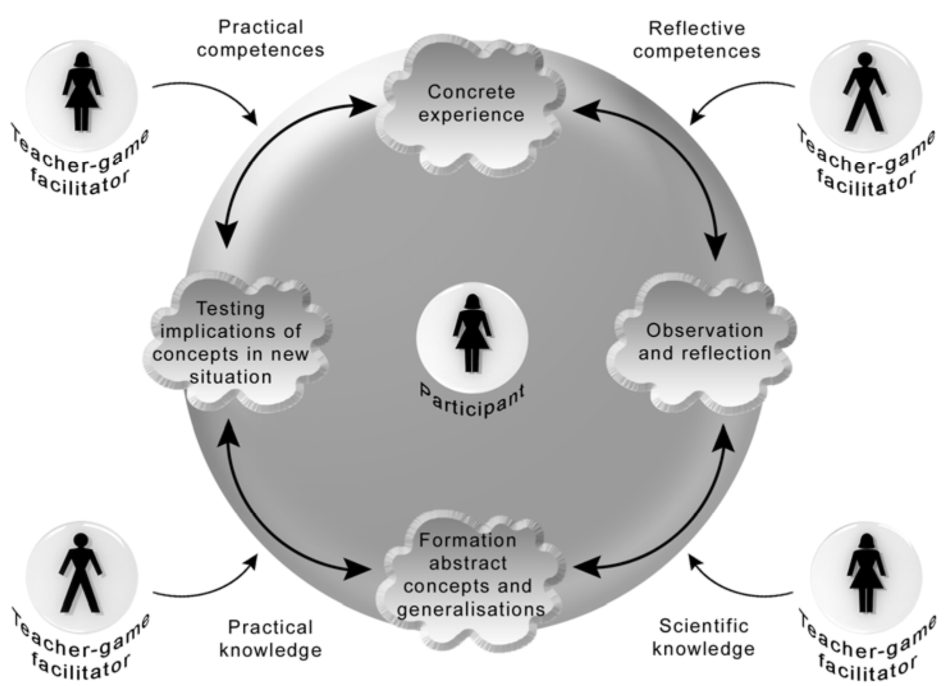

Figure 3-5. Enriched model of experiential learning in education based on Kolb (Kolb, 1984)

Sometimes participants lack the competences and knowledge (and sometimes the will) needed to turn a game played in an educational setting into a learning experience. This can apply to basic game-specific competences a participant or facilitator might need, like the ability to use the hardware interfaces needed to play a computer game (Egenfeldt-Nielsen, 2004). Missing competences can make playing a game hard work and will create the demand for lots of explanations or demonstrations. Having insufficient prior knowledge can inhibit advanced-level discussions or result in negotiated nonsense and irrational action – for instance, just clicking the mouse to see what happens.

The learning loop can be walked through several times during a game session, depending on the amount of time available and the type of game. In each round the facilitator can be more or less involved; however the facilitator has to avoid disturbing the playing process. Reflection is done after the game play. In some cases it is possible to start a new game session and test the adapted reference systems again.

Recognition of facts

The first of three groups of learning objectives is the learning of facts or increasing one's knowledge about a subject. Frequently, serious games concern a specific problem or real-world situation and are developed from a certain theoretical background. In these games, one of the learning objectives is to increase the domain-specific knowledge about the simulated system. A second objective is that players become aware of the theoretical background of the simulated system.

If we apply this to the understanding of complex systems, the same distinction can be made: 1) increasing facts about the simulated system or 2) increasing knowledge about theoretical concepts of complex adaptive systems.

Domain-specific content: The first possible learning objective is to increase the knowledge about the system under study. They type of information is closely related to the subject of the game. It is obvious that a game about fun parks will transfer less knowledge about cities and vice versa, while they respectively teach elements about running a fun park and developing a city. For the designer of the game, this means that the simulated system has to be comparable and have a certain level of realism.

Theory-based notions: The second possible learning objective is to use games to transfer knowledge about theoretical notions. The Beer Distribution game (MIT Sloan School of Management) about supply chain management, for example, shows the concept of delays in feedback mechanism. According to Laurillard (1992), computer games can support the conceptual and intuitive understanding of theoretical knowledge in the area of science. For complex adaptive systems, concepts which can be transferred by gaming include path dependency, emergent behaviour, networks and interaction. To reach this theoretical knowledge, the game has to be carefully designed and reflective thinking has to be encouraged (Laurillard, 1992).

Recognition of processes

The second group within the cognitive domain is the recognition of processes, translated by Garris as procedural learning objectives (Garris et al., 2002). Procedural knowledge refers to learning procedures, but also to understanding patterns of processes and behaviour. According to Backlund (2000 in Backlund, 2002 p.8), understanding is the awareness and knowledge of the nature of the connections. These connections are the relationships between elements and their environment. Learning the different procedures and learning about system's reactions is part of the game. In the Super Mario series, players have to reach the end of the level as quickly as possible, but players can also collect coins which provide extra hearts, or toads and flowers to receive more power. In games like SimCity and Civilization, these different procedures or objectives are more complicated. The different objectives and procedures are interdependent and even sometimes conflicting. To reach the final goal, the player has to balance between these different procedures. Recognition in processes can be divided into understanding different linear processes and understanding system behaviour based on the individual decisions of the players.

Linear processes: By understanding processes within a complex adaptive system, we mean that the players increase their knowledge about the evolving structure of the relations and the possibilities to intervene in the system to reach the objectives. This understanding is a more linear perspective of the relations.

Complex behaviour: In complex adaptive systems, the total system behaviour is based on the combined effects of the decisions of the agents. This behaviour is not necessarily a linear sum of the action; if anything, this behaviour shows non-linear dynamics. The second objective related to understanding patterns is the understanding of this non-linearity. It is about recognizing the non-linear behaviour as well as explaining this behaviour based on the structure of the system and the individual actions.

Intellectual ability

The third cognitive learning domain is that of increasing intellectual ability. Within gaming this domain has been explained as implementing knowledge from the game in new (real-world) situations. Gaming can also contribute to developing reflective competences. Within complex adaptive systems it not only refers to implementing what is taught in the theory but also observing behaviour and adapting to new situations. Thus, the reflective competences are also relevant for managing complex adaptive systems and become part of the individual learning objectives.

Managers of complex infrastructure systems have to deal with the physical surroundings as well as the social multi-actor environment. They therefore need competences to deal with both.

Physical environment: Dealing with the physical environment requires some specific skills related to the profession and accepted working processes; a manager of a large infrastructure project needs other professional skills do a constructor or an account manager.

Social environment: Dealing with the social multi-actor network demands another type of competences. A multi-actor setting is characterized as an arena consisting of many different actors with different opinions and objectives. To influence the direction of the group, managers have to convince others to follow their ideas. Aside from knowledge and professional skills, good social skills, like communication, negotiations and collaboration, are necessary.

These physical and social management skills are, in combination with the knowledge and understanding of patterns of the system, relevant to understanding complex infrastructure systems. These skills improve the recognition of complex adaptive system behaviour and the success of interventions by managers in the system.

Individual learning objectives for the understanding of complex systems

Based on the cognitive learning domain described by Bloom (1964), which was applied to the cognitive learning objectives of gaming by Garris (2002), six different types of individual learning objectives related to understanding complex infrastructure systems can be identified (see Table 3-1). Games can be used to increase subject-related content and theory-related notions; they can be used to understand linear and complex processes within complex systems; and they can be used to practice the management of physical and social networks.

Some argue that practicing management skills does not fit within the cognitive learning domain; however, in this case we see practicing skills as reflective and critical thinking and recognize the different interventions an actor can make in the management and design of infrastructures. Therefore, we have decided that it fits within the cognitive domain. Furthermore, it is clear that the objectives are closely related and that it is not possible to teach these objectives separately from each other. Nonetheless, it structures our thinking about possible learning effects.

Table 3-1. Learning objectives for understanding complex infrastructure systems, based on the learning domains described by Bloom (Bloom et al., 1964), which are adapted to the game-based cognitive learning objectives of Garris (Garris et al., 2002)

Cognitive learning domain (Bloom et al., 1964)	**Applied to game-based learning objectives** (Garris et al., 2002)	**Applied to the understanding of complex infrastructure systems**
Recognition of facts	Declarative knowledge	Domain-specific content Theory-based notions
Recognition of procedural facts	Procedural knowledge	Understanding linear processes Understanding complex behaviour
Development of intellectual ability skills	Strategic knowledge	Management of the physical environment Management of the social environment

In the literature we read that different learning outcomes can be reached by playing games within an educational setting in school as well as in professional trainings. The type of learning that finally emerges by playing games about complex infrastructure systems is still unclear. In the empirical part of this research, these learning outcomes are further researched, as well as the way in which different input variables such as the starting knowledge about the subject, the computer and game experience and the game itself influence these experiences.

One important remark is that games will not always be the best or most efficient way of learning. In higher education, theory is transferred from teacher to students in lectures. Projects, internships or games can be used to link theory with practice. It is outside the scope of this study to do a comparative study between different learning methods. Some researchers who did this are Egenfeldt-Nielson (2005), Blunt (2006) and Squire (2004).

3.4 Conclusion

In this chapter we have introduced the concept of serious gaming and why this is interesting in simulating socio-technical systems. Secondly, games are considered as CAS, which leads to several design requirements for games. Finally, we show the use of serious games as a supporting tool for better understanding infrastructure systems.

Serious games: adding elements to simulation games

Serious games are games with a serious purpose in education, policy and training, but also in health, politics and advertising and with the use of the technology and gaming concepts from the video game industry. In this dissertation, the focus lies on serious games as a sub-set of simulation games. These serious games are interesting for simulation games because they offer new possibilities in simulating socio-technical systems; they provide the possibility of integrating large-scale simulation models and offer a better visualization of the dynamic system state.

Simulating CAS in serious games

When serious games are used for increasing the understanding of CAS, they need to contain several CAS characteristics. When a game is divided into players, rules and interaction, and game output, it shows levels of perspective comparable to those needed to understand CAS. By comparing these levels we conclude that serious games can simulate CAS if they consist of multiple players and/or multiple adaptive agents, flexible rules and dynamic interaction, and an open game outcome. These requirements have to be used in the game design process in order to develop a game with such complex properties as similarity, diversity and adaptation of agents, evolution of the system and self-organization, path-dependency, robustness and instability.

Understanding infrastructure systems through gaming

Understanding complex systems has been an important objective of simulation games for many years. Based on the characteristics of games as semi-bounded systems and the similarities games have with the characteristics of complex systems, games are a safe environment within which to experiment and test policies, ideas and actions which are too expensive, dangerous or time-consuming to pursue in real life

(Barreteau, 2003; Klabbers, 2006b). Furthermore, games are a motivating activity (Malone, 1981), and research has shown that the retention of lessons learned in games is high (Egenfeldt-Nielsen, 2005). Serious games increase these characteristics by simulating a more realistic and immersive environment and by motivating game concepts.

Serious gaming can support the understanding of infrastructures in two ways. The first is by analysing the socio-technical system behaviour of the players interacting with the simulated physical environment. Each gaming session explores one possible future path. Observers can analyse the strategic behaviour of the players in the game, the dynamics in the social network, the physical network and the interaction between them, and the emergent system behaviour. If the game is played multiple times, the outcomes could be used for the analysis of properties such as self-organization, path-dependency, instability and robustness.

The second way in which gaming can support the understanding of infrastructures is the individual learning of the participants. When properly used, games can be used for all types of learning, but related to understanding of the complexity this research focuses on the cognitive learning outcome. On the individual level, gaming can be used to increase subject-related content and theory-related notions; it can be used to understand linear and complex processes within complex systems; and third, games can be used to practice the management of the physical and social network. Important for this learning process is the reflection on the game play process. This reflection is done in the game by the feedback and externally by the facilitator.

The theoretical exploration of the relationships between design of infrastructures, complex adaptive systems and serious games shows that:

- Infrastructures can be considered as complex adaptive systems,
- Under certain conditions, serious games can simulate complex adaptive systems, and
- Serious games can support the understanding of the complexity of infrastructures in two ways.

In the following chapters, these relationships are further explored in an empirical way. As a demonstration and experiment, a serious game was developed, tested, played and evaluated. The approach of this empirical part of the research is explained in the next chapter.

4. RESEARCH APPROACH FOR USING GAMING TO EVALUATE THE UNDERSTANDING OF COMPLEXITY

'Our primary problem is that we have little theory on which to base our efforts. We don't really know what a game is, or why people play games, or what makes a game great… We need to establish our principles of aesthetics, a framework for criticism, and a model for development… We, computer game designers, must put our shoulders together so that our successors may stand on top of them.'
Chris Crawford (in Salen & Zimmerman, 2006)

Introduction

In the previous chapters, it was argued that infrastructures could be considered as complex adaptive systems in a socio-technical context (Chapter 2). Secondly, serious gaming was introduced as an intervention which has the capacity to simulate socio-technical complex adaptive systems, to improve our understanding of these complex systems (Chapter 3). We identified two levels on which this understanding could take place. The first level is that of the observer's perspective. The observer stands outside the system and acquires a holistic view of the simulated system. The second level is the improved understanding of the system by the participants of the game. By becoming part of the system, they can experience its complexity. These two ways of increasing knowledge can influence each other; players' observations can support the analysis of the system behaviour, and greater knowledge of the system behaviour increases the quality of the facilitation and the learning of the individual. However, we focus here on the separate contributions.

To explore these contributions of gaming in practice, a serious game was developed according to the criteria defined in Chapter 3 and was extensively evaluated on the two levels of understanding complexity by gaming. To validate new theories, these have to be supported with empirical evidence (Duke, 1998). However, the field of gaming research is still searching for a generally accepted research method for evaluating the value of gaming (Gosen & Washbush, 2004; Klabbers, 2006b). Since games have found their way into business, policy, education and communication, questions emerge about the effectiveness of their use and their impact on policy making. 'It works, that is all we have' is a frequent observation (Duke & Geurts, 2004). In other words, there is no unified scientific evidence of the value of gaming for decision making and policy support (Mayer, 2009). Likewise for other uses of games, such as training and education, there is no unified evidence (Wilson et al., 2009), and the evidence that exists is often anecdotal (Dempsey, Haynes, Lucassen, & Casey, 2002; Gredler, 2004; Hays, 2005; Kirriemuir & McFarlane, 2004). An important next step is to analyse whether serious gaming leads to effective learning outcomes (De Freitas & Griffiths, 2007).

One of the reasons for the fragmentation of game research methods is the wide variety of types and uses of games and participants. A single coherent evaluation method does not necessarily fit such diversity. These methodological problems and the variety of games make it difficult to answers the questions of if and why games work. More structured and comparative research is needed to show the value for practitioners and to improve game design (Druckman, 1995). Second, much gaming research is based on methods from several related fields, such as media studies, sociology, psychology, policy science and computer sciences. Although there is nothing wrong with using existing and well-known research tools and techniques, these do not always fit the characteristics of gaming. Third, game researchers face the dilemma of design science versus analytical science (Klabbers, 2006a, 2009a). Whereas in the analytical sciences the objective is to verify theories, in the design sciences the objective is to build and assess an artefact. Both types of sciences use different research methodologies.

The lack of a common methodology means that we need to develop a research approach to evaluating the use of gaming in understanding complex infrastructure systems. This approach is based on earlier design and evaluation studies adapted to our specific research questions. As a starting point, a design research approach was chosen (Section 4.1). In order to explore the different perspectives of gaming for understanding complex infrastructure systems, we evaluated the entire process from conceptual game design to the analysis of the game outcome. Each step in the process is explained in more detail in Sections 4.2 through 4.5. This chapter ends with the outline of Chapters 5 through 8, which deal with the Maasvlakte 2 case.

4.1 The design research approach

To analyse the value of gaming for understanding complexity, a real-world example was chosen and extensively evaluated. The following research questions needed to be answered after the empirical study:

RQ4: What are the lessons learned from the development of a serious game about complex infrastructure planning?

RQ5: What lessons learned about the complex system behaviour in gaming can help us to improve our understanding of complex infrastructure systems in reality?

RQ6: What knowledge and skills do players gain about complex infrastructure systems from being involved in and part of the system?

The general steps of the approach consisted of selecting an infrastructure system which could be considered complex, developing a game about this system, playing this game with several participants and evaluating the outcome (See Figure 4-1). Because we developed a serious game, an artefact as it were, and tested whether this design worked for our purposes, a design research approach was appropriate (Klabbers, 2006b). This approach focused on designing and evaluating artefacts to solve real-world problems (Hevner, March, Park, & Ram, 2004).

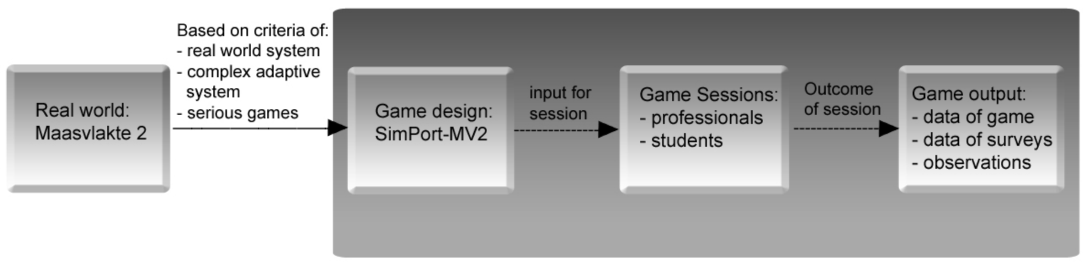

Figure 4-1 General research approach

4.1.1 The selection of the Maasvlakte 2 case

Before explaining the research approach in detail, a short introduction to the selected case and arguments for this choice are given. An in-depth analysis of the situation and the problem can be found in Chapter 5.

One of the interesting infrastructure projects in The Netherlands is the extension of the Port of Rotterdam with the land reclamation project Second Maasvlakte (MV2). This project has many infrastructure characteristics and a large spatial impact. The construction project of the first phase will take about five years, and the use of the area is intended to be long-term. The project has to contend with high sunk costs because of the construction of the area, uncertain revenues dependent on the economic activities in the area, and an uncertain political environment.

The system exists within a multi-actor environment. The Port of Rotterdam Authority, represented by the Project Organization Maasvlakte 2, deals with different departments responsible for different aspects of the project and many external organizations, including government, environmental organizations, industry and emergency organizations. Because these actors influence the design process of Maasvlakte 2, a socio-technical system perspective was appropriate for the analysis.

The problematic situation is the lack of knowledge about the consequences of several strategic decisions related to the construction of Maasvlakte 2 and the negotiation approach in this dynamic environment. The objective, therefore, was to acquire a better understanding of the complexity of the system and how to deal with this complexity.

Maasvlakte 2 is an infrastructure with a large spatial impact, the process of bringing the project to fruition is taking place within a multi-actor context, and there is a lack of understanding of the system's complexity. The Port of Rotterdam Authority was enthusiastic about the use of serious gaming to gain a better understanding of the consequences of the strategic decisions. This topic fulfilled the requirements for the case. The case of the planning and design of Maasvlakte 2 was therefore selected.

4.1.2 Design science, design research and action research

The design research approach was used as a starting point. The objective of design research is to create and evaluate new artefacts intended to solve identified problems (Hevner et al., 2004). The important question of design research is 'does it work?' rather than 'are the hypotheses true?' In this research, we did not define a hypothesis, because we have not identified the specific variables on which serious gaming has an effect. Our questions related to the contribution of serious gaming in supporting the understanding of complex infrastructure systems in general. These questions were more in line with the 'does it work' question of design research.

Design research started in the 1960s and was inspired by applications of novel, scientific and computational methods (Cross, 2001). Some researchers defined design research as a philosophy, called 'design science'. But there is a difference (Cross, 1993). Design science is a problem-solving paradigm with a background in engineering disciplines and is seen as antithetical to behavioural science (Hevner et al., 2004) and analytical science (Klabbers, 2006b). In addition to engineering disciplines, design science can be found in medicine and management (Van Aken, 2004). Cross concludes that 'design science refers to an explicitly organized, rational and wholly systematic approach to design; not just the utilization of scientific knowledge of artefacts, but design in some sense as a scientific activity itself' (Cross, 1993; 2001 p.53). On the other hand, design research is considered to be a methodology, because several steps have been developed describing how to execute this type of research (Vaishnavi & Kuechler, 2007). These steps are explained in Section 4.1.4.

Another approach which could be part of the design science paradigm is action research. Action research is defined by Reason and Bradbury as:

> A participatory, democratic process concerned with developing practical knowledge in the pursuit of worthwhile human purpose, grounded in a participatory worldview, which we believe is emerging at this historical moment. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities (Reason & Bradbury, 2001 p.1).

Design research and action research both fit within the design science paradigm, where knowledge generation comes from doing (Brydon-Miller, Greenwood, & Maguire, 2003). They both have an action component, within a real-world system or some sort of everyday experience, and the researcher is an active participant instead of a passive observer (Wadsworth, 1998). It is therefore also called 'participatory action research'. Action research could also be part of design research to make the link between the design and the application field.

Although all research seems to have an action component to it, action research sets out to explicitly study something in order to change and improve it. At the start of the research, the end situation is unknown because it evolves over time (Wadsworth, 1998). The participatory component also means that other human beings are part of the research (Wadsworth, 1998). These are the problem owners, the people who are the subject of the research and those who benefit from better information about the situation.

There is one clear difference between action research and design research. Design research focuses on creating new artefacts for problem solving (Jarvinen, 2007). The idea is that creating new artefacts not only produces a product but also produces new design knowledge. Therefore, the two main activities in design research are building and evaluating new artefacts. The assessment criteria for the evaluation are value and utility. Furthermore, according to the design research approach, the client has to be involved in the process, because it is the client's problem that has to be solved.

4.1.3 Reasons for choosing a design research approach

The efforts of the (simulation/serious) gaming community are embedded in design science as well as in analytical science. Klabbers and others (Hofstede & Meijer, 2007; Kriz & Hense, 2006; Mallon & Web, 2006) agree that although it is difficult, it is possible to combine these two sciences because of the multidisciplinary character of games. Once a game is developed it can be used in a policy process according to design science, or it can be used as a tool in the analytical science tradition to develop and test theories.

The objective of this research was to explore the possibilities of using gaming for understanding complex infrastructure systems and to answer the question 'does it work?' This question fits within the design science paradigm. Moreover, the problem-oriented perspective of the case and the participation of the problem owner in the development of an artefact indicated that the research had to follow the design science paradigm. Furthermore, the artefact – the game – had to be evaluated. And because the development of the artefact is part of the research, a design research approach was chosen. The analytical approach fit less well, because we were not testing a hypothesis. Furthermore, the development of a game is not a completely scientific process; it is partly a creative process. The influence of the opinions of the stakeholders about the perspective of the problem and boundaries also make an analytical study difficult. However, in the validation and testing of the game play and its effects on increased understanding, a more analytical view was chosen, as will be explained in Sections 4.4 and 4.5.

4.1.4 Steps of the design approach

The design research approach consists of three closely related cycles of activities: the relevance cycle, the rigor cycle and design cycle (Hevner, 2007). The design cycle is the iteration between core activities of building and evaluating design artefacts and is based on the knowledge from the rigor cycle and relevance cycle. In the design cycle five iterative steps can be identified (Vaishnavi & Kuechler, 2007): awareness of the problem, suggestion of an artefact, development of the artefact, evaluation of the artefact and conclusions (Table 4-1).

Awareness of the problem: Together with the client or problem owner, the problem is structured. This activity leads to a project proposal.

Suggestion for the development of an artefact: Within design research, a tool or artefact is designed. It is also possible that the suggestion is to design a policy. This output suggests a tentative design.

Development of the artefact: The development is an iterative process allowing for the revisitation of the earlier steps in order to clarify the problem situation.

Evaluation of the artefact: The important question in this step is: does the artefact work according to the objectives as set earlier in the process?

Conclusion: In this last step, the tool or outcomes are used to solve the problem.

These steps are comparable to the steps in the development of simulations (Law & Kelton, 2000), policy processes (Dunn, 1981) and policy games (Duke & Geurts, 2004). In these developments, there is also a problem identification and conceptualization, justification of a particular approach, specification, validation and evaluation and conclusions.

Design research approach		**Empirical study Maasvlakte 2**	
Process step	Output	Process Step	Output
Awareness of the problem	Proposal	Problem analysis and conceptualization Second Maasvlakte system	Insights in problem field and identification of questions
Suggestion	Tentative design	Justification for selecting gaming approach	Game requirements and basic game concept
Development	Artefact	Game development	Game SimPort-MV2
Evaluation	Performance measures	Evaluation of: a. System understanding b. Individual understanding	Value of SimPort-MV2 on system and individual understanding
Conclusions	Results	Conclusion	Results

Table 4-1. Steps of the design research approach (Vaishnavi & Kuechler, 2007) and the steps followed in this dissertation

For the development of the serious game about Maasvlakte 2, which is a combination of policy games with a simulation about a policy process, these steps fit nicely with the steps of the design research approach. For our Maasvlakte 2 case, this led to the following steps (see Table 4-1 and Figure 4-2). These steps are described in more detail in sections 4.2 to 4.5.

Problem analysis and conceptualization: This step consisted of analysing Maasvlakte 2 as a complex adaptive system and identifying the knowledge gaps related to the long-term behaviour of Maasvlakte 2. Within the project many other problems and knowledge gaps were identified, having far-reaching consequences for the project. These are outside the scope of this research.

Justification for selecting a gaming approach: The second step was the justification of using a serious game to increase the understanding of this system and to reduce the identified knowledge gaps.

Game Development: The third step was the development of the game SimPort-MV2. The game is based on the situation and considerations of the Maasvlakte 2 project in 2004. The design criteria were related to the game requirements of roles, rules and resources, with additional requirements derived from the design of infrastructures and complex adaptive systems.

Evaluation of system and individual understanding: The next step was to evaluate the use of the game SimPort-MV2 in two ways: evaluation of complex system behaviour over time and evaluation of the understanding of complex infrastructure systems by the participants of the game. The data from the sessions were analysed to search for patterns of behaviours which contribute to the understanding of infrastructure systems. Surveys were used for the analysis of the contribution of the individual's understanding of complexity.

Conclusions: In the conclusions provided in Chapter 9, the questions of if and in what way games can be used to understand complex infrastructure systems are answered. The results are related to the theoretical ideas from the previous chapters. Second, several recommendations are given for the development and use of serious games for understanding CAS. In addition, the future development of the game SimPort-MV2 and research into gaming for understanding CAS are discussed.

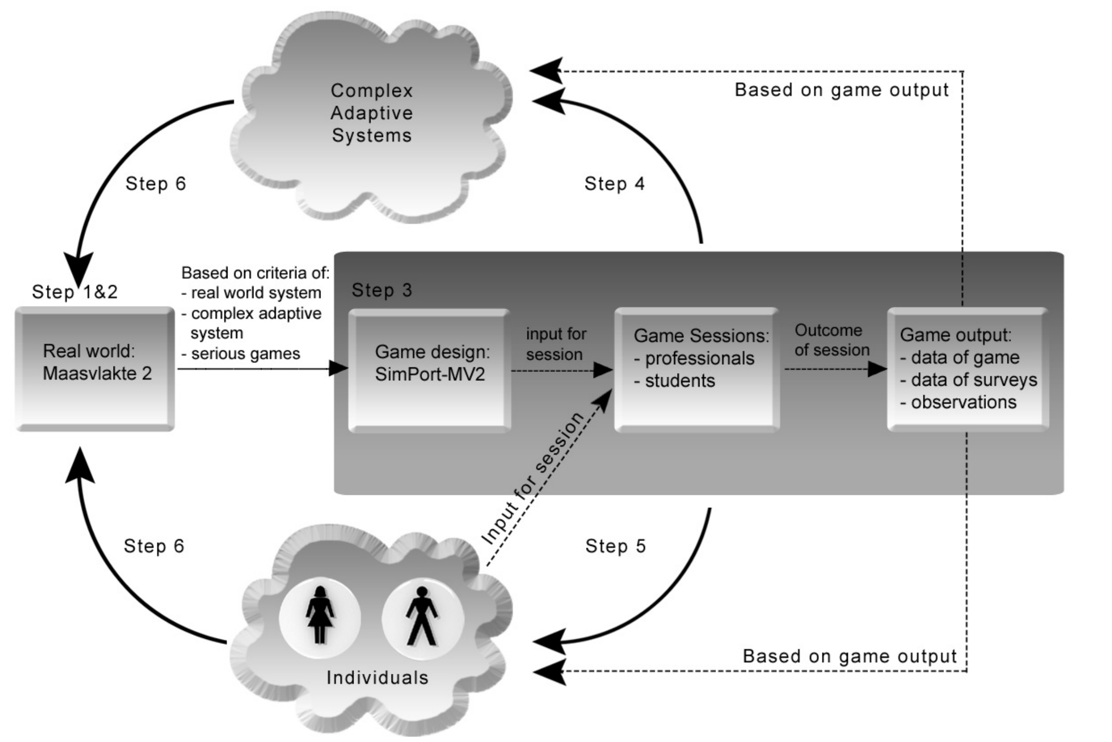

Figure 4-2 Case approach understanding complexity Maasvlakte 2

4.1.5 Limitations of the design research approach

The first limitation of this approach is the influence of the researcher. This influence is insurmountable in an action research approach. One of the risks is the research bias of the researcher, which influences the validity of the outcome. This bias can be observed in the design and facilitation of the game. By developing and validating the game in a team drawn from different disciplines and in close cooperation with the Port of Rotterdam, we tried to reduce this bias. The sessions were also facilitated by a group of people. Nonetheless, we must acknowledge this bias.

The second limitation related to this approach is that a single case must be chosen. This single case makes it difficult to generalize the results. However, this research was not intended to test and refute a hypothesis. If it had been, one case would not have been sufficient to draw a conclusion. This research was an exploration of the possibilities and aimed to develop more specific research questions. Therefore, instead of focusing on a single detail and testing this in multiple cases, a wide-ranging single case was chosen in order to explore the possible solutions.

4.2 Steps 1 and 2: Problem and choice for a serious game

The first two steps of our design research approach were gaining awareness of the problem and suggesting a design. The problem – or knowledge gap – of the Maasvlakte 2 land reclamation project had to be defined, and we needed to justify the use of serious gaming for solving the problem or gap.

4.2.1 Problem analysis: Maasvlakte 2

For the problem analysis, we used different types of documentation, such as newsletter articles, advisory reports, governmental decisions (Key Spatial Planning Decision and Environmental Impact Assessments), judgements of the objections on the documents (which are brought to the Council of State of The Netherlands), Internet sites of different organizations involved and the official documents of the Port of Rotterdam. Based on this information, an historic overview of the development of the Port of Rotterdam could be generated. Furthermore, the context and the decision-making process of the Maasvlakte 2 project was described. The documentation also provided insights into future developments.

For the identification of the expected problems and dilemmas in the execution phase of the project, the information from the documentation was used to draw some conceptual maps about the project. These maps were verified through several interviews with employees of the Port of Rotterdam Authority. The interviews can be described as semi-structured, inasmuch as the interviewer had a list of discussion topics. A starting point for the discussions was a conceptual map, to which the interviewee could react by correcting inaccurate conceptions and adding elements to the described processes. After each interview, the map was updated and used in the next interview. This conceptual map was used to define the relevant agents and their relations as well as possible complex system behaviour. The map also furnished insights into the parallel processes and expected dilemmas between the construction and exploitation processes.

4.2.2 Justification of a serious game

The second step was to propose a design to solve the problem. In Chapter 3, we proposed serious gaming as a promising tool to simulate complex adaptive systems and to contribute to a better understanding of infrastructure systems. Instead of developing an artefact based on the problem, we needed to provide arguments that support why the questions fit our proposed solution. The characteristics of the Maasvlakte 2 and the identified lack of knowledge of the system behaviour made it possible to test the value of serious gaming.

To evaluate serious gaming, we needed to play serious games and collect data from the sessions. It would have been easiest to use an existing game, such as a commercial product off the shelf. These have proven to be successful, and no time would have had to be spent on development. However, this would only have been possible if the game were to have fit our purpose. SimCity, for example, is about strategic decisions and long-term planning. However, this game does not focus on port management and strategic planning. Furthermore, SimCity is a single-player game, whereas we argued for a multi-player game to simulate the social network. The simulation games in the Tycoon series are also single-player. Therefore, SimCity and games from the Tycoon series did not fit our requirements.

The second step was to search for a game about port design and management. Several games were found; however, they do not deal with the questions relevant for Maasvlakte 2. For example, there is the Ship Simulator game, developed by V-Step, which is about manoeuvring a ship in a port area (VSTEP B.V., 2006). Another game is Containers Adrift, developed at Delft University of Technology, which simulates the planning of an inland container terminal (Mayer, Bockstael-Block, & Valentin, 2004). Although the objective of the game was more closely related, the dilemmas deviate from the ones we would like to see in a game about the building and negotiation processes of Maasvlakte 2. Therefore, it was decided to build a new game which would fulfil the requirements derived from the analysis of the problem, from the characteristics of complex adaptive systems and from games for supporting understanding.

At the end of the first two steps, there was a problem description and a conceptualization of Maasvlakte 2 from a complex adaptive systems perspective. It was further argued how serious gaming could be used to reduce the knowledge gaps and what type of game had to be developed.

4.3 Step 3: Game development

The third step was the development of a serious game. The design and development of a game was bounded with practical (time, people) and technical (hardware and software) limitations as well as content-related requirements. These requirements were based on: 1) the subject Maasvlakte 2 and planning and design issues, 2) characteristics of Complex Adaptive Systems and 3) serious gaming for policy support. In any game development process, combining these requirements can lead to conflicts. Therefore, developers constantly have to balance realism, game and education (Harteveld, 2007; Harteveld, Guimaraes, Mayer, & Bidarra, 2010). This was true for our team as well.

4.3.1 An analytical and creative process

Many books about game design have been written from different perspectives and with different objectives (Björk & Holopainen, 2005; Crawford, 1984; Crookall, Greenblat, Coote, Klabbers, & Watson, 1987; Duke, 1975a, 1975b; Duke & Geurts, 2004; Greenblat & Duke, 1975; Salen & Zimmerman, 2004; Schank, 2002). These authors illustrate that it is possible to develop games in different ways. Depending on the type and objectives of a game, some approaches fit better than others.

In general, game design can be seen as a combination of an analytical process and a creative process (Klabbers, 2006b). The analytical design approach gives a clear overview of the boundaries and choices made, if the design is properly documented. Nevertheless, the success of the game is highly dependent on the creativity of the design team. In other words, designing games is always more or less an art and is difficult to structure. Ideas arise spontaneously and suddenly become important elements in the game.

Game design is also a balancing process between developing a simulation, containing conceptualization, specification, validation and use, and writing a story complete with styles, plots, genre, characters and settings. The development of a serious game, especially for policy support, normally starts from the simulation perspective, in which it is important to make an abstract simulation of a real-world system. For entertainment games, the focus lies more on the storyline of the game. Simulating reality is less important. Nevertheless, both aspects have to be taken into account; a mere simulation of reality does not result in a game.

The development of a game around Maasvlakte 2 faced the challenges of a combined analytical and creative design, and the development of both a real-world simulation and a story. Because one of the important requirements was the validity and realism of the outcome, the analytical and simulation perspective was chosen as the starting perspective. Therefore, the design approach of Duke and Geurts (Duke, 1980) for designing policy games was used. This approach consisted of 21 steps divided over five phases. These phases were partly comparable with the steps of the design research approach. The only difference was that the first two steps were reversed.

Phase I is to setting the stage for the project, which is related to administrative tasks, as well as to argue why gaming is an appropriate method. This phase is comparable to the suggestion in the design research approach.

Phase II is to clarify the problem, which has the same objectives as gaining awareness of the problem of the design research approach. We call this phase the conceptualization of the real-world system.

Phase III is designing the policy exercise, where the real-world system has to be translated into gaming components and where creativity and introduction of the story line have to be added. This leads to a conceptual game design.

Phase IV is the development and evaluation of the game design. In this phase, all elements have to be specified and related to develop a game. Phases III and IV are two activities in the development of the artefact as described in the design research approach.

Phase V is the implementation of the game in the real-world system. This consists of playing the game with the intended audience and evaluating the effects. This phase is comparable to the evaluation and conclusions in the design research approach.

The design sequence of Duke and Geurts does not focus on the development of a serious game. For the design of our serious game, the steps of computer simulation and video game design had to be added to the approach. In Phase III, in addition to a conceptual game design, there also had to be a conceptual computer environment. The development of the game and computer environment was an iterative process because they had to be strongly related. In phase IV, an additional step had to be taken, which was the development and validation of the computer game environment.

These five phases contained the same activities as the steps in the design research approach. The game design process described the development of the product in finer detail, while the design research approach had two steps of evaluation and drawing conclusions. While considering the importance of the evaluation, the game design process was suitably able to be followed.

4.3.2 Starting up…

In the start-up phase of any game development project, the technical and financial limitations have to be made clear to the client and the designers in order to determine the desired outcome and to avoid disappointment at the end of the process.

Second, a design team has to be formed, which must consist of game designers, programmers, system specialists, facilitators and others (Duke & Geurts, 2004 p.279). The client has to assume the role of content expert.

Third, there need to be a problem statement, a game objective and clear boundaries for what is to be taken into account. Finally, the game design requirements have to be determined, based on the type of game and the objectives.

4.3.3 Conceptualization

The conceptualization phase is comparable to Phases II and III of the model of Duke and Geurts (Duke, 1980; Duke & Geurts, 2004; Wenzler, 1993). The conceptualization phase for serious games consists of a conceptualization of the real-world system, game concepts and computer game environment. The objective of the conceptualization of the real-world system is to investigate what the real problem is, what actors and elements are parts of the system and how these are related to each other. The boundaries of the game also have to be further determined. This is a critical step, because the game and the validity of the outcomes are dependent on the boundaries. When the boundaries are too tightly delineated, there is a risk that several alternatives or influences could be ignored (Duke & Geurts, 2004 p.268). The outcome of this step is a coherent mental map of the system, which provides a blueprint for the game.

In the conceptualization of the game design, the objectives in the game, the format and the elements have to be developed. The team has to translate the system components which emerged in the conceptualization of the system into game elements, roles and performance indicators. Duke and Geurts (2004) introduced the System Component/Game Element matrix to support the translation of system elements into gaming elements. This matrix, with the system and game elements along the axes, can be used as a brainstorming tool in which people fill in each cell of the matrix, or as an analysis tool to go step by step to each cell. After filling in the matrix a selection has to be made.

Another way of defining the game elements is to follow the Game Design Pattern approach of Björk and Holopainen (2005). They developed a collection of game patterns and defined the relations of each pattern to other patterns, based on the idea of patterns in architecture. Starting from one pattern, related patterns can be found which reveal new relations to other patterns, resulting in a snowball effect. Their book of 2005 focused almost exclusively on patterns of entertainment games. Recently, they have been researching the possibility of adding learning game patterns to their list.

Finally, a conceptualization of the computer game environment has to be made. Causal diagrams, UML diagrams and Story Boards can be used to structure processes and relations in the computer game model. These diagrams will be used by programmers; this forces the designers to be precise and complete. Designers have to go back to the client if elements and relationships are unclear. In this conceptualization phase, special attention has to be given to the human-computer interface (Klabbers, 2006b p.132). The interface has to be recognizable to the client, has to have a game look and feel and has to be intuitive for the player.

4.3.4 Specification

In the specification phase, all relevant details of the game elements have to be collected and all materials, including role descriptions, stories, manuals and other paraphernalia, have to be developed.

For the specification of Maasvlakte 2, we used design documents, business case information and information about existing negotiations. We obtained the real data from the Port of Rotterdam, under the conditions that we make clients unrecognizable and redefine expected costs. Therefore, we developed our own clients and designed slightly different building processes. Costs of the separate activities are spread differently over the alternatives, which cannot be converted to the original business case.

Another step in the specification is the development of the computer game world. A designer can do this in any of three ways: designing from scratch; using development software not specifically used for game design, such as Flash; or using game engines, for example, the Unreal Engine, originally used for the development of the First Person Shooter Unreal Tournament but now on the market as a game engine. Each of these ways has advantages and disadvantages in terms of flexibility and programming time (Bekebrede & Harteveld, 2007; Mayer, Jager, & Bekebrede, 2007). SimPort-MV2 was developed from scratch in order to have complete flexibility in the design. Consequently, the development of the game was more time-consuming.

4.3.5 Game validation

Before a game can be used in a larger context, the game has to be validated. This is a second activity in the fourth phase of Duke and Geurts' design process. Validation has the objective of checking 1) the model building, or the reliability of the game, 2) the realism of the behaviour of the game, also called the validity of the game (Peters, Visser, & Heijne, 1998; Raser, 1969) and 3) the playability or usefulness.

In the simulation literature, a distinction is made between internal and external validation (Cook & Campbell, 1979; Feinstein & Cannon, 2002). Internal validation is used to answer the question 'do the model's relationships represent true causality?' or, translated for games, 'is the game built properly and is it playable?' Variables such as model construction, rules, materials for the players, the balance of tasks, the speed of the game and the results have to be verified (Duke, 1974). The verification approach is well-known in the field of (computer) simulations. 'In this research, the validation of the computer model was done with the following methods: internal debuggers, viewing output reports, evaluating step-by-step traces and expert review. Based on the internal validation, the reliability of the model was checked.

External validation of a game can be split into two types of questions. The first is the correspondence of relevant phenomena outside the simulation with the outcome of the model, i.e. 'does the simulation model represent actual external phenomena?' The second point is the usability or playability of the game.

In general, validity of the realism of a simulation game is the degree of correspondence between the reference system (reality) and the simulated model (Peters et al., 1998 p.22). The strength of the conclusion for real-world intervention is determined by the validity of the model (Peters et al., 1998).

The game SimPort-MV2 deals with future developments, and it is not possible to compare the game's outcome with the real-world system outcome that will exist in 30 years. Therefore, the external validation of the game is based on the perceived realism of the players and their idea of the game's detail, also called 'face validation' or 'psychological reality' (Raser, 1969). Face validation is based on the look and feel of the model's results. It is a qualitative and rather quick method of checking for inconsistencies and errors. To collect data about the realism and level of detail, we used a post-game survey and comments in the debriefing about realism and missing aspects. The comments of the professionals were especially worthwhile in the analysis of face validity. Other methods for validation were test runs with, for example, extreme situation and sensitivity analysis.

To test the playability of the game, we performed several test runs. The first group of players consisted of the people from the design team. Within several sessions, the designers played (part of) the game and were critical of each action, movement and outcome. Next, we had the first session at the Port of Rotterdam. These players were aware that they were participating in a test, and they continued playing even after something went wrong. They are examples of the 'sympathetic player' (Duke, 1974). Based on this validation, small modifications to improve or extend the game were made. One example of an adaptation is the development of a tutorial. With the tutorial, the player has the opportunity to practice all the operations in the computer environment before starting the 'real' game.

Finally, true to Duke and Geurts' design process, we used a set of validation questions which related more to the evaluation of the game. These questions were about the effects of gaming in different settings, for example the educational validation (Feinstein & Cannon, 2002). These are discussed in subsequent sections.

4.4 Step 4: System understanding

The purpose of this game is to gain a better understanding of the system behaviour of Maasvlakte 2. Analysis of the game's outcome could support the decision making of the Port of Rotterdam. Therefore, we analysed the outcome of the game, namely the change from the starting situation (t=0 or 2007) to that of the players and the session after 30 simulated years (t=30 years or 2037) (see Figure 4-3).

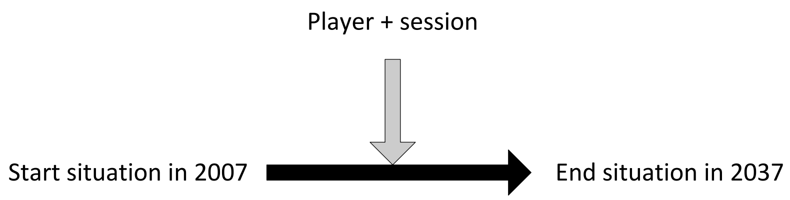

Figure 4-3. Measuring the complex system behaviour based on the input of the player and the dynamics of the session

The research questions for this part were twofold: first, can we recognize patterns of behaviour based on the characteristics of complex adaptive systems, and second, what can we learn from this analysis about possible future behaviour of the building and exploitation of Maasvlakte 2?

4.4.1 Complex system framework

The properties of the complexity framework, as introduced in Chapter 2, were used as 'lenses' to look at the data. The characteristics of the complexity framework were translated into variables and dynamics in the game (Table 4-2). Elements on the agent and network levels were the input of the game and the changes that occurred during the game. However, the emergent system behaviour was only observable after playing.

The properties at the agent level were agent diversity, adaptation, and interface and protocol similarity (See Chapter 2). Agent diversity was directly related to the diversity of the players. Adaptation was the learning that took place in the game and the changing strategies. Interface and protocol similarity were, for example, the appointments to exchange information.

On the network level, there were two properties: network dynamics and network evolution. An indicator of network dynamics was the flow of information between the players, and an indicator of network evolution was the structure of the team.

At the system level, the emergent system behaviour was determined based on the final situation of the simulated Maasvlakte 2. Indicators were financial performance, lay-out and client satisfaction; these offered insights into the solution space. The properties on this level were self-organization, path-dependency, robustness and instability. We used the output variables, scenarios and decisions of the players to determine if there was self-organization, which processes were path-dependent and for which variables the system was robust or instable. By combining the end results and the strategies and actions in the game, some general observations about the strategic choices for the Port of Rotterdam were explained.

Table 4-2. The perspective of complex adaptive systems to analyse the game output

Complex Adaptive System	**Indicator in the game**
System Level: properties	
Emergent behaviour	Solution space (based on finance, client satisfaction and lay-out)
Self-organization	Decisions and structure of the team
Path dependency	Building strategy Starting work packages
Robustness and Instability	Based on the economic input and the decisions of the players Observed by the general lay-out of the area and the general division of clients
Network level: properties	
Network dynamics	Information exchange Contracting clients
Network evolution	Changing structure of the team Growth of the area
Agent level: properties	
Adaptability	Changing strategies Learning

Agent diversity	Different people, different clients
Interface and protocol similarity	Learning the game language

4.4.2 Collection of data on system understanding

There were two types of data used for the analysis of system behaviour: the game output and observations. Each decision of the players made in the computer was saved. We collected information about the strategic choices and their motivations, the sequence of construction in the Maasvlakte 2 area and the final situation of the area, based on finance, construction and satisfaction of the clients.

The second source of information came from observations during game play. This source of information gave us insights into the negotiation and communication processes outside the computer simulation. The observations were semi-structured – that is, no observation format was used. Observation formats were used once, but this proved to be unmanageable, as the focus was too much on the less important and detailed discussion, without any conclusion. Therefore, we focused on the more general discussions in the teams and during the debriefing. In the debriefing, many aspects of the most important discussions were repeated, and these gave us enough information about the process.

For the validation of the use of the outcome for the real project, several interviews were conducted with players of the game working at the Port of Rotterdam and involved in the real-world project in different ways.

4.4.3 Data analysis

All of the game output was collected and structured in an SPSS data file, a program for statistical research. Several qualitative variables were added to the file, for example the final lay-out of the map. For these variables a categorization was made, including whether a lay-out was clustered or not. The values were assigned by the researcher.

Based on descriptive analysis, the solution space of the game could be calculated. In this way, the extreme values and averages of, for example, the minimum and maximum costs or income of all the sessions played were defined.

The second step was to analyse the consequences of the different strategies chosen and economic situations for the solution space. Finally, the system behaviour was explained based on the other characteristics of complex adaptive systems.

These analyses provided insights into whether the game can be considered a simulation of complex adaptive systems and into the possible behaviour of the real-world Maasvlakte 2 project. The interviews about validity were used as a reflection on these outcomes.

4.4.4 Limitations

There are several limitations to our analysis. In the first place, we need to be aware that SimPort-MV2 is a data-generative tool. The game is not designed to calculate the optimal way of building or exploiting Maasvlakte 2. In the game design, many choices were made to simplify the game. For example, the negotiation process was done in two steps, while in reality many more iterations take place before a contract is signed. Furthermore, the data used approximated real data but were not exactly the same. This means that the game only simulated complex behaviour on a high level of abstraction, and this does not provide information about a single client or working package.

Second, complex adaptive systems are open systems, and by deciding to develop a simulation, it became a (semi-) closed system. For the players, it may have appeared to be an open system because of the outside influences, such as the economic changes and political messages; however, these were constructed by the game developers. In theory, small changes in the real-world system not taken into account in the game could yield a completely different behaviour if the system is not robust to this change. This limitation makes it impossible to calculate the optimal design and building process of MV2. Moreover, the intention and involvement of the players were important for the validity of the outcome. By frustrating the game, the atmosphere for other players became less motivating; the outcomes also sometimes became extremely different and invalid.

It was not the intention of the game to calculate optimal design or building processes. The results of the game were used to search for patterns of complex system behaviour and gain a better understanding of the complex behaviour of Maasvlakte 2.

4.5 Step 5: Individual understanding

The final research question was whether players gained a better understanding of complex infrastructure systems from playing the game. In Chapter 3, variables of policy relevant to understanding complex adaptive systems were identified. These variables relate to declarative knowledge about the subject and complex system concepts, procedural knowledge of linear and complex processes and strategic knowledge of dealing with technical systems and social systems. In addition to the question of whether or not games increase the understanding of one of the mentioned outcomes, the question arises as to which factors influence this learning process. In this part of the research, the change undergone by the player was measured (See Figure 4-4).

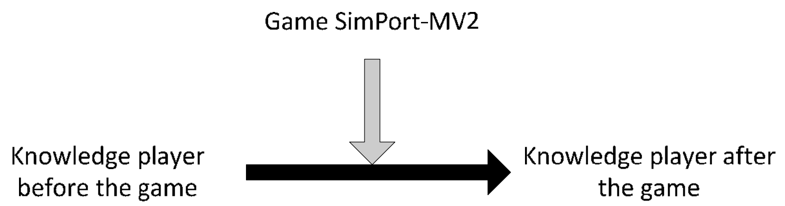

Figure 4-4 Model for evaluating individual understanding of complex adaptive systems

For the evaluation of individual learning, we used the formal logic model developed and tested by Kriz and Hense (Hense, 2004; Kriz & Hense, 2006). This section starts with the theory behind the model, followed by the adaptations made to make the model useful for this research.

4.5.1 Formal Logic Model

Kriz and Hense designed a formal logic model to evaluate games (Hense, 2004; Kriz & Hense, 2006). This model is a theory-based evaluation framework which was earlier used in evaluation research (Rossi & Freeman, 1993) but only recently for the evaluation of simulation games (Hense, 2004; Kriz & Hense, 2004). The idea behind the model is to open the black box of input and output, take the gaming process into account and find relations between input, process and outcome. With this model it is not only possible to test if learning objectives are reached, but also to show how and why games work. Although the use of a formal logic model is related more to analytical science, it has applicability to the gaming process. Further, the model is related to the question of whether the artefact works and evaluates the game in its unique context. Therefore, this model is an example of linking analytical science and design science (Kriz & Hense, 2006 p.281).

Kriz and Hense used their model for the evaluation of a business game, called TOPSIM. Their model was built from the literature about simulations, approaches of situated and problem-oriented learning, models about measuring the quality of teaching and learning, and from the entrepreneurship literature, which is the subject of the game. They added some demographic and motivational variables to the model, because these are proven factors for learning motivations (Kriz & Aucher, 2005).

Most of the categories are suitable for the evaluation of SimPort-MV2. There are two differences which made it necessary to adapt the framework. The first is the subject of the game. TOPSIM is about entrepreneurship, so the model measures learning about this topic. SimPort-MV2 is about complex adaptive systems, which means the variables about entrepreneurship had to be replaced with variables about these complex systems. The second difference is related to the type of game. TOPSIM is a board game, whereas SimPort-MV2 is a computer game. Variables like the computer experiences of the students and teachers, the quality of the interfaces and the accessibility of the virtual environment influence the input and process of the game play and the outcome. Therefore, the model used by Kriz and Hense had to be adapted to the situation of SimPort-MV2. The adapted framework is presented in Figure 4-5. The blocks with the numbers 1, 5, 9, 13, 14 and 15 are adapted for the evaluation of SimPort-MV2.

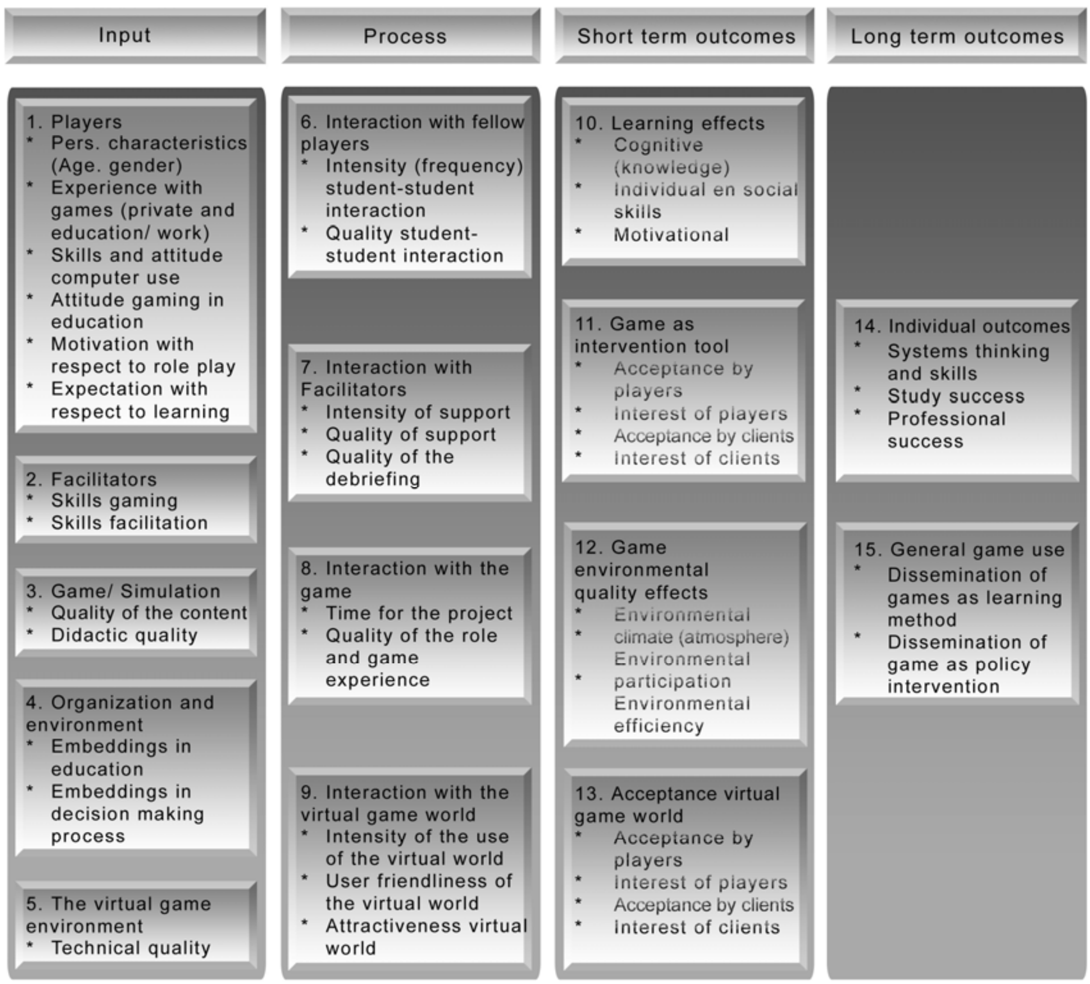

Figure 4-5. Evaluation framework for measuring effects of playing games (Mayer et al., 2007 based on Kriz & Hense, 2006)

The variables in the model are divided into four groups: input, process, short-term outcomes and long-term outcomes. The input variables give an indication of the starting situation of the game. The process is related to the activities in the game session. The short-term outcomes are the outcomes directly after the game, and the long-term outcomes are the retention of the knowledge acquired and the influence of the game on the decision-making process. This last aspect cannot be measured within the time frame of this research, because the building and negotiation process of the real Maasvlakte 2 will go on for a couple of decades. We mention it, however, to show the complete framework. Next, the blocks within the framework are explained.

Input

Volery and Lord (Volery & Lord, 2000) define three success factors for (online) gaming, namely the technology, the facilitators and the student's perspective on the use of technology. According to Christopher and Smith (1987) (in Leigh & Spindler, 1998), the game must be well-designed and resourced, it must be suitable for the intended learning goals and the particular group, and the ability and mindset of the 'presenter' or 'facilitator' must match the facilitation requirement of each activity. Further, Gosen and Washbush (1999) believe that the behaviour of the facilitator, the game design and the atmosphere variable, both alone and in combination, probably produce unique and substantial effects on learning in simulation experiences. Based on these conclusions, we identified five categories of input variables, namely player, facilitators, (simulation-) game, organization, and virtual game environment. These five blocks of variables describe the starting positions of the game session.

Players: All players are unique. There are demographic differences such as age, gender and differences in game experience (Chang, Lee, Ng, & Moon, 2003), computer experience (Prensky, 2001), and learning styles (Kolb, 1984). These differences cause variety in game play as well as different experiences (Faria, 2001). These variables contribute to the motivations and expectations with respect to the game and are important for the reflection and learning results (Deci and Ryan in Coughlan & Connolly, 2001; Kriz & Hense, 2006). Participants who are unfamiliar with the environment may be excluded from the activity, as was observed by De Freitas et al. (De Freitas, Rebolledo-Mendez, Liarokapis, Magoulas, & Poulovassilis, 2010). Experience about the topic also influences the learning outcome, as Hmelo-Silver and Pfeffer (2004) showed in an experiment about learning about complex systems. Novices focus on static components, and experts search for integrated elements. Jacobson (2001) also found differences between the complex systems experts and novices in an exploratory study on the use of complex system concepts in problem solving.

Facilitators: The role of the facilitator is often as important as the game itself in terms of whether useful learning has taken place (Birmingham 2001 in Kirriemuir & McFarlane, 2004). The facilitator assists players during the game, supports critical thinking and facilitates a debriefing, important for reflection on the difference between game and reality. Skill in observing the behaviour in the game and abstracting it from the game to reality is a relevant input factor and must be taken into account.

Game/Simulation: The quality of the game is important. The content and information level have to fit with the mental framework of the player. The didactic quality of the game is also relevant. Just like bad teachers, bad games are ineffective (Alsagoff, 2005).

Organization: The fourth input variable is the relation between the game and the context in which the game is played. Games are played with a reason, which calls for a clear relationship between the reason and the game. The learning outcome will be more important than a high score in the game. For games within the decision-making process, the outcome of the game could influence this process, but this has to be emphasized.

Virtual game environment: The last block is the technical quality of the virtual game environment. This is the quality of the hardware and software used and the quality and clearness of the interfaces and the human-computer interaction.

Process

The second group of variables is related to the gaming process. One of the assumptions within learning theory is that when students are more involved in and spend more time on a certain topic, they learn more (Kriz & Hense, 2004). For the description of this process, we observe the interactions. We identify interaction between individual players and between the players and facilitators, as well as the interaction of the players with the game and the virtual game world.

Interaction with fellow players: The interaction between the players is an indication of their involvement in the game, and of the way a game stimulates thinking and discussion about the content and supports the shared construction of knowledge among players. Team cohesion is related to the final game performance (Wellington & Faria, 1996).

Interaction with facilitators: There is also interaction between the players and the facilitator for the explanation of the game and the reflection on the learning experiences.

Interaction with the game: This interaction is the involvement of the players and their immersion in their role for the duration of the game.

Interaction with the virtual game world: When the players have the illusion of immersion in the game world, their self-consciousness and time awareness begin to disappear and their engagement level increases (Csikszentmihalyi, 1991). The measurement of immersion in the game world is based on the user-friendliness of the interface and the attractiveness of the game world.

Short-term outcomes

The outcomes of the game are split into short-term effects and long-term effects. We used four short-term variables: the learning effects, the game as learning tool, environmental quality effects and the acceptance of the virtual world.

Learning effects: There are several learning objectives. However, for this research we analysed the cognitive learning about the subject of the game, the theoretical concepts, linear and complex processes and dealing with the technical and social system.

Game as intervention tool: The acceptance of games as an intervention tool is important for the outcomes. The game has to be taken as a serious and interesting tool for players as well as clients of the game. Interest can be stimulated by elements of competition, attractiveness and fun (Chang et al., 2003; Virvou, Katsionis, & Manos, 2005).

Game environmental quality effects: This is the effect on the atmosphere in the class or policy-making process. Participants in a game share an experience which could change the relationships between the people.

Acceptance of the virtual game world: In computer-based games, the evaluation needs to consider technical aspects as well (Sheard & Markman, 2005; Virvou et al., 2005). The players are expected to be acquainted with computer games or willing to learn. Lack of competency in using computers can distract the player from immersion (Lim, Nonis, & Hedberg, 2006).

Long-term outcomes

It is interesting to know what happened within the game session, but it is also important to see what the players do with their new experience or knowledge. Do they have a different view of the system, and do they change their behaviour? Does this lead to educational or professional success? The long-term effects of the game are hard to measure, especially when the game is played only once. A distinction is made between long-term, individual learning and evaluation of the game as an intervention method to understand complex adaptive systems.

Individual outcomes: The long-term individual outcome is the retention of the knowledge or the behavioural change of the player. Measuring this long-term effect is outside the scope of this research. All players would have had to be followed for a number of years. Such intensive data collection is outside the time limitations of the research; therefore, it was not possible to collect valid information about the impact of the game on later professional practices or on the decision-making process of the Port of Rotterdam.

General game use: In this research, these long-term outcomes were interpreted as a generalization of the use of games for understanding complex, adaptive, multi-actor systems.

4.5.2 Collection of data on individual understanding

The data for the analysis of individual understanding was collected through surveys and observations. A survey collects data about a broad range of variables which are needed to link input, process and output. Furthermore, we searched for a general indication of the possible individual learning effects. Our observations are presented in this subsection to give the outcome of the survey analysis some context.

For the measurement of the learning outcomes, there were also several other options, such as knowledge tests, self-reporting measures and post-training tasks. A disadvantage of these methods is that they are time-intensive in terms of the collection and the analysis of the data and are therefore not feasible for a large number of participants. Furthermore, a knowledge test is suitable for the purposes of learning about the subject and theoretical concepts, but it is insufficient for measuring the understanding of processes and dealing with the technical and social system.

The survey we used consisted of a pre- and post-gaming questionnaire. The pre-gaming questionnaire contained questions about the background of the players and their expectations about the game. In the post-gaming survey, the questions focused on the experience, the quality of the session, the game and the virtual world. The surveys can be found in Appendices A and B. The observations were made by the facilitators of the game during the session and the debriefing.

4.5.3 Data analysis

The survey data was analysed with SPSS. This analysis consisted of two steps. The first step was a descriptive analysis of the variables of the model. This analysis was used to answer the questions of if and what the players had learned. The results of the survey were compared with the observations and the qualitative information from the debriefing and compared with the expectations based on the theory. We used this analysis to describe the different groups of players and their backgrounds. The main focus group was the professionals of the Port of Rotterdam, for whom the game was developed. We compared the results of this group with results from a group of professionals also in the field of port management and design but unrelated to Maasvlakte 2. Furthermore, a comparison was made between the current managers and the future managers of complex projects, who are now the students of Civil Engineering and Technology, Policy and Management at Delft University of

Technology. Although not all students will become port managers, they represent the managers of the future.

The second step was to analyse the relationships between different input variables, the game play and the learning outcome. Factor analysis was used to combine different aspects of a variable and reduce the number of variables for correlation analysis between input, process and outcomes. We decided not to test all relationships which can be derived from the theory-based evaluation framework. Relationships which cannot be tested because they are caused by the choice of a single case, or which are not relevant for answering the research question, were not included in the correlation analysis. This meant that seven variables of the evaluation framework were taken into account for further analysis. The different relationships between these variables are visualized in Figure 4-6.

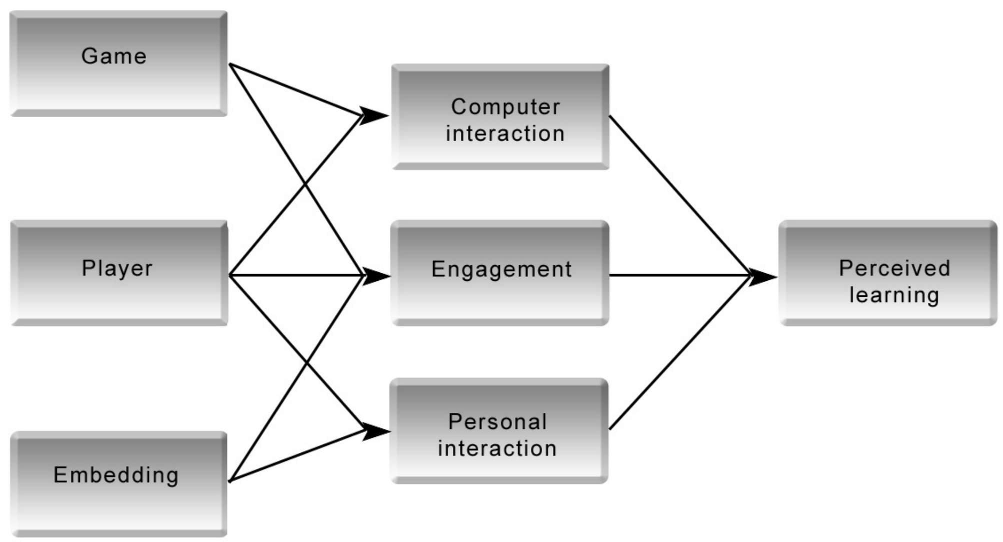

Figure 4-6. Relations between the input, game play and output variables, which will be analysed with the game SimPort-MV2

There are three inputs or independent variables – player, game and embedding of the game – which possibly influence the variables: computer interaction, engagement of the game play and personal interactions. These in turn are expected to influence perceived learning.

The 'player' variable consists of the demographic indicators, such as age and gender, the computer and game experience indicators, and the expectation indicators, and is comparable with the block players. Blunt (Blunt, 2006) researched the effects of gender and age on learning by gaming in his thesis. He concluded that people above the age of 40 learn significantly less than younger people, and he suggests that this is because the older players learned by 'tell-test' and the younger players grew up with technology-enhanced environments (p.127-128). The 'game' variable, block 3 in the framework, is built up of rules and goals, challenge, control and representation[6] and is almost constant, as we only analysed one game. There are only two versions, which are comparable in game concept but vary in the interfaces. The variable 'embedding' is the context in which the game is played (e.g. education, policy making) and the quality of the facilitation, which corresponds with blocks 3 and 4 of the evaluation framework.

The variable 'computer interaction' refers to the quality and interaction with the computer simulation related to content and interface; this variable is the combination of blocks 8 and 9. Because of the differences among the players, they could also perceive this variable differently, which could cause different learning outcomes. The variable 'engagement' is related to the fun and motivational effects of playing the game. This variable is expected to be related to the game design, the concept as well as the product, and the personal feeling of the individual players. Engagement is expected to increase when the game is embedded well in the context. The third throughput variable is 'personal interaction', which is the quality of interaction between individual players and between the facilitators and the players (blocks 6 and 7). Therefore, this variable is dependent on both.

The final outcome is 'self-perceived learning' (block 10), which is related to the three aspects of cognitive learning as described in Chapter 3. This 'perceived learning' is based on 'computer interaction', 'enjoyment', and 'personal interaction'. In the experience of Zagal and Bruckman (Zagal & Bruckman, 2008), players can confuse playing for fun and entertainment with playing for critical analysis and understanding, and fully experiencing a video game is comparable to being skilful at playing it. This game play in relation with the focus on reflection is important for the final learning effects. In the same way, the operation of the computer can become a bottleneck if the player is not acquainted with using a computer simulation. Wilson et al. (Wilson et al., 2009) offer the proposition that as the challenge feature in the game increases, declarative knowledge and retention will also increase until the point at which challenge leads to frustration.

[6] These characteristics are a subset of the characteristics derived by Garris et al. (2002) The complete set they discuss are fantasy, rules/goals, sensory stimuli, challenge, mystery and control.

4.5.4 Limitations

This approach has several limitations that we should be aware of. In the first place, we tested the perceived learning of the players. We did not measure the pre-gaming knowledge about complex adaptive systems or the knowledge afterwards. Aside from practical reasons, this could not be tested because the answers to questions about the behaviour of the complex adaptive system of Maasvlakte 2 are unknown. The second limitation is that many aspects, such as practicing social and professional skills, cannot be measured in a knowledge test. Because we wanted to have an indication if players gained a better understanding of CAS, we were satisfied with the perceived learning. When we know which aspects are improved best, tests can be developed in follow-up research to measure the difference before and after playing the game.

4.6 Introduction to the empirical chapters

This chapter bridges the theoretical and empirical parts of the research. The purpose of this chapter was to explain the approach followed in the empirical part, based on what was learned from the theory.

Game research makes it possible to combine analytical and design sciences. We decided to adopt the perspective of design science because our objective was to learn about the development of a game and test if it works. Within the steps of design research, several analytical instruments were used to answer our questions. In this way, both sciences were integrated. For each step in the process, the objectives and the approach used to collect and analyse the data were given. Attention was also given to the design process of the game.

In the following chapters, the results of the analyses will be discussed. Each chapter describes one step of the process, and in doing so contributes to answering the main question (Figure 4-7).

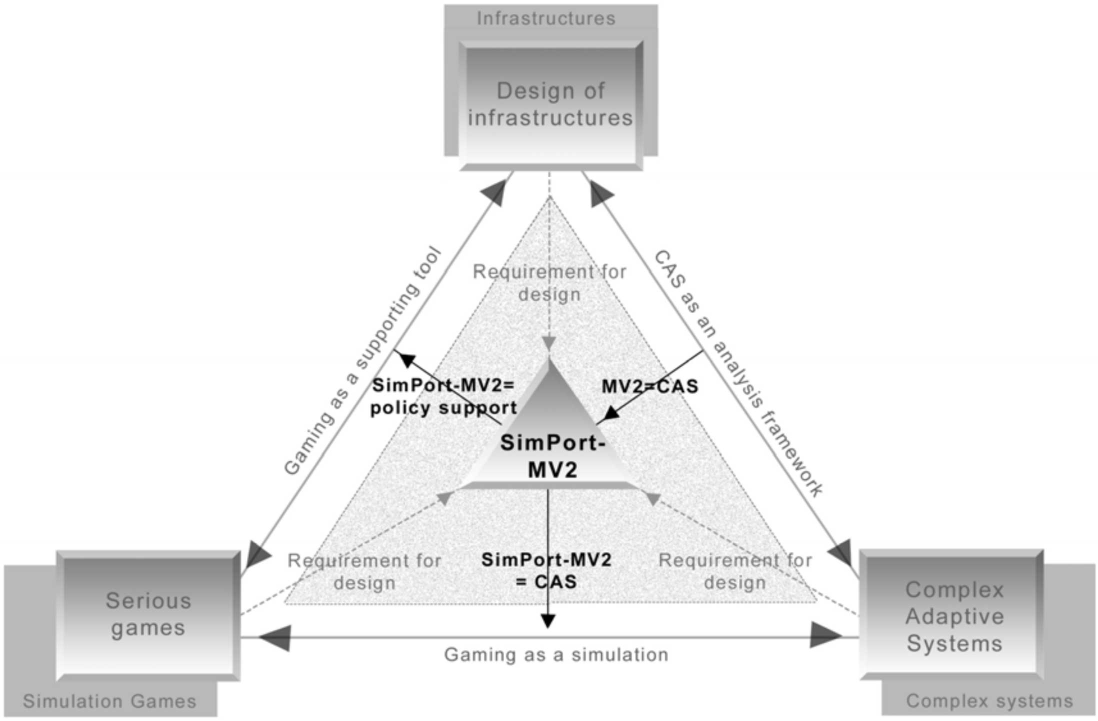

Figure 4-7. Case chapters related to the research framework

Chapter 5 starts with the explanation of the Maasvlakte 2 project as a complex system based on the characteristics of design of infrastructures and concepts of Complex Adaptive Systems. Second, an explanation is given for why a serious game has to be developed. In Figure 4-7 this is the arrow MV2 = CAS.

This chapter is followed by a chapter about game design, the triangle in Figure 4-7. Chapter 6 thus discusses the choices that have to be made in order to develop a playable game which is still a realistic simulation of the complex adaptive system Maasvlakte 2.

Chapter 7 describes the game SimPort-MV2 as a Complex Adaptive System (arrow SimPort-MV2 = CAS), based on the output of the game related to the complex adaptive system framework.

In Chapter 8, the use of gaming for policy support is analysed. This is based on the individual learning about CAS and MV2 by the players. The elements which could influence the learning are also discussed. (In Figure 4-7 this is the arrow SimPort-MV2 = policy support.)

By adopting different perspectives on describing the development and play of a simulation game and by using different methods to collect data and ways of analysing the data, we tried to give a broad overview of the possibilities and the limitations of using games to understand complex adaptive systems, especially as related to infrastructure systems. In the final chapter, the conclusions are summarized and recommendations are given which could be used to improve the use of gaming for serious purposes.

5. MAASVLAKTE 2: FROM OPEN SEA TO PORT AREA

> In his speech at the Top conference Maasvlakte 2 on 12 December 2007, the Alderman of Economy, Port and Environment of Rotterdam, Mark Harbers, was happy to say 'we managed it'. He meant that the designed zoning plans were open for participation. Next, he described a brief historical overview. He said that at the start of the preparation of the PKB+ PMR in October 1997, they had come up with the idea to start building in 2000. It is clear that they did not manage that, and the building has not yet begun.
> (Harbers, 2007)

Introduction

The Port of Rotterdam (PoR) in The Netherlands, between Rotterdam and the North Sea and adjacent to the *Nieuwe Waterweg*, is one of the largest seaports in the world. Projections of demand indicate that greater quantities of cargo will have to be handled, from 5 million TEU in 2003 to 13 million TEU in 2020, and between 25 and 40 million TEU in 2040. Furthermore, many more commercial enterprises want to locate in the immediate area of the port (Gemeente Rotterdam, 2004). Estimates suggest that the available space in the Port of Rotterdam will be fully occupied by 2010, making it impossible to meet any further space demands. The recognition of the capacity problem by the Dutch government in 1997 led to the start of the Rotterdam Mainport Development Project (PMR, an abbreviation of the Dutch name *Project Mainportontwikkeling Rotterdam*). The objective of this project is to extend the port area and to improve the environmental quality of Rotterdam.

The Maasvlakte 2 land reclamation project, a subproject of the PMR, is the leading case in the empirical analysis of the use of serious gaming for understanding complexity. This chapter introduces the Maasvlakte 2 project from the perspective of complex adaptive systems. Based on this perspective, several possible dilemmas for future construction and exploitation of Maasvlakte 2 can be identified. We go on to argue why serious gaming can be a valuable tool for exploring the consequences of a number of decisions and for encountering possible dilemmas.

Because complex adaptive systems are based on the historical evolution and interaction with the environment, this chapter starts with a short overview of the co-evolving growth of the port area (Section 1) and the decision-making process of the Rotterdam Mainport Development Project (Section 2). In Section 3, the processes surrounding Maasvlakte 2 are described.

5.1 The co-evolution of the Port of Rotterdam

The Rotterdam Mainport Development Project (PMR) is the most current project in a long history of developments of the Port of Rotterdam. Because the decisions being made now are based on earlier activities, we briefly introduce some major steps of the development of the Port of Rotterdam. The first port activities date back to the 13th century. Since that time, the area has developed in several steps and became the largest port for many years. In 2008 the Port of Rotterdam was the fourth largest harbour in the world after Shanghai, Zhousan (both in China) and Singapore (Havenbedrijf Rotterdam N.V., 2009a) and the largest in the Hamburg-Le Havre region with a market share of 35% and a throughput of 421 million tons in 2009 (Port of Rotterdam, 2009). It can be said that the evolution of the Port of Rotterdam has been a co-evolving process because of the influence of other systems.

5.1.1 From the 13th century through the 1970s

In the 13th century, dams were built along the River Meuse to reduce the intrusion of salt water from the sea and to protect the land against flooding. Consequently, there was an opportunity to transport cargo from one side of the dam to the other side. This spot became a perfect place for trade and led to the development of the city of Rotterdam. In the 16th century, Rotterdam also became the place to unload the merchant ships from South America and the Dutch East Indies.

The rapid growth of the port area began in the 19th century, as a result of three developments in the area: the rise of industry in the Ruhr area in Germany, the canalisation of the Meuse (*Nieuwe Waterweg)* river (in 1872) and the *Akte of Mannheim* (1868), an agreement which opened the Rhine for shipping. Between 1920 and 1940, the port was extended with the *Waalhaven* and *Merwehaven* followed by the *Eemhaven* in the '50s and the *Botlek* to meet the demand of the petroleum industry. The Port of Rotterdam built the *Europort* in the 1960s, which made the port accessible for super tankers. Finally, the expected growth of the petroleum sector led to the building of the Maasvlakte, which is now called Maasvlakte 1. The first ship entered Maasvlakte 1 in 1973 (see Figure 5-1).

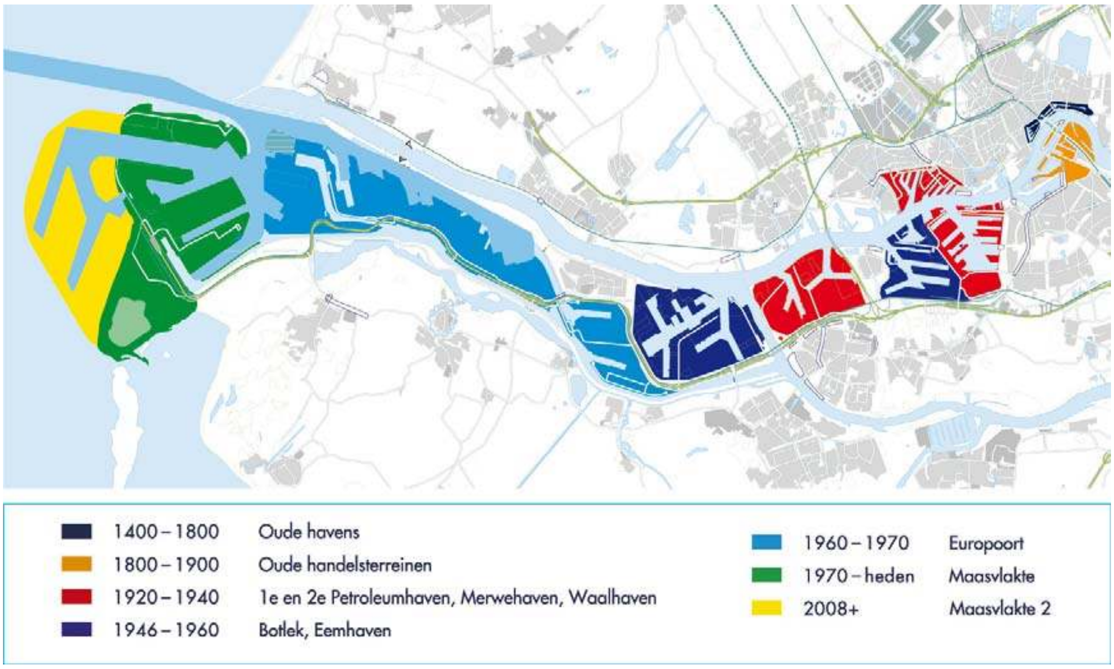

Figure 5-1. The historical growth of the port of Rotterdam (from www.portofrotterdam.com)

The development of the PoR can be described as a co-evolving process, where an originally small system has grown gradually, based on the changing environment, into what it is today. The first growth activities were inspired by changes in accessibility of the sea and river. Later, increasing activities were stimulated by the rise of industries. Each step in the growth process was an adaptation or expansion of existing infrastructures and land use. In the 20th century, the port area was extended from Rotterdam towards the west up to the coast, which made further growth impossible except by reclaiming new land.

5.1.2 The process of co-evolution continues

The development of Maasvlakte 1 (MV1) was not the end of the co-evolving process of the Port of Rotterdam. Since the completion of MV1, discussions about Maasvlakte 2 (MV2) have started. This discussion stalled after the stagnation of the growth of the Port of Rotterdam due to the oil crisis, which resulted in hardly any new parcels being rented. Consequently, the new MV1 areas remained empty for many years (Kuipers, 1999). The trigger for restarting the discussion was the strong increase of container throughput from the growing economies in Asia and Brazil. A result of the capacity shortage and growing demand, the Maasvlakte 2 is just the next step in the evolving process.

The Port of Rotterdam has some experience with land reclamation, gained from the MV1. However, the decision-making process around MV2 shows some differences.

The first difference is that the building of MV2 has a purely economic reason, while MV1 was also needed to fulfil the requirements for a new harbour entrance.

A second difference is the influence of stakeholders in the decision-making process. In the MV1 project, the project team consisted of many engineers, with less involvement of other actors, while the MV2 project has to deal with many different types of stakeholders. One group of stakeholders is environmentalists. Environmental issues were not a priority in the decision-making process of MV1, whereas in the decision-making process of MV2 an Environmental Impact Assessment had to be written and approved by the government, and the effects on natural resources will have to be compensated.

Finally, to avoid unnecessary investments in land reclamation, the Port Authority will first need to search for a more efficient use of the existing port area and phase the building of new parcels (Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, Ministerie van Financiën, Ministerie van Economische Zaken, & Ministerie van Landbouw Natuur en Voedselkwaliteit, 2003). They learned from MV1, when the new land remained vacant when the demand for space stagnated.

The knowledge of earlier experiences, the changed environment and a shortage of space were taken into account in the Rotterdam Mainport Development Project.

5.2 Rotterdam Mainport development project

The double objective of the Rotterdam Mainport Development Project is to increase capacity and improve the quality of the environment. This project can be considered a large infrastructure project, where many public and private organizations have different stakes in the development of the Port of Rotterdam.

5.2.1 A short project overview

The Port of Rotterdam needs to continuously develop in order to remain the leading port area in Northwest Europe. Limitations to growth in the existing area have been on the agenda for a long time. As early as 1993, the possibilities for extension were written down in the ROM Rijnmond covenant, signed by 23 public and private organizations (Programmabureau ROM-Rijnmond, 1993). In the covenant, the organizations also agreed to search for an appropriate equilibrium between the strengthening of the Rotterdam Mainport and improving the environment. With this two-fold objective, the organizations showed their intention to deal with economic and environmental issues.

Based on the ROM-project, the Exploration of Spatial Shortage in the Rotterdam Mainport (*Verkenning Ruimtetekort Mainport Rotterdam*) was started in 1996. The objective was to investigate the use of space and the urgency of the shortage. The conclusion of this exploration was that the current space is insufficient to deal with the growing demand of the chemical, container and distribution sectors. The PoR will face a shortage of space before 2020, and this will have consequences for employment levels and added value for business in general, and the transportation and distribution sectors specifically. The PoR needs to expand to maintain its position in the world market. On 14 July 1997, the Dutch House of Representatives decided in favour of the Spatial Shortage in the Rotterdam Mainport project (Tweede Kamer der Staten-Generaal, 1997).

The same two-fold objectives were described in the Port Plan 2020 (*Havenplan 2020*) of the municipality of Rotterdam (Gemeente Rotterdam, 2004). Their ambition for the PoR is to gain and maintain a strong international position. The PoR has to become a high quality area which can deal with future international developments. This ambition was translated into the objectives to strengthen the internal position of the port and industrial area, to contribute to the economic structure of the city of Rotterdam and its surroundings, and to contribute to a better living environment and spatial quality.

These three documents led to the start of the Rotterdam Mainport Development Project (PMR). The PMR took over the two-fold objective, which meant that the economic activities and the quality of the area became equally important.

In The Netherlands, each large infrastructure or spatial planning project must have a Key Planning Decision (PKB, or *Planologische Kernbeslissing*). The PMR started with the procedure of the PKB$^+$ Rotterdam Mainport Development Project (PKB$^+$ - PMR) in 1997 (see Table 5-1 for the timeline). The plus in the PKB$^+$ means that concrete policy decisions about the benefits and necessities of the project and its actual realization have been set down. These policy decisions are binding for other governmental organizations and stakeholders. Because of the size of the project, an Environmental Impact Statement (MER, or *MilieuEffectRapportage*) was also required.

Table 5-1. Timeline of the PKB PMR procedure

Activity	Year
Memo Startnotitie PKB+/m.e.r Mainport Ontwikkeling Rotterdam	1997
Publishing PKB+ PMR part 1/MER PMR	May 2001
Publishing PKB+ PMR part 2	14 November 2001

Published PKB+ PMR part 3a Kabinetsstandpunt	21 December 2001
Second Chamber agreed with the Kabinetsstandpunt of the PKB+ PMR part 3	25 April 2002
Publishing PKB+ PMR part 4	1 September 2003
Council of State decided that appeals are based	26 January 2005
Publishing revised version revised PKB PMR part 4	September 2006

In the *Startnotitie PKB$^+$/m.e.r Mainport Ontwikkeling Rotterdam* (Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, Ministerie van Economische Zaken & Ministerie van Landbouw Natuur en Visserij, 1998) the process of the PKB-procedure was set down, including moments of stakeholder participation. This was followed by the PKB$^+$ PMR Part 1/MER PMR in 2001, where a set of measures and different alternatives were compared for the criteria of nature, recreation, environment, landscape, economy, space, traffic and transportation, safety, sea and coast, and finance. The Dutch Cabinet delivered the following opinion (Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, Ministerie van Landbouw Natuur en Visserij, Ministerie van Economische Zaken, & Ministerie van Financiën, 2001):

- Reinforce the position of The Netherlands as an international trade and industry country and assume the strong points of the Dutch economy to be a given,
- Create requirements for new likely clusters, like building on existing clusters,
- Choose sustainable development and continue to pay attention to improvements of the environment, especially in the Rijnmond Area,
- Do not adopt a ‘wait and see’ attitude, but be pro-active in innovation.

Further, the Cabinet concluded that the existing space is inadequate to deal with the expected demand and that this problem is urgent, considering the long decision-making process. To reach the objectives and reduce the shortage of space, the Cabinet created space for three projects: better use of the Existing Port Area Rotterdam, land reclamation: Maasvlakte 2, and 750 ha Nature and Recreational Area.

After publication, stakeholders were able to respond to the content of the MER PMR and PKB$^+$ PMR. Several public hearings were organized for a verbal explanation of stakeholders’ comments. The results of the participation, together with the managerial consultation, the advice of the MER Commission and their legal advisors, and supplemented research, were summarized in the PKB$^+$ PMR part 2.

In the Statement of the Cabinet (PKB$^+$ PMR part 3a), the Cabinet decided that the three projects, as described in the PKB$^+$ part 1, have to be realized together to safeguard the two-fold objective. Each subproject will have a separate realization plan and timeline. The Cabinet was aware of the uncertainties of the project; however, they decided to arrange PKB^+ PMR and gave permission to expand the port's activities with a phased land reclamation project, following market demand. The opinion of the Dutch Cabinet about the project was submitted to the House of Representatives for approval. On 25 April 2002, the House of Representatives agreed with the Statement of the Cabinet.

The final decision, together with the concrete policy decisions for the Rotterdam Mainport Development Project, was described in PKB^+ PMR part 4. In this part, all policy decisions were determined. After publication, stakeholders had the opportunity to lodge appeals with the Council of State, Department of the Administration of Law (*Afdeling Bestuursrechtspraak van de Raad van State)* against the concrete policy decisions. Many organizations did this. On January 26, 2005 the Council of State decided that appeals had a legitimate basis. The concrete policy decision about land reclamation, the search for a sand extraction area and the 750 ha Nature and Recreation project were upheld. Further, the appellants asked for a concrete policy decision related to the Sea reserve to assure the compensation of damage caused by the land reclamation project over the long term. Consequently, the PKB^+ PMR had to be revised.

In September 2006, the revised PKB PMR part 4 was sent to the House of Representatives (Ministerie van Verkeer en Waterstaat & Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, 2006). The most important change, compared with the earlier version, was to change the concrete policy decisions in decisions of vital importance (*beslissingen van wezenlijk belang*). The changes were supported by additional research into the effects of the land reclamation on the Wadden Sea and into the consequences of nature preservation projects for the farmers. Due to changes in the procedures governing large projects, two additional assessments were needed: the Strategic Environment Assessment (*Strategische Milieubeoordeling*) and the Suitable Assessment of Land Reclamation (*Passende Beoordeling Landaanwinning*). These assessments were included in the revised PKB PMR.

In total, the PKB procedures took around eight years and will hold for 15 years. In the process, several decisions were made which reduce the solution space of the development. For example, three subprojects were defined which have to be sufficient to reach the long-term desired end situation. Furthermore, the two-fold objective remained, and several requirements were set for the design of the land reclamation.

5.2.2 Reducing the complexity: three sub projects

The PMR project was split into three subprojects: better use of the existing port area, Maasvlakte 2, and the 750 ha Nature and Recreational area (see Figure 5-2). This combination guarantees the two-fold objective of stimulating economic growth and improving the environmental quality. Furthermore, by giving the subprojects their own budget and timeline, they are easier to manage. The Maasvlakte 2 subproject is split into land reclamation and nature compensation. The nature compensation is additional to the 750 ha Nature and Recreational Area. Although the projects are split, they are still dependent upon each other. For example, the land reclamation can only start when there is sufficient progress in the other projects.

The division of responsibilities, finance, monitoring and evaluation of the projects are written down in the *Bestuursakkoord PMR* (*Bestuursakkoord inzake uitvoering van het Project Mainportontwikkeling Rotterdam*, 2004). This agreement was signed on 25 June 2005 by the partners involved: the Dutch State, the province of South Holland, the city region of Rotterdam, the municipality of Rotterdam and the Port of Rotterdam. For each project, the responsible partners had to agree on the procedures, risks, finances and responsibilities within the subproject in execution agreements (*Uitwerkingsovereenkomst*). Each of the agreements was signed on 2 September 2005.

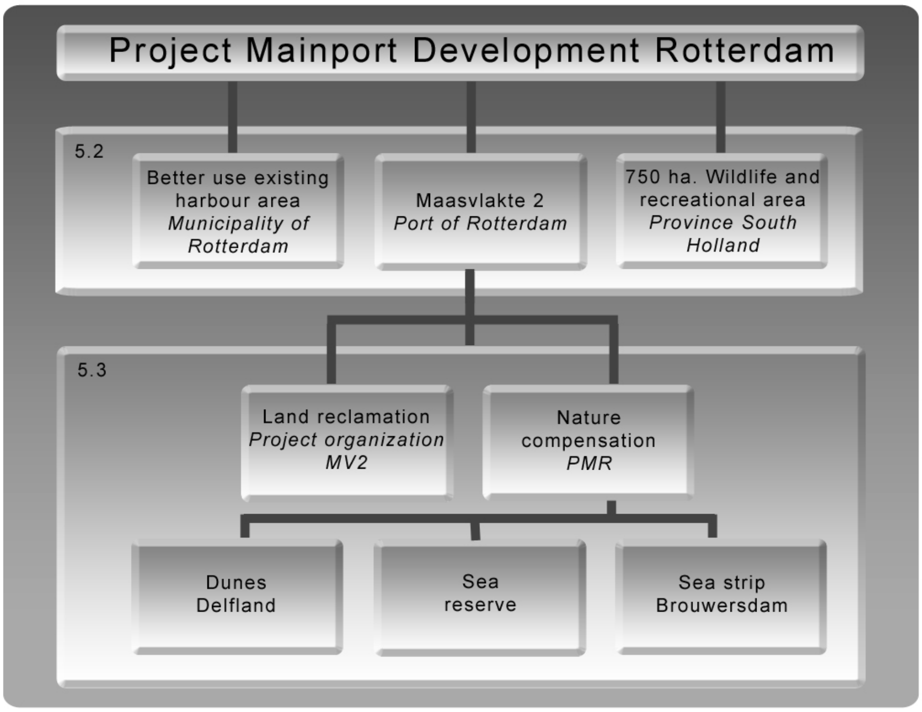

Figure 5-2. Project Mainport Development Rotterdam, with the land reclamation of Maasvlakte 2 being one of the subprojects (www.portofrotterdam.com)

Better use of the existing port area

The ambition of the subproject 'better use of the existing port area' is to make more intensive use of the existing Rotterdam Port area and to improve the living quality with quality of life projects[7] (Municipality Rotterdam, Kingdom of The Netherlands, Province South Holland, & City Region Rotterdam, 2005). The project considers the existing harbour and industrial area in the municipalities of Rotterdam, Schiedam, Vlaardingen and Maassluis and does not aim to resolve the total shortage of space. In practice, intensification means placing more cranes, reclaiming small tracts of land, and relocating activities. The *quality of life* projects include reducing noise by placing sound barriers and limiting the decibels produced by new and growing business, and developing recreation areas and parks. This project is the responsibility of the municipality of Rotterdam. The projects must be finished by 2021, and the total costs are calculated to be at least € 48 million (2002 price levels) (Municipality Rotterdam et al., 2005 p.6).

Maasvlakte 2

The objective of the Maasvlakte 2 subproject is to reclaim 2000 ha of new land and compensate for the loss of flora and fauna on the seabed. The Port of Rotterdam is responsible for the land reclamation project. Because of the size of the project in terms of time and costs, they established a project organization MV2. This organization has responsibility for the design of master, zoning and building plans, as well as issuing tenders for contractors and builders, finding clients and managing all legal, political and environmental issues. The nature compensation project is coordinated by PMR, which must create a seabed protection area 10 times the size of the MV2 area. The total costs are estimated at € 2.9 billion. The State is contributing € 726 million (2011/2012 price level) to the project in two stages in 2011 and in 2012 (Kingdom of The Netherlands & Havenbedrijf Rotterdam N.V., 2005).

750 ha Nature and Recreational area

The third project is meant to improve the quality of life in the region of Rotterdam. The largest nature area will be developed between Rhoon en Barendrecht, the *Landschapspark Buytenland*. Other projects are replacing and enlarging the golf course of Midden-IJsselmonde, a new greenway for slow traffic, public transportation between Midden-IJsselmonde and Rotterdam-South and two nature areas developed on the north side of Rotterdam. The province of South Holland is leading this project. The ambition is to finish this project within 15 years of starting; however, high quality

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[7] http://www.maasvlakte2.com/en/project/mainportontwikkeling/existing_rotterdam_area/index.jsp, retrieved 10 April 2008

natural areas cannot be realized within this period. The total costs are calculated to be € 148 million (2002 price level), to be paid by the partners of this project (the Kingdom of The Netherlands, the province of South Holland, the municipality of Rotterdam and City Region Rotterdam, 2005).

5.2.3 Social environment

Stakeholders had different opinions about the necessity of the project, the solutions and the long-term consequences, and tried to influence the decision-making process. This meant that the decision-making process took place in a dynamic actor network in which the involvement of these actors was not equally divided over the years and influenced the process in different rounds.

In the first place, the Port of Rotterdam has a central role in the entire process. They face the capacity shortage and want to extend their activities to follow their mission to develop, in partnership, a world-class European port (www.portofrotterdam.nl). The Port of Rotterdam was a public organization but became a public corporation in 2004 with two shareholders: the municipality of Rotterdam and the Dutch State. Also involved in the problem statement period was the Dutch Cabinet. Together they decided about the urgency of the shortage problem and its importance for the public (Gemeente Rotterdam, 2004; Tweede Kamer der Staten-Generaal, 1997).

Five Ministries coordinate the PMR and are responsible for the preparation of the PKB and MER: *Ministerie van Verkeer en Waterstaat*[8], *Ministerie van Landbouw, Natuur en Voedselkwaliteit*[9], *Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu*[10], *Ministerie van Financien*[11], and *Ministerie van Economische Zaken*[12]. Finally, the Dutch Cabinet, the Dutch House of Representatives and the Senate decide about the PKB PMR and the subprojects.

The European Union was asked for advice after decision-making at the national level. The European Commission (EC) had to check whether the financial contribution of the Dutch government was not in conflict with the EC Treaty Law, Articles 87 and 88. They decided that the Dutch government is only allowed to support the construction of the outer contour (European Commission, 2007a, 2007b).

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[8] the Ministry of Transport, Public Works and Water

[9] the Ministry of Agriculture, Nature and Food Quality

[10] the Ministry of Housing, Spatial Planning and Environment

[11] the Ministry of Finance

[12] the Ministry of Economic Affairs

During the PKB procedures, stakeholders were able to participate and respond to the proposals and decisions. Many organizations used these opportunities to criticize the urgency of the problem or the negative consequences of the project. They were concerned that adequate attention might not be paid to their core values, such as environmental or business issues. For example, the surrounding municipalities were afraid of decreasing air quality, accessibility or visibility. The province of Zeeland looks after the position of the Port of Vlissingen and the visibility of the coastal area. Other complaints came from farmers who would be forced to move or change their businesses because of the nature projects. And many reactions came from environmental organizations, which worried that the environmental issues had been ultimately removed from the agenda. Finally, some protest came from fisheries, such as the Dutch *Vissersbond*, *Productschap Vis*, and *Stichting Noordzee*, who demanded that attention be paid to the fish stock and fishing area.

Complex social-technical system

The PMR is an illustration of a complex, socio-technical infrastructure system. On the one hand, many different stakeholders were involved in lodging complaints against decisions or participating in informational meetings organized by the project partners. The appeals of the opponents delayed the process, sometimes setting the process back, including delays in decision making and the binding judgment of the Council of State. Organizations also behave strategically, for example by lodging an appeal against the PKB or a permit, followed by contacting the Port Authority to negotiate about a solution. If a solution is found, the appeal is withdrawn. The late agreement between the Port of Rotterdam and *Milieu Defensie* about CO_2 reduction is an example of this behaviour.

On the other hand, the project contains many physical aspects of constructing a new area and its consequences on the natural environment, but also involves industrial activities and transportation. Much research had been conducted into expectations and the precise urgency of the future problems as well as the consequences of different alternative solutions.

Now that all of the hearings, complaints and revisions of the PKB and MER are over, the decision-making process of the PMR is finished and approved. The execution of the three projects is under the authority of different organizations, each with its own timeline and budget. The PMR has to coordinate and control the progress and tuning of the projects. This reduces the complexity of the projects and safeguards the two-fold objective of the PMR. Yet this does not mean that the subprojects are simple; in each project, characteristics of complexity can be found. The subproject Maasvlakte 2 is further explored below.

5.3 Land reclamation: Maasvlakte 2

A closer look is given here to the processes around the subproject Maasvlakte 2. Maasvlakte 2 (MV2) is a new, to-be-reclaimed land area of 1000 ha, which constitutes an extension of 20% to the existing port area. MV2 must become a deep sea and prime location, with a short turn-around time for vessels and an excellent transhipment hub (ie. sea to sea transhipment). Based on the prognoses, the 1000 ha for port and industrial activities are divided over three sectors: 625 ha for container terminals, 165 ha for distribution and 210 ha for the chemical industry. Parts of reclaimed land is needed for infrastructure, the sea wall and recreational areas. In the planning, MV2 must be finished and fully occupied by around 2037.

The process of realizing MV2 had already begun in 1993, and in 2004 it was clear that MV2 was going to be built. This started a phase of decision-making processes around the construction and exploitation. In this section, the three main processes and decisions surrounding the land reclamation project MV2 are introduced: 1) the legal procedures and permissions, 2) the design of the lay-out of the land reclamation and 3) the processes of contracting builders and contracting clients.

5.3.1 Procedures and permission for the land reclamation project

In addition to the PKB and MER for the PMR, several procedures needed to be started, and several permits had to be granted for Maasvlakte 2. The permits and other documents were the outcome of research and negotiations. Consequently, several additional criteria were defined. The main obligations and permissions were the EU requirements, the Environmental Impact Assessments, the zoning plans and permits.

EU - Natural Habitat Directive advice

The Port of Rotterdam was obliged to ask the European Union for advice on the effects on the Nature 2000 zones caused by the land reclamation, Article 6, Paragraph 4, of the Council Directive 92/43/EEG[13] (Natural Habitat or Natura 2000). The conclusion of the European Commission was that 'the expected change of the habitat structure and frequency of appearance of the species influence the total coherence of Natura 2000 and (…) needs to be compensated appropriately' (Commissie van Europese Gemeenschappen, 2003 p.7). Further, the Commission noticed that the phased construction of the land reclamation project is essential. In case of unexpected

[13] 21 May 1992, the conservation of natural habitats and of wild fauna and flora

consequences for the Natura-2000 zones, compensation can be provided (p.9). The proposed set of measures is sufficient as a compensation for the effects of the land reclamation project, with the condition that they be implemented with the same speed as the phasing and that a management plan be used to assure long-term effectiveness.

MER – Construction and MER – Use

Two MER studies had to be conducted for the determination of the environmental effects of the construction and the use of MV2, respectively the MER-A (*MER-Aanleg*, or MER-construction) and the MER-B (*MER-Bestemming*, or MER-use). MER-A was necessary for the decision of the Ministerie van Verkeer en Waterstaat about the concession for the land reclamation and sand extraction. MER-B supported the design and zoning plan by the Municipality of Rotterdam.

In MER-A it was argued that the phasing of the outer contour is not necessary. Due to the changing lay-out of the outer contour (see 5.3.2), the reduced uncertainties of the effects on nature and sufficient market demand for deep-sea related industry (Berkenbosch, 2007 p.13), the phasing of the outer contour will not be done since it only increases the costs. However, the internal land areas will be constructed according to market demand. In addition, a sea reserve will need to be defined with a size of 25,000 ha in the *Voordelta* for the compensation of the loss of a 2,500 ha of sea area.

The MER-B was necessary because Maasvlakte 2 is a business park with a size greater than 150 ha. It has significant infrastructure facilities such as rail, road and pipeline, and is a recreation area with more than 225,000 visitors a day. In the MER-B, four lay-out alternatives were compared for three different scenarios of client distribution. The result of the comparison was that in order to develop a sustainable port area, 1) industries have to be clustered, 2) road transportation has to be discouraged, 3) industries have to try to exchange minerals, residues, and residual heat and 4) control and maintenance have to be provided in a sustainable way (Projectorganisatie Maasvlakte 2, 2007b).

After publication, questions and comments were gathered. These were answered and written down in the memorandum ‘Further explanation on questions and remarks commission MER November 2007’ (*Nadere toelichting op vragen en opmerkingen Commissie MER November 2007*) (Projectorganisatie Maasvlakte 2, 2007a). The judgment of the MER commission was that ‘all essential information is available in the *MER-Aanleg*, *MER Bestemming* and the memorandum’ (Commissie voor de milieueffectrapportage, 2007 p.1). With this judgment the MER A and B will be able to be used further in the decision-making process.

Zoning plan Maasvlakte 81 and Maasvlakte 2

Before functions could be assigned to Maasvlakte 2, a zoning plan for Maasvlakte 2 (*Bestemmingsplan Maasvlakte 2*) was required. The zoning plan determines the different functions of the area, which consist of commercial use of container terminals, chemical industry, distribution centre, transportation, outer contour with the possibility of building wind towers on it, outer contour with a recreational function, water (dock basin) and sea (North Sea).

Furthermore, the existing Maasvlakte 81 Zoning Plan had to be revised, because the land reclamation will lie partly within the area having the function 'sea' in the Maasvlakte 81 Zoning Plan. Also, a revision of the Sea Area 1999 Zoning Plan was necessary because it had to include the noise contour of MV2. The municipality of Rotterdam approved the changes in the zoning plans on 22 May 2008.

Permits

The building of Maasvlakte 2 can only begin after several permits have been obtained for the building, sand extraction and environmental issues.

The Port of Rotterdam needs a granted concession pursuant to the Law of 14 July 1904, *houdende bepalingen omtrent het ondernemen van droogmakerijen en indijkingen* by the *Queen,* because the reclamation was not done by the State. This was approved on 23 May 2008 (Ministerie Verkeer en Waterstaat, 2008). Because the North Sea is a '*waterstaatswerk*' (public work element), permission according to the law *Beheer Rijkswaterstaatswerken* is needed for building. The Ministerie van Verkeer en Waterstaat approved this permit on 2 June 2008 (Ministerie van Verkeer en Waterstaat, 2008).

For the sand extraction, a permit for extraction (*ontgrondingsvergunning*), based on the *Ontgrondingswet* and the *Rijksreglement Ontgrondingen,* is necessary. On 18 April 2008, Ministerie van Verkeer en Waterstaat granted the permits for the sand extraction for a period until 2033 under the condition of a monitoring programme before, during and after the extraction.

Finally, two permits were granted for environmental issues. On 16 April 2008 the Ministerie van Landbouw, Natuur and Voedselkwaliteit granted exemption from the flora and fauna law. This was needed for the plant *Epipactis palustris (moeraswespenorchis)* and the animal *Bufo calamita (rugstreeppad)*. On 17 April 2008, the Ministerie van Landbouw, Natuur and Voedselkwaliteit quality gave the permit pursuant to the law of Nature Protection 1998 (*natuurbeschermingswet 1998).* This was based on the knowledge that there are no effects on the natural beauty or scientific value of the protected nature reserve; there are insignificant negative effects on the nature characteristics of a couple of the Natura-2000 areas: Haringvliet, Grevelingen and Oosterschelde. The significant effects on the Natura-2000 area Voordelta are sufficiently compensated.

Several complaints were lodged against the permits. To reduce the time for a legal procedure, agreements are made between the different appellants and the Port of Rotterdam. The agreement on a sustainable Maasvlakte between *Milieudefensie* and Port of Rotterdam is an example of this compensation (Havenbedrijf Rotterdam N.V. & Vereniging Milieudefensie, 2009).

The procedures and permits ensured that decisions were made carefully. The different types of procedures and many different organizations which approved or granted permits made this a complicated process. Although the permits are related to certain aspects, for example the building, use, sand extraction or nature compensation, they also relate to and are important for the total project.

The MERs, Zoning Plan and permits set several requirements for the construction and use of MV2 which contribute to the two-fold objective of the project. The phased outer contour is not necessary, but the internal land areas have to be constructed in phases based on the market demand. A sea reserve of 25,000 ha has to be assigned for the compensation of 2,500 ha lost due to the construction of Maasvlakte 2, and environmental effects of sand extraction and land reclamation have to be monitored. Furthermore, the Port of Rotterdam has to cluster industries and discourage road transportation to reduce environmental impact from the use of MV2.

5.3.2 Designing new land

The design process for the lay-out of the land reclamation began in 1995 with the development of a design for the environmental impact assessments (Ministerie van Verkeer en Waterstaat, 2000). Designers presented a budget design in which the costs were lower than the political target amount of 4 billion guilders (1999 price level). This became the reference design for land reclamation (Figure 5-3) which was used as an example for the operational design. Furthermore, the design was used in the PKB-PMR procedure, the MER PMR and as the upper boundary for environmental effects.

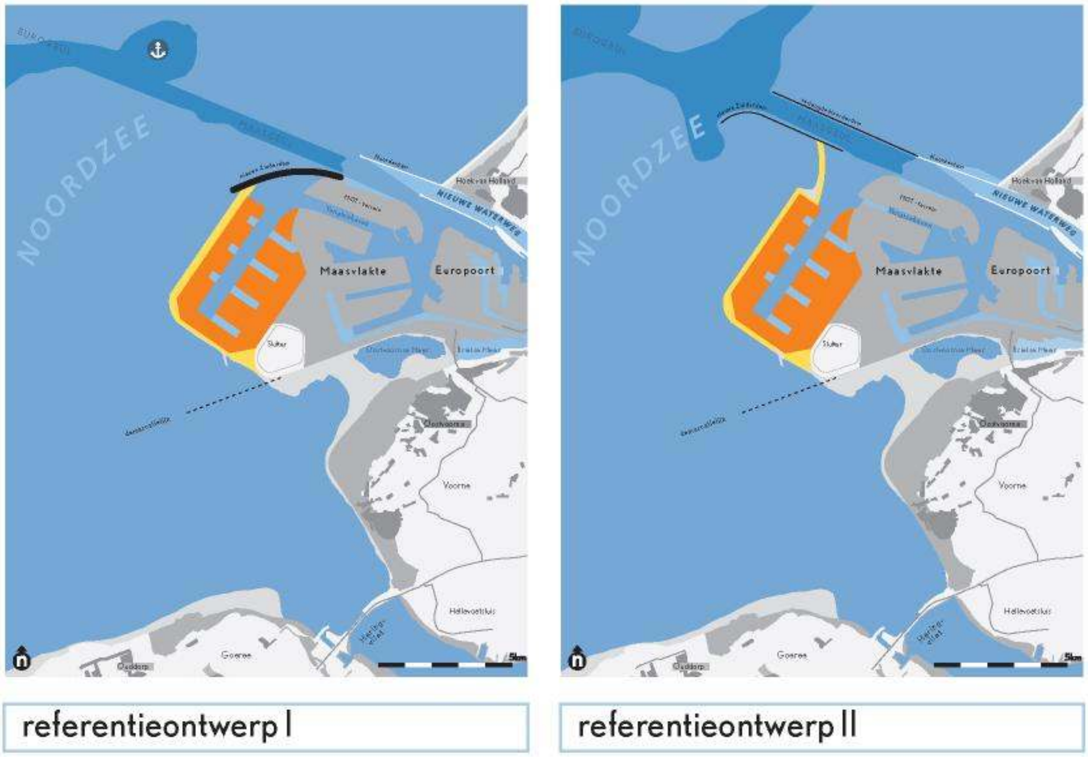


Figure 5-3. Reference designs of the Maasvlakte 2 area, with on the left side the entrance via Yangtze Harbour and on the right side an open entrance to the sea (Snoo & Fikken, 2004 p. 8)

In 2002 the PMR began an exploratory study of the effects of several design choices on criteria such as nautical accessibility and safety, lay-out and phasing possibilities, mitigation and compensation effects on nature, procedures, integrated planning and costs (Hellebrand & De Snoo, 2003). The studies of spatial planning and other procedures produced four variables for optimizing the reference designs: opening of the area, orientation of the soft seawall, opening up for inland shipping, and lay-out for placing activities (see Table 5-2).

In this study, an attempt was made to test the design variables on all the requirements and wishes written down in the PKB$^+$ PMR part 3, the Public Programme of Requirements, the Functional Programme of Requirements and the requirements of the experts. One of the outcomes of the exploration was that there were several conflicting criteria, for example, nautical accessibility and safety, or the flexibility of the coastal system and the investment and maintenance costs. In other words, there is no optimal solution, and each alternative has advantages and disadvantages (Hellebrand & De Snoo, 2003).

Table 5-2. Four important design variables for the design of the Maasvlakte 2, linked with several options for each variable (Hellebrand & De Snoo, 2003 p.35-37)

Design variable	Options
Opening to sea	Via opening Yangtze harbour Own opening via extended Maas mouth Own opening via Zuiderdam
Orientation soft seawall	Two walls with an angle of 90 degrees More or less stretched wall direction SE-NW
Inland opening up	Extending Yangtze harbour Enlarge Hartel channel
Lay-out	Activities land reclamation and MV1 clustered Activities land reclamation and MV1 separate

The conclusion of the study consisted of seven design choices. The final design has to be an area with a compact lay-out (see Figure 5-4 3), a streamlined design of the outer contour (see Figure 5-4 4) and an entrance via the Yangtze harbour (see Figure 5-4 1). The contraction point, the most seaward-lying point of Maasvlakte 2, which influences the water flow for the Maas entrance, has to be as far as possible from the Maas channel (see Figure 5-4 2). To reduce the effects of the land reclamation project on the Haringvliet entrance, the orientation of the soft sea wall must be south-east to north-west (see Figure 5-4 5), and a larger grain size has to be used in the bedding (see Figure 5-4 6). Last, concentrated activities at the eastern part of the land reclamation, next to Maasvlakte 1, have advantages for clustering and lowering the investment in infrastructures on Maasvlakte 2 (see Figure 5-4 7).

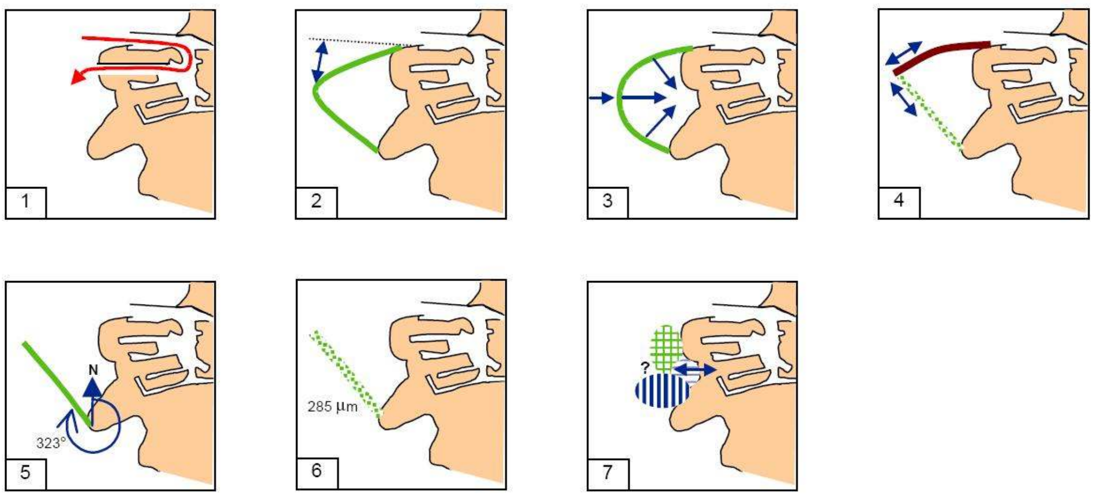


Figure 5-4. Preferential design choices based on the Exploration Design Space research (Hellebrand & De Snoo, 2003)

The PoR draws up the cut-through alternative (*doorsteekalternatief*), based on the research of the design choices. One important reason for choosing the entrance via the Yangtze harbour is the lower investment and maintenance costs. In the first construction phases, new areas are built next to Maasvlakte 1, so MV1's facilities can be used. These preferences lead to the following design (Figure 5-5). The internal lay-out of the MV2 is not fixed; this is dependent on the launching customer and the demand for space. This alternative is used for the calculation of the Business Case, the assessment for the requirements of the PKB^{+} PMR, the public programme of requirements, the EU Birds and Habitat Directive and technical feasibility.

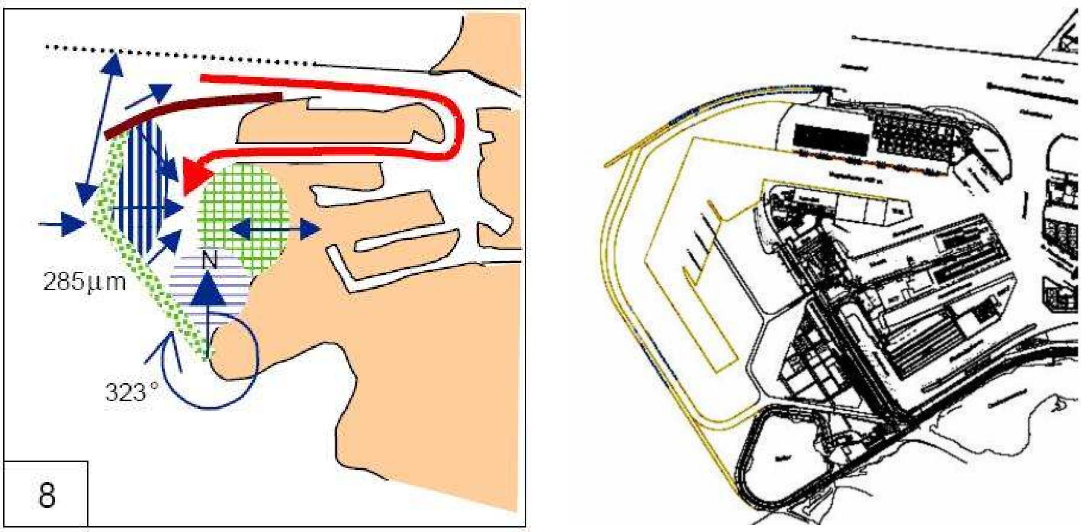


Figure 5-5. The lay-out of Maasvlakte 2 based on the preferred design choices (Snoo & Fikken, 2004 p.30 and p.31)

After defining the outer contour, discussions about the optimization of the inner lay-out began. This led to a new design '*doorsteekvariant Masterplan 1*' in 2004 (see Figure 5-6). This design changed slightly in 2007 to increase the length of the quays (Figure 5-7).

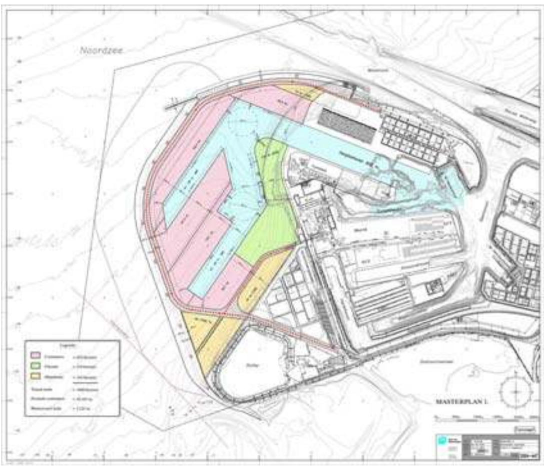


Figure 5-6. The coloured part shows the boundaries of the land reclamation project Maasvlakte 2. The pink areas are the parcels reserved for container terminals, the green areas are the parcels for chemical industry, and the yellow areas are for distribution (Port of Rotterdam, 2004).

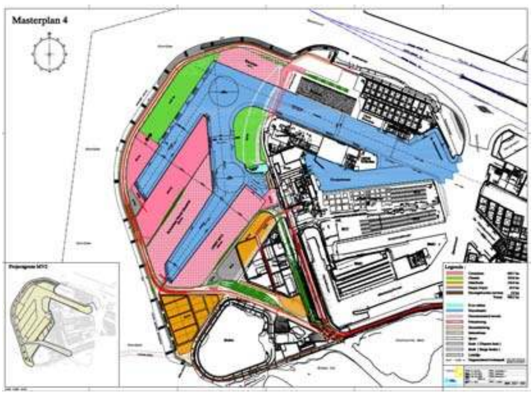


Figure 5-7. Latest design, with some minor changes in comparison with Masterplan 1, which increased the length of the quays (Port of Rotterdam, 2009)

The design of MV2 is evolving over time and follows a technical system perspective. The technical requirements, costs, and Business Case are leading criteria for the design. The effects of the design on other criteria such as safety and nature are tested afterwards.

5.3.3 Flexible and controlled development

The next step is the process of selecting a contractor and defining procedures for contracting clients. Based on the experience of MV1 and the list of requirements followed from the decision-making process, the Port of Rotterdam would like to have more control over the development and be more flexible to adapt to changes in the environment.

Building Maasvlakte 2

The final lay-out of MV2 is defined by the Port of Rotterdam and agreed to by the State. The additional costs of changing this design are borne by those who propose the changes. Next, the Port of Rotterdam decides which tender procedure is chosen, with the requirement that the contractor must develop an innovative construction (*Bestuursakkoord inzake uitvoering van het Project Mainportontwikkeling Rotterdam*, 2004).

The Port of Rotterdam opted for a design and construction contract, which means that a functional programme of requirements was tendered. The European tender process for the first phase started in September 2005. This tender consists of 2.4 km hard sea wall (stones), 8.4 km soft sea wall (sand), 700 ha of port area, 2 km deep sea quays (-20 m), and 1 km barge / feeder quays (-11/-13 m), dredging the dock basins, construction of the infrastructure (11 km roads and rails) and the maintenance of the sea wall for the first five years. The criteria were price, building time and sustainability. Of three qualified consortia of builders, the PUMA consortium, consisting of *Koninklijke Boskalis Westminster BV* and *Van Oord Dredging and Marine Contractors BV*, won the tender. They started building on the 1st of September 2008, with the expectation of finishing the first parcels in 2012.

Depending on market demand, the Port of Rotterdam will be able to start the second tender procedure for the second phase.

Negotiation with clients for Maasvlakte 2

As agreed upon in the PKB PMR, Maasvlakte 2 will be built for deep-sea related activities, and the basins, with a depth of NAP -20 metres, will make the port accessible for the newest generation of containerships. Because the Port of Rotterdam needs to find clients that fit this deep-sea related profile and influence the agreements in the contract, they followed a tender process for the first client.

Beginning in 2005, the Port Authority published an open call for interests for the first terminal on Maasvlakte 2. The open call consisted of three phases: pre-qualification, qualification and negotiation. In the pre-qualification phase, the ambitions and intentions of the candidates were collected and the candidates were assessed on their experience. In the qualification phase, the candidates sent a business proposal based on the bid and these were assessed on four criteria (see Table 5-3).

Table 5-3. Explanation of the criteria for the bidding process of the first terminal

The criteria for open assessment
▪ Financial (counts for 40%): Fee for the use of the terminal, the expected amount of transhipments. If the realization differs from that expected, there will be a no-claim bonus system. This means extra income from port dues is shared with the company who exploits the terminal, or terminals pay a percentage of the missed port dues when the realization is lower. ▪ Strategy and Marketing (25%): Role of the terminal in the European and worldwide market and the extent of the contract load and carriers. ▪ Sustainability (20%): The modal split (percentage of hinterland transportation via rail and inland shipping in relation to road transport), emission of noise, light and air pollution. ▪ Terminal concept (15%): Productivity of the terminal, efficient design for handling of diverse transportation and the materials used.

In the negotiation phase, the Port Authority exchanged information with five candidates, which was used for the final bid. The Rotterdam World Gateway consortium, consisting of the stevedore DP World and four carriers, submitted the best offer and was contracted for a terminal size of 156 ha and a capacity of 4 million TEU operational in 2013. In the meantime, APM terminals also started negotiation and signed a contract for a terminal of 167 ha and a capacity of 4.5 million TEU, operational in 2014.

In both cases, the Port of Rotterdam aimed to have more control over finance and strategy, but especially over sustainability. For example, agreements are made about the terminal design and modal split. For now, the PoR follows the strategy that only contracts which fit the strict requirements of sustainability are signed.

The building and exploitation process are strongly related. In the first place, building can only start when the first client is contracted. Furthermore, building can continue when there is sufficient demand. This integration increases the flexibility of the system, because it is easier to adapt to a changing environment. At the same time, it makes the process and coordination more complex.

5.3.4 The future: further exploitation

The permits are granted, the first clients have been contracted, and on September 1st 2008 construction began (Van Haastrecht, 2008). However, the project is not finished. There are many questions about what will happen in the future. For example, how can the PoR ensure that the building decisions made today will not be regretted 10 or 20 years from now? Is it feasible to reject less profitable clients when there is less overall demand for land, especially in the early years of exploitation? How can the PoR attract lukewarm but interesting and profitable clients? What if client demands are not in accord with allocation or zoning plans? How is the coordination between different departments responsible for different processes in the project? And how should one deal with changes in the environment which influence the demand for space and thereby the expenditures and income?

In the decision-making phase, several questions were already answered and set down in documents, such as the requirement of starting with the second building phase. However, changing political and economic climates may provide an excuse to restart discussions about either the benefit and necessity of the reclamation or the agreement on the management and maintenance of the outer contour, which will be passed on to the Dutch State after ten years whereas the responsibility of the land areas, infrastructures and quays lies with the Port of Rotterdam (*Bestuursakkoord* *inzake uitvoering van het Project Mainportontwikkeling Rotterdam*, 2004; Kingdom of The Netherlands & Havenbedrijf Rotterdam N.V., 2005).

Other questions are not so easy to answer. For example, in what way will client demand develop? The Port Authority has defined strict requirements for the activities surrounding Maasvlakte 2, in order to fulfil environmental requirements and to guarantee income. In 2008, two consortia of clients were contracted. The prognoses for the future were optimistic. However, what happens when demand lags behind predictions, for example, as occurred when the transfers in the first quarter of 2009 declined (Havenbedrijf Rotterdam N.V., 2009b), or when clients are not interested because of the strict requirements? The long term nature of the project makes prognoses uncertain. Although many decisions have been made, there are still uncertainties for the future and it is unknown what their effects will be on the performance of MV2.

5.4 Maasvlakte 2: a complex infrastructure project

The start of the PMR was a milestone in the history of the development of the port area. It was also the start of a large and complex decision-making process. The ministry of Transport, Public Works and Water called this project a 'complex matter', because of the diverse social and economic values that come together in the project, reflected in the large number of organizations, commercial companies, governments and citizens (Ministerie van Verkeer en Waterstaat et al., 1998).

5.4.1 Maasvlakte 2 as a complex adaptive system

In Chapter 2, a complex adaptive framework was developed, which can be used for describing the complexity of the Maasvlakte 2 system. Maasvlakte 2 has characteristics of complex adaptive systems, and by taking this complex systems perspective, dynamics and future behaviour can be explored.

If we take the geographical and project boundaries of Maasvlakte 2 as the system boundary, then this system is an open system and is related to several other systems such as the PMR project as well as the entire port. Maasvlakte 2 is influenced by and affects the environment, including the economy, the natural environment, water and transportation. This environment is dynamic, and these dynamics are uncertain. The growth of the container market, the attention to environmental issues, and technical developments are all subject to change during the development of Maasvlakte 2. The Port of Rotterdam has to make decisions about the development of the MV2 in an uncertain environment. For example, between 1987 and 1997, the focus changed from a shortage of space for chemical industries to a shortage for the container sector (*Tweede Kamer der Staten-Generaal*, 1997 p.5). Then, after several years of increasing transfers, the beginning of 2009 showed a decrease.

Second, the Maasvlakte 2 system itself consists of many different subsystems and active elements. Subsystems include construction, exploitation, legal procedures and transfer of goods. Each of these systems is based on the relations between diverse physical elements, such as dikes, parcels, quays, pipelines and roads, as well as social elements such as the Port Authority, customers, emergency organizations, pilotage services and facility companies. Several of these elements can be described as agents, which are related to each other and interact. For example, the Port Authority decides on a strategy for contracting clients. This affects interested companies, who react to this behaviour. Besides the direct reaction of clients, this decision affects the number of clients and has environmental and financial effects.

Although Maasvlakte 2 can be considered in subsystems, these are all highly related. Decisions about construction of the area influence the negotiation process and vice versa, and both influence finance. Furthermore, the system evolves as a result of the construction and adding new activities. New structures and new relations cause new dynamics.

The total value of Maasvlakte 2 can only be defined according to the integrated outcome of the individual elements. Building Maasvlakte 2 on time and within budget is irrelevant when no terminals or industry are settled. It is the combination of the subsystems and elements which could make Maasvlakte 2 a valuable area. The analysis of the design and decision making so far does not yield any insights into future system behaviour. Based on the characteristics of complex adaptive systems, self-organization, path-dependencies and emergent behaviour are expected to occur in the coming decades. The system is expected to be robust for some dynamics and choices; however, it could be instable for other aspects.

5.4.2 Problems and dilemmas of the Maasvlakte 2 project

As in other large infrastructural projects, the Maasvlakte project also faces several dilemmas. It is unknown how the system will behave due to the dynamics over the short and the long term. In the short term, there are expectations for the demand of clients, but this does not guarantee long-term demand. Effects on the quality of flora and fauna and of international connections are calculated, but the outcomes have a broad range of uncertainty. In addition, the consequences of strict negotiation policies could be accepted for the short term, but this acceptance may change.

A second dilemma is related to the multi-actor network of public, private and non-governmental organizations. Even now that construction has started, stakeholders have different interests in Maasvlakte 2, for example between different functions and values. In the future, this could also lead to conflicts which possibly further delay the project.

There is a continuous dilemma between, on the one hand, the positive economic effects of a growing economy, increased employment and a better image for Rotterdam and The Netherlands as a distribution country; and on the other hand the negative environmental effects of increased pollution, less safety, more traffic and other problems. Governmental organizations and the Port Authority are in favour of extending the activities; however, legislation and stakeholders want to ensure that the environmental issues are safeguarded. This dilemma is solved by the recognition of the need for compensation projects. However, many effects are unknown and will only be encountered during the construction and use of Maasvlakte 2. Therefore, after the construction of 500 ha of land reclamation or 1 year before the term of operation is ended, a mid-way evaluation must be made. This evaluation has to take into account the economic situation, the quality of the port area, nature effects, mitigation and compensation projects, and the spatial and economic development of the southwestern Netherlands.

Consequently, the costs and planning could vary. Costs of large projects are often higher due to new technologies or additional activities. Building costs are also difficult to estimate because the dredging sector is known for instable prices. To reduce the risks of exceeding the budget, the Port of Rotterdam decided to use a design and construction contract for the first phase of the project, and the responsibility and risks lie with the builder.

So far, the project has already displayed the delays in planning which are inherent to large infrastructure projects. The plan in 1997 was to finish the PKB PMR part 3 in 1999. Due to the demand for more research into the effects of the project, PKB part 3 was published in 2001. In 2004, the plan was to finish the first parcels in June 2010 (Port of Rotterdam, 2004). In 2008 this was delayed to 2013. Further delays are not allowed because of the signed contracts. However, delays are never planned; new protected species or archaeological constructions may be found which may call for new research, or bad weather conditions could delay the construction process.

The problems and dilemmas observed in the project are similar to the problems and dilemmas of other large infrastructure projects. The project will take 10-15 years to realize, and the same number of years of decision making is needed before the realization can begin. The use of the project will be even longer than the planning and realization period. The consequences of decisions have direct but certainly long-term effects as well. The essence of the project is balancing economic development and environmental issues. Finally, the investments are high and revenues uncertain. Many expected problems are dealt with by agreements or further research. However, it is not possible to prepare for the unexpected, which is caused by the interaction of different processes, dynamics and decisions.

5.4.3 Dealing with complexity

There are two ways to deal with the uncertainties which remain. In the first place, a great deal of research has been conducted into environmental effects (Berkenbosch, 2007; Projectorganisatie Maasvlakte 2, 2007b) (there are more than 6,500 pages of environmental studies), into optimizing the construction and lay-out (Hellebrand and De Snoo 2003; Plugge, Kant et al. 2003; Snoo and Fikken 2004), and into nautical accessibility and safety (Expertisecentrum PMR, 2003). The studies are valuable because they are very detailed and relevant to a small aspect of the system. However, these studies do not take into account the integrated system.

A second strategy is to make agreements that deal with uncertainties. In the *Bestuursakkoord* (*Bestuursakkoord inzake uitvoering van het Project Mainportontwikkeling Rotterdam*, 2004), in the Key Planning Decision (Ministerie van Verkeer en Waterstaat et al., 2003), in contracts with contractors and clients and in agreements with environmental and fishery organizations, agreements are made about measuring effects, reducing emissions, reducing unnecessary investments and sharing risks.

These two strategies still do not remove all the uncertainty. Many questions about the reactions of clients, the attractiveness of the port area, adaptation to changing environments and dealing with further delays are still unanswered and cannot be resolved by reports and agreements. Only time will yield the answers.

Because we are still unable to look into the future, we use simulations to provide some insights into future behaviour. The role of the social network in the Maasvlakte 2 requires a socio-technical perspective. That is why a serious game has been developed. The objective of the game is to provide in a couple of hours a holistic view over a period of 30 years. Furthermore, it is useful to take a complex adaptive systems perspective because the Maasvlakte 2 system contains many characteristics of these systems. Properties at the system level could support the understanding of systems behaviour.

5.5 Conclusion

This chapter introduced the land reclamation project Maasvlakte 2. We illustrated the history of the development of the port area and concluded that Maasvlakte 2 is another extension project with some unique characteristics, including the reclamation of land and the attention to environment impact. Furthermore, the Rotterdam Mainport development project was introduced in order to set the boundaries within which Maasvlakte 2 will be built.

The first steps towards the realization of Maasvlakte 2 are already finished; the permits, the required reports and the zoning plans have been approved. Construction began in 2008, but there are still many uncertainties as to how the area will be developed and which dilemmas could be observed in the future. To gain additional insights into possible future paths, a serious game has been developed. In the next chapters, the development of the game, analysis of the outcomes and players' experiences will be extensively investigated and discussed.

6. BUILDING A COMPLEX SYSTEM IN A GAME

Introduction

The questions related to the future situations and possible dilemmas in the construction and exploitation of Maasvlakte 2 can be researched by gaming the processes. To achieve this, a new serious game had to be developed around the strategic decisions and their consequences for the development of Maasvlakte 2. This chapter describes the development process of the serious game SimPort-MV2.

The challenge for the designers was to develop a game that is realistic, educational, enjoyable to play and which can be researched. First, it had to simulate the Maasvlakte 2 system at the level of strategic decisions. Second, the game needed to be educational for the participants in the sense that it would allow them to gain a better understanding of the dynamics of the system. Because our focus is understanding Complex Adaptive Systems, the game had to be a simulation of such a system. Third, the game had to be an enjoyable activity. Finally, it had to be possible to research the outcomes of the game, which meant saving the decisions and having enough players. Therefore, in the game design process, many choices had to be made about what must be within and outside the scope of the game, and the level of detail needed to fulfil those requirements. The design choices and their consequences for the validity and use of the game are explained in this chapter.

As described in Chapter 4.2 and 4.3, the development of the game was accomplished in several steps: conceptualization, specification and validation, all of which are described in this chapter. We start with the organization and boundaries of the game development project. Section 6.2 describes the outcome of the conceptualization phase. Within this phase, the designers had to select the most important and relevant sub-systems, processes and relationships between them. The final design of the game is described in section 6.3. Describing a highly interactive game in words is difficult; in fact, it may be impossible to convey the ‘vibes’ of the game via text. Therefore, many screenshots are used for illustration. In section 6.4 it is explained that the game fulfils the requirements for our purpose. In section 6.5 we reflect on the development process and the final game design.

6.1 Organization and boundaries

The development of the game started with organizing the process and the design team (see Section 4.3.2). The project boundaries were also set.

6.1.1 Starting situation

The development of the game began in 2004. At that time, the PKB+ PMR part 4 was sent to the Dutch Cabinet, and the preferential design '*doorsteekvariant*' was chosen (see 5.3.2). The Port of Rotterdam was investigating the consequences of different strategies and planning decisions for the construction and exploitation of the land reclamation project. To support this process, the design team was asked to develop a serious game to allow decision makers to play with these strategic choices and experience the long-term consequences. The aims of the game were therefore:

- To gain better insight into any unforeseen, undesirable and unintentional effects of one or more development strategies and design variations in the medium term (10-30 years) as a result of exogenous uncertainties (economic, market, technological) and the strategic behaviour of the parties involved.
- To stimulate thinking about the project as a whole and in a multidisciplinary way within the Port of Rotterdam, considering the commercial and technical/infrastructural aspects, interests and choices.

The game was developed by a group of experts, combining their knowledge about Maasvlakte 2, game design, simulation and programming. The group consisted of game designers of Delft University of Technology, Maasvlakte experts from the Port of Rotterdam and programmers of the company Tygron Serious Gaming. On several occasions, other people were involved in collecting data, providing information, testing the game and facilitating game sessions.

6.1.2 System boundaries of Maasvlakte 2

Setting the system boundaries was a necessary and difficult process and was important for two reasons. The first reason is that it was not possible to take all variables and relationships into account. Choices had to be made about what should be within and outside the scope of the system. The second reason is that setting boundaries provided greater focus on the important processes and aims of the simulation. It resulted in players not getting bogged down in all the complicated processes. This was difficult to achieve because a balance had to be struck between the variables taken into account in order to simulate the system realistically and maximize the processing capacity of players, in order to convey the message of the game. Together with the client, four boundaries were set: 1) lay-out of MV2, 2) simulated processes, 3) environmental changes and 4) output criteria.

1. The geographical boundary is the Maasvlakte 2 area and not the entire port area. We used the lay-out '*doorsteekvariant Masterplan 1*' (see Chapter 5, Figure 5-6). Although this lay-out was adapted several times, this was not changed in the game because it had no consequences for the game objectives or play.

2. Of all the processes surrounding the decision-making process, it was decided to focus on the internal decision-making processes related to building Maasvlakte 2 and negotiating with clients. Legal processes, like applying for permits, changing zoning plans, etc. were taken for granted. Actors outside the Port Authority, such as governmental and environmental organizations, are not part of the decision-making team. When necessary, these actors are played by the facilitators.

3. Extreme events, such as terrorist attacks and floods, are outside the scope of this game. It is not the objective to show the consequences of these events. Extreme changes in European and Dutch law, which could have consequences for the function of the area as whole, were also not taken into account. Several likely dynamics, though, such as economic fluctuation, were integrated into the scenarios.

4. The output criteria are related to the objectives of the PoR and are used for the scoring system. These criteria are based on the direct effects on Maasvlakte 2 and are represented by the financial situation, client satisfaction and the final division of clients. Direct effects on the total port area and indirect effects on employment in the region are not taken into account.

6.1.3 Timeline of development

The development of the game was a lengthy and iterative process. The process started with interviews about the land reclamation project and the conceptualization of the game, leading to a 'conceptual map'. After presenting the prototype of the game to the Port Authority, the collection of data and writing of scenarios, roles and clients began. This led to a paper-based prototype of the game, which was the starting point for the development of the computer game SIMMV2. On 31 August 2005, the first test session of SIMMV2 was played. While we were constantly adapting the game and solving technical problems, SIMMV2 was played seven times by a total of 36 teams.

The participants of each session provided feedback on the content as well as the playability of the game. We received positive feedback on the game play and the message. However, there were some criticisms of parts of the interfaces and boundaries. Therefore, in February 2006 a redesign process began. This led to new interfaces, an efficient calculation system and more flexibility for adaptations in the game. The total redesign called for a new name for the game, which became SimPort-MV2. In October 2006, the first session of SimPort-MV2 was played.

The development of the game and the game play sessions ran parallel to the decision-making process of the Port of Rotterdam. The Port of Rotterdam prepared the construction of Maasvlakte 2 and contracted several potential clients. The game development and the Port of Rotterdam's preparation process influenced each other. Regular meetings were scheduled to discuss design choices, to exchange information and to include the latest developments in the real-world system.

Hereafter in this chapter and in the following chapters the name SimPort-MV2 is used. Only when data is specific to the game SIMMV2 do we refer to it separately.

6.2 Conceptualization: reducing and developing a complex system

The first design step was the conceptualization of the Maasvlakte 2 system and the game (see Section 4.3.3). All relevant elements had to be taken into account to develop a valid representation and simulation of a complex adaptive system. At the same time, the number of elements and their relationships was reduced in order to develop a playable game (see also Duke & Geurts, 2004; Wenzler, 1993). It is the art of a game developer to include the necessary elements and relations. This sections shows the conceptualization of the real-world system which is used in the game. The port management team, the realization of the Maasvlakte 2 area, the exploitation of the Maasvlakte 2 area and the dynamic project environment are described.

6.2.1 Port managers

The game focuses on the decisions of the Port Authority related to the construction and exploitation of Maasvlakte 2. The key players are from within the Port Authority. Consequently, actors outside the Port Authority are not taken into account as key players.

The Port of Rotterdam launched a separate project organization which is responsible for design, building and conditions such as permits. The commercial department is responsible for finance and internal and external communication. Because the conditions are outside the scope of the game, four tasks have to be accomplished: construction of the Maasvlakte 2 area, negotiation with clients, internal communication and finance.

6.2.2 Realization of the Maasvlakte 2 area

One of the simulated processes is the realization of the Maasvlakte 2 port area. In 2004, the planned building process consisted of two steps as a consequence of the time needed for the nature compensation project. To start the construction earlier and save time, this two-phased approach was chosen. The first phase is the reclamation of 800 ha net land area, followed by the second phase of replacing the outer contour and reclaiming 200 ha more area.

After fulfilling the legal requirements, the building of the outer contour can begin, including roads, rails, cables and sewage infrastructure. Once this is completed, the adaptation of Maasvlakte 1 and dredging the Yangtze harbour can be started. The land reclamation can also start, based on the demands of the clients. Finally, the contracted clients can build their facilities. The second phase can begin when the first phase is completed, assuming there is still a demand for space. The remaining process is the same: replacing the outer contour, building the infrastructure, reclaiming land and constructing the buildings for the clients. A depiction of this process can be found in Figure 6-1.

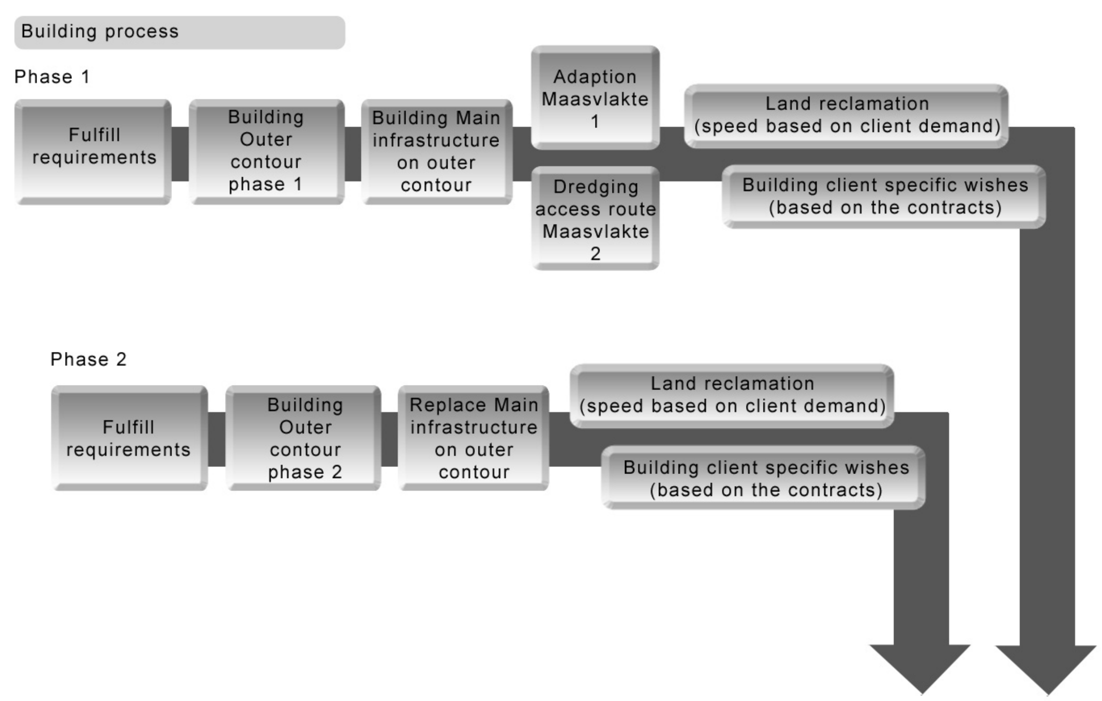


Figure 6-1. Two-phased building process of the Maasvlakte 2 area

One of the strategic questions is how to tender this construction process. One tender could be used for building the entire area. However, this would make the Port of Rotterdam inflexible with respect to changes. The tender could also be split into smaller parts, which would offer greater flexibility but would demand more coordination. To examine the different options and their consequences, the participants of the game have to choose among four building strategies. These strategies differ in the number of building packages (from two large packages to 11 small packages), building time, and costs. One strategy is to build the outer contour directly in the desired location after a delay caused by the nature compensation project.

Later in the preparation process of the real Maasvlakte 2 area, the Port Authority decided to abandon the two-phased building process. This alternative is less costly and, due to other delays in the process, the nature compensation was finished on time.

6.2.3 Exploitation of the Maasvlakte 2 area

The second relevant process for the game is the negotiation with potential clients. As is common practice, companies attended a consultation session at the Port Authority to show their interest. The PoR started a project team for the negotiation process, while the clients wrote a proposal stating their requirements. This proposal was compared with the availability in the port area. Based on this outcome, the project team wrote a letter of recommendation and the client had to write a business case, which was checked by several departments of the Port Authority. When the business case was approved, the contract was signed. See Figure 6-2 for a schematic depiction of the process.

This process had long been successful but had the disadvantage that the Port Authority could not search for the most interesting clients. For this project, the Port Authority wants to follow a more active negotiation approach, to avoid fragmentation on Maasvlakte 2. They want to select the most appropriate clients who fulfil the stringent criteria. For the first client, a bidding process was followed in order for the Port to have greater influence over the agreements.

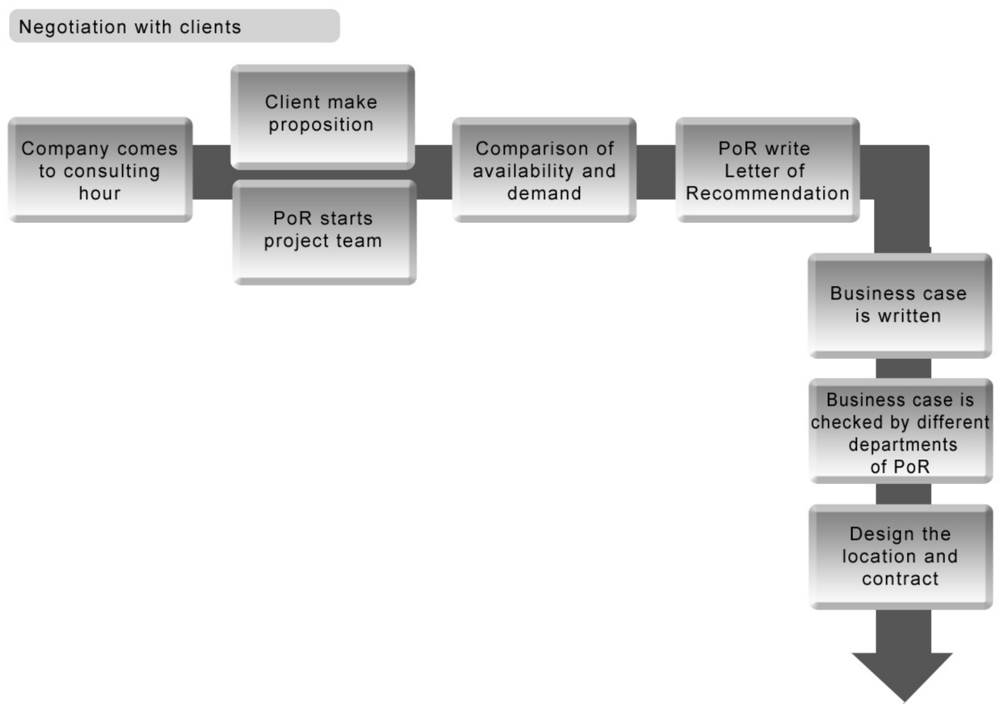


Figure 6-2. Negotiation process of potential customers for the Port of Rotterdam

In the game, the players can choose to follow a normal or an active negotiation approach. In the normal approach, players wait until clients contact them. In the active approach players actively contact clients and start negotiating. In the game, the negotiation process is simplified. It is not the objective to learn how to write letters of recommendation or business cases. These lengthy research processes are outside the scope of the game. When there is contact between the players and the potential client, the client sends his proposal, the first offer. This offer specifies a number of criteria, such as area size or delivery date. The players compare this offer with the availability and requirements, change some values, and send a counter-offer. The potential client reacts to this by either rejecting the counter-offer or sending a second offer. Finally, the team has to decide to contract the client or to reject the offer.

6.2.4 Performance indicators

Ultimately, the Port of Rotterdam will be judged on the performance of the project. The performance is based on financial, spatial and process indicators. The financial indicators are costs and income of the Maasvlakte 2 area. The costs consist of the construction of the outer contour, land reclamation, infrastructure and quays. Exploitation adds maintenance, pilots and security costs. The income of the area is based on the rent of parcels and, by processing and transporting goods, calculated into the port dues. Spatial indicators are the clustering and synergy between different companies on Maasvlakte 2. This could reduce transportation costs of raw materials and waste of industrial processes. Third, the process indicators illustrate the internal as well as external communication and quality of the negotiation process.

In the game, these three categories of indicators are simulated and used in the debriefing of the game. The computer model calculates cost and income based on the development of Maasvlakte 2 and the contracts with clients. Furthermore, client satisfaction is based on the negotiation process and whether or not the team complies with the contract. The internal communication and the clustering are based on observations.

6.2.5 Challenge to combine the processes

The building and negotiation process can be considered two separate processes. However, the Port of Rotterdam tries to combine the processes by postponing the construction and expediting the rent of the parcels to reduce the amount of vacant areas. Vacant areas cost money for maintenance and therefore constitute a loss of income. In the optimal situation, land reclamation starts after contracts are signed. This approach increases the risks of not complying with the contract when the building is delayed. Furthermore, the different options for phasing the construction could lead to different outcomes. The costs are lower if the area is built without phasing, but this advantage is undone when client demand lags behind and areas remain vacant. The game provides a safe environment in which to play with these options and experience the consequences.

In the conceptualization phase, many choices were made about what must be taken into account and what is outside the scope of the project. These choices led to a conceptual design which focuses on two core processes, namely the construction of the land reclamation, contracting the clients, and the interaction between these processes. In order to emphasize the interaction, the separate construction and negotiation processes are highly simplified. Consequently, the outcomes of the game are only valid on a high level of abstraction. No detailed conclusions can be drawn about individual clients or the most efficient strategy.

6.3 SimPort-MV2: create your own future

The outcomes of the conceptualization are used for the development of the game. Key actors have to be translated into players, processes have to be translated into activities and performance indicators have to be translated into game output (see section 4.3.4). Furthermore, the simulation of the physical system and the interfaces of the computer simulation have to be developed. The outcome of this process is the game SimPort-MV2.

6.3.1 General game set-up

The participants of the game have to form teams of three to six persons. Together, they are the directors of the Port Authority with virtually all responsibilities and competencies to plan, coordinate, and implement the decisions necessary to build, equip and exploit Maasvlakte 2 in the coming 30 years. The team of directors is split into three roles, played by one or two participants.

- The General Director wants to build the area in an efficient way, with the lowest costs and with a manageable time span.
- The Commercial Director wants to contract clients and have satisfied clients.
- The Infrastructure Director is responsible for the construction of the area, which must be completed before the clients arrive.

For a couple of hours, this team will be faced with a difficult and serious challenge:

> Make appropriate planning and implementation decisions, individually and collectively, that will lead to a satisfactory design and exploitation of the second Maasvlakte (1,000 ha) over a 30-year period.

The general set-up of a gaming session is shown in Table 6-1. The game starts with an introduction of the game leader, who presents the reason for playing the game and explains the objectives and tasks. In the first round, the players have to decide on their strategies. These consist of a building strategy, a commercial strategy and an allocation plan. In rounds 2, 3 and 4, the players begin building and contracting clients. In the first period, the building will receive greater attention while later on, the client process becomes more important. After rounds 2 and 3, there is some time scheduled for an internal team evaluation. In this evaluation, the players can recapitulate what they have done, how the process is organized, and whether they are playing according to their initial planning, and they define the tasks for the next round. At the end of the game, a central debriefing is given. In this debriefing, the teams explain their approaches and results, and the outcome and processes in the game are discussed.

Table 6-1. Steps of play in a SimPort-MV2 session

Introduction	Game facilitators present game objectives, rules and tasks.
Round 1	Determining the building and commercial strategies and drawing up an allocation plan. Time stands still in this round (2007).
Round 2	First period of 10 years (2007-17). The building process must be initiated, and the first negotiations with customers can be conducted. In 2017 there is a review and update of performance to that point.
Team evaluation	Based on the internal team evaluation, the players can make adjustments in role division, strategy, etc.
Round 3	Second period of 10 years (2017-27). The building process continues, negotiations with customers are in full swing, and customers are assigned to land in the port. In 2027 there is another performance update.
Team evaluation	Based on the internal team evaluation, the players can make adjustments in role division, strategy, etc.
Round 4	Third and last period of 10 years (2027-37). In 2037 there is a final performance update.
Debriefing	Upon completion of the game, there is an evaluation of several aspects such as strategy, processes, collaboration and the end result. Lessons are drawn that can apply to the real world.

6.3.2 Round 1: selecting the strategy

After the participants have had some time to become familiar with what they are expected to do, the game begins. In round one, the team decides on a building strategy, a commercial strategy and an allocation plan.

Building strategy

The team can choose one of four building strategies, which are composed of various building packages. The number of building packages varies with the strategy, from a minimum of two to a maximum of eleven. Due to technical feasibilities, building packages have certain requirements before building can begin.

The choice of strategy will influence costs, flexibility and lead times in the actual building process later on. There are many trade-offs and choices: for example, greater flexibility requires more coordination among team members, as well as higher costs and a longer lead time. On the other hand, less flexibility could lead to difficulties if, for example, the demand lags behind predictions.

Table 6-2. The players can choose from four types of building strategies

The four building strategies are:
1. Fast forward: two building packages, quick, but little flexibility.
2. Carrying on, but not rushing it: five building packages that represent a compromise between speed and flexibility.
3. Maximum flexibility: eleven building packages, with maximum flexibility but slow and requiring a great deal of coordination.
4. All at one go: four building packages, the outermost contours of the project are placed in their definitive location.

Commercial strategy

Second, the team must choose one of two commercial strategies. These two strategies are based on the normal approach of the negotiation process and the alternative, active approach. In the first strategy, the port waits for clients to show interest, while in the second strategy the port is proactive; only clients who fit the allocation plan are of interest.

Table 6-3. The players can choose one of two commercial strategies

The two commercial strategies are:
1. Come as they may: a suitable solution is sought for each individual customer.
2. On top of things: the port authority establishes a number of criteria, and customers must comply with these to get a contract.

Allocation plan

During the strategy phase, the team also draws up an allocation plan for the future port area. This plan shows where each business cluster will be located. The team may make changes to this plan during the course of the game. Allocation plan locations on the map are shaded according to a set of colours, representing different business sectors (Figure 6-3 shows the general lay-out, the text in the figure is not relevant).

Figure 6-3. Picture of defining the allocation plan.
The different colours represent the different types of clients.

In this first round, the participants become aware of the different strategic choices which have to be made, and they must think about the expected consequences of these decisions. After the team has made its choices and entered them in the simulation, the strategy phase is finished. Only then does the game leader start the time clock for the simulation.

6.3.3 Round 2 and beyond: building and commercial activities

In round two and beyond, the players implement various building and commercial activities based on their chosen strategies and evaluate how they perform. These activities include: selecting and initiating building activities, negotiating with and contracting customers, assigning land to customers, and performance-based evaluation.

Selecting and beginning building activities

In round two, the Infrastructure Director selects the various building packages and decides on the starting date for building and the speed (normal or fast) of implementation. In addition to the building packages, other projects must be initiated in the building process, such as chemical logistics service centres, inland shipping terminals and distribution centres.

The entire building process, from sea to 1,000 ha of useable land, can take 15 years or more and shows many path dependencies. Planning errors and external delays in the building process are very likely to occur, which will impact the commercial process and port performance. The team's challenge is to minimize errors and manage uncertainties. Figure 6-4 shows an image of the building activities.

Figure 6-4. Picture of the building screen. The big frame shows the Maasvlakte 2, the right side shows the menu within the building system. Below, news flashes and several performance indicators can be found. In the upper line, the tabs to different subsystem can be found, along with the date in the game.

Figure 6-5 Picture of the negotiation with clients. The big frame shows the negotiation process, in the left tab the requirements of the client can be found, and in the right tab the player can give his reaction. In the frame on the right side, the clients in the negotiation process are listed and the details of the selected clients can be found.

Negotiating and contracting customers

The simulation model contains the names of and information about more than one hundred potential customers, divided among four sectors: container terminal operators, chemical companies, distribution companies and alternative clients (a category that includes new types of industry such as a biomass production plant or non-port-related activities like a diamond storage facility). All clients and their information can be found on a *long list.* The companies that have sent a request to the team or whom they have sought to contact are put on the *short list.*

Some customers from the long list will automatically seek contact with the management team. The Commercial Director may also seek contact with a company. After receiving an offer from a company, players can make a one-time counter-offer. They send it to the company, which accepts or rejects it. Companies that reject the counter-offer are unlikely to seek contact again in the near future. When the Commercial Director and a company have reached agreement, a contract is signed, and the client information can be transferred to the Infrastructure Director for planning and building. Figure 6-5 shows an image of the negotiation with customers.

Assigning land to customers

During negotiations the team must ascertain where a customer wants to be situated and where they *can* in fact be placed on the map. After a contract has been signed, the Infrastructure Director must place the customer on the port map. The location chosen must comply with the contract and progress of the land reclamation. Only when the parcel of land is reclaimed and ready can customer operations begin and income be generated for the port.

6.3.4 The performances of the management team

After each year, a performance update is automatically provided for the preceding play period(s). The team is given a summary of incomes (based on port dues and land rental), of expenditures (construction costs), and client satisfaction (calculated from aspects such as waiting time, parcels delivered on time and adherence to the contract). A port map reveals the status of the construction, the rented parcels, the types of located companies, and whether there is any clustering of specific industrial activities. The team results can be compared with the results of other teams. Figure 6-6 shows an image of the performance evaluation.

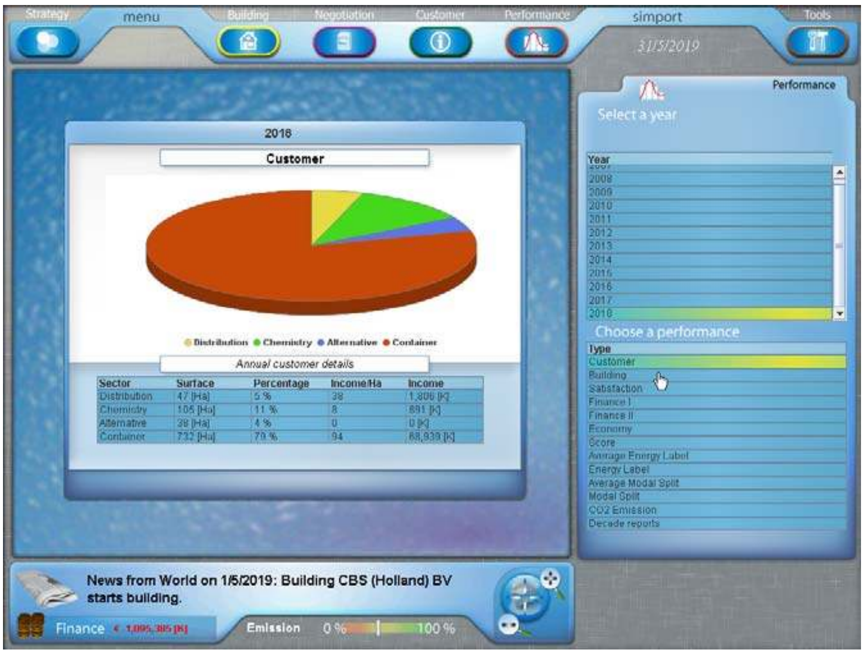


Figure 6-6 Picture of the performance. In the frame on the right side the year and the type on information can be selected. The information is given in the main frame.

In the three rounds of ten-year simulations, the participants have to execute their chosen strategies. They will encounter the possibilities and limitations of their strategies and observe the consequences of their actions over a longer period. In the debriefing, attention is given to these observations and experiences. The experiences are related to the real Maasvlakte 2 project and lessons can be drawn from them.

6.4 Validation and testing

An important step is the validation of the design of the artefact (see section 4.3.5). This validation does not start at the end of the development, but takes place throughout the development process and can be seen as constantly iterating between constructing and validating (Duke, 1980). A distinction is made between the internal validation, which is also called verification, and external validation. The objective of the verification is to check whether the game is implemented accurately and if the game is reliable. The objective of the external validation is to determine whether the game is an accurate or valid representation of the real world system (Peters, Visser, & Heijne, 1998). Finally, the game is tested for playability, to investigate if the game concept and interfaces were understandable for the players.

6.4.1 Verification

During verification, the implementation of the elements and relations in the simulation model is checked. This is done by talks and walks through the game with and without the computer simulation to test the game flow.

Other steps in the verification process consist of testing the computer simulation. Each step of the input was checked and several tests were performed to check whether the calculation model was implemented accurately. For example, we checked when a building package was selected and defined to start on a particular date, and determined that this happened correctly. Special attention was paid to the requirements between building activities. This process continued until all aspects were checked and repaired and it was decided the game was reliable for playing.

6.4.2 Realism of the game

In the first session, playability and realism of the game in comparison with the Maasvlakte 2 project were tested with a group of people from the Port of Rotterdam. Because the game SimPort-MV2 deals with future developments, it is not possible to compare the game outcome with the real world system. Therefore, the external validation of the game is based on the perceived realism by the players and their idea of the game's detail, also called face validation. They were positive about the realism of the clients and emerging processes. The participants also gave valuable suggestions for improvement, which were mostly related to the feedback. After implementation the game was played with other teams.

Representation of the real-world system

For the representation of the real-world system, we used face validation in particular. Via a questionnaire, the participants were asked if they agreed that the game was realistic and detailed enough for the purposes. The opinion of the experts was especially valuable. Because of the differences between the two versions of the game (SIMMV2 and SimPort-MV2), the first step of analysis was to see if the answers between the two versions were comparable. With the use of an independent t-test for comparing means, we concluded that the answer to the question about realism differed significantly between the two versions of the games.

The game SIMMV2 was assessed as being sufficiently realistic for the aims of the game (see Table 6-4). There were suggestions to improve the game by including fluctuations in the economy and environmental issues. SimPort-MV2 contains more possibilities for reflecting the dynamics of the economy and the political situation, and the lay-out and the performance indicators were improved. The participants assessed this version as being more realistic.

These statistical numbers are further supported by the participants' general comments. Some statements include, 'primary problems of internal cooperation, negotiation and decision making seems terribly true', 'realistic simulation with many opportunities' and 'realistic choices'.

Table 6-4. Answers to the question of whether the game was realistic, split into the game SIMMV2 and SimPort-MV2

Question SAKS37 Given the aims of the simulation game, the game was sufficiently realistic.							
n	mean	Std. dev.		SIMMV2		SimPort-MV2	
				Frequen-cies	Percen-tage	Frequen-cies	Percen-tage
SIMMV2			Strongly disagree	2	1.1	2	0.9
177	3.49	.83	Disagree	19	10.7	12	5.5
SimPort-MV2			Neutral	59	33.3	57	25.9
220	3.70	.76	Agree	84	47.5	127	57.7
			Strongly agree	13	7.3	22	10.0

A second indicator of realism is the level of detail. For this variable, no difference was found between the two versions of the game. This is as expected, since the level of detail was not changed. According to the participants the game is sufficiently detailed (Table 6-5). Only 5.3% disagree with this statement.

Table 6-5. Answers to the question of whether the game was sufficiently detailed

Question PAKS36					
Given the aims of the simulation game, the game was sufficiently detailed.					
n	mean	Std. dev.		Frequencies	Percentages
400	3.79	.74	Strongly disagree		0.0
			Disagree	21	5.3
			Neutral	99	24.8
			Agree	224	56.0
			Strongly agree	56	14.0

The third indicator is further expansion of the game. The participants agree on the statement that the game should be further expanded (μ=3.9 σ=0.9). Based on players' comments, two types of expansion can be distinguished. The first is adding more functions to the game to support the decision-making process, for example, an option to calculate the amount of vacant area left. The second type is adding more elements to the system. For both versions, participants asked for more economic fluctuations. Participants of SimPort-MV2 also asked for environmental effects, safety, hinterland connections and employment.

From these results it can be concluded that the game is sufficiently realistic and detailed for the purposes of the game. The realism was improved after the redevelopment leading to SimPort-MV2. Players suggested extending the game with more functions and more variables. Several of their comments were adopted and implemented in SimPort-MV2. However, we observed that participants always have suggestions for additional elements and that the boundaries of the game are constantly stretched.

Representation of a complex adaptive system

Another perspective from which to look at validity is the representation of a complex adaptive system. In Chapter 3, several design criteria are determined for simulating a complex adaptive system in a multi-actor context.

The first criterion is that the game has to simulate a multi-actor context, where interactions and the diversity of actors become visible. It was suggested to develop a multi-player game where this diversity and these interactions emerge. SimPort-MV2 was developed as a multiplayer game, and although the players have the same team objectives, diversity between the roles became clear.

Second, the rules have to be flexible. In the game, the participants choose their own way of interacting with each other, which offers possibilities for self-organization. Furthermore, they have to define their strategy and decision-making process. In this way they define their own rules.

A third criterion is that the game is an open or emergence game. The outcome of the game emerges from the decisions of the players. The number of choices and the different order and time schedules of activities are sufficient to consider the game to be an open game. The diversity in financial situations and lay-outs of the maps after 30 years supports this openness. On the other hand, the solution space is bounded by the decisions of the players. For example, once a client is contracted and a parcel assigned, no other clients can rent the same parcel. In this way, path dependency becomes an outcome that must be dealt with.

Fourth, to simulate the open character of CAS, the game leaders have several options to influence the system from outside. Examples of these options are the economic circumstances, the second offer in the negotiation and the log messages.

The circumstances for simulating a complex adaptive system in this game are therefore available. The questions of whether this leads to complex system behaviour and what can be learned from the behaviour of this complex adaptive system are discussed in Chapter 7.

6.4.3 Playability of the game

The third criterion for a successful game is the usefulness of the artefact, or playability. Because SimPort-MV2 is a computer game, playability is split between game concept and computer simulation. Just as for the indicators of the realism of the game, the answers are checked for any statistical difference between the two versions of the game. In case there is a difference, the outcomes are split.

Game concepts and materials

Several indicators were chosen to validate the playability of the game. From the results of Table 6-6 and Table 6-7 it can be seen that the players agree that the game was built in an interesting and stimulating way and that they enjoyed taking part in the game. In general, the players were also positive about other indicators, such as clarity and quality of the rules, tasks and materials.

Table 6-6. Answer to the question as to whether the game was built in an interesting and stimulating way

Question PAKS5 The simulation game was built up in an interesting and stimulating way.					
n	mean	Std. dev.		Frequencies	Percentages
403	4.23	.61	Strongly disagree		0.0
			Disagree	3	0.7
			Neutral	30	7.4
			Agree	242	60.0
			Strongly agree	128	31.8

Table 6-7. Answer to the question of whether the players enjoyed playing the game

Question PAES5 I enjoyed taking part in the simulation game with others.					
n	mean	Std. dev.		Frequencies	Percentages
402	4.26	.65	Strongly disagree	1	0.2
			Disagree	2	0.5
			Neutral	33	8.2
			Agree	222	55.2
			Strongly agree	144	35.8

The last indicator for the validity of the game concept is whether the players would like to play the game again. A difference can be found between the versions of the games. SimPort-MV2 has a significantly higher score. More people would like to play again. However, the opinions of the players are still diverse.

Table 6-8. Answer to the question of whether the participants would like to play again

Question PAKC6 I would like to play SimPort-MV2 again sometime.							
n	mean	Std. dev.		SIMMV2		SimPort-MV2	
				Frequencies	Percentage	Frequencies	Percentage
SIMMV2			Strongly disagree	10	5.6	5	2.2
179	3.45	1.05	Disagree	20	11.2	18	8.1
SimPort-MV2			Neutral	55	30.7	37	16.6
223	3.89	0.99	Agree	68	38.0	99	44.4
			Strongly agree	26	14.5	64	28.7

Computer simulation

The second part is the playability of the computer simulation. It is important that the computer is seen as a supporting tool and that it does not disturb the process of communication and decision making. This means that the computers must be easy to use. From the answers in Table 6-9, we observe that most of the players agree with the statement that the computers were easy to operate. Less than 10% of participants had problems with the navigation between the different types of information. For most participants the navigation was clear.

Table 6-9. Answers to the question of whether the computer was easy to operate

Question PAKC29 The computers in the game were easy to operate.					
n	mean	Std. dev.		Frequencies	Percentages
401	3.93	.85	Strongly disagree	5	1.2
			Disagree	25	6.2
			Neutral	54	13.5
			Agree	225	56.1
			Strongly agree	92	22.9

A second criterion is whether the players liked to use the computers (Table 6-10). The answers show that only 3% of the participants disagree with the statement that they enjoyed using the computers in the game. The enjoyment of using the computer is correlated with the operation of the computer (corr. = 0.517 p .000). This means that participants who scored higher on the statement about using the computers also had a higher score on the enjoyment of using the simulation. Some other positive aspects are that players liked the interfaces; these interfaces were understandable and they gave an adequate sense of the changes in the Maasvlakte 2 area.

Table 6-10. Answers to the question of whether the players enjoyed using the computers

Question PAKC30 I enjoyed using the computers in the game.					
n	mean	Std. dev.		Frequencies	Percentages
401	4.05	.70	Strongly disagree	1	0.2
			Disagree	11	2.7
			Neutral	50	12.5
			Agree	244	60.8
			Strongly agree	95	23.7

The insights into the performance indicators are not clear for all the players. Approximately 10% disagreed and 40% was neutral as to whether the interfaces gave adequate insights into the performance (Table 6-11). One reason for this could be that the players hardly had any time to study the performance indicators, because they were busy with other things. Or it could be that the indicators did not give the information they needed. For example, the players asked for an indicator which showed the amount of area which is available, but this information could not be found in the indicators.

Table 6-11. Answers to the questions about the insights into the performance

Question PAKC38					
The user interfaces gave enough insights into the performance of Maasvlakte 2.					
n	mean	Std. dev.		Frequencies	Percentages
395	3.44	.78	Strongly disagree	7	1.8
			Disagree	32	8.1
			Neutral	155	39.2
			Agree	181	45.8
			Strongly agree	20	5.1

We found one significant difference between the SIMMV2 and SimPort-MV2 in relation to the stability of the computer game. This difference is the number of malfunctions of the computer. SimPort-MV2 scored significantly better, with a difference of 0.39 points on average.

One of the comments which we regularly received was that the participants would like to have a ‘practice round’. The participants had the feeling that at the start of the game they were busier finding their way through the interfaces than with the activities of the game. To give the players more confidence, a tutorial of the game was developed. After the first introduction of the objectives of the game, the players had some time to use the tutorial. The value of the tutorial is to introduce the way in which the players have to put their decisions into the software and where to find the relevant performance indicators. The tutorial cannot be used as a mini-game with the same learning objectives, because the processes and challenges are not part of the tutorial. From the results of the survey (Table 6-12), we can conclude that the tutorial was clear and increased the understanding of the game.

Table 6-12. SimPort-MV2 tutorial

	N	Mean	Std. Deviation
The tutorial increased my understanding of SimPort-MV2.	75	3.85	.68
I could follow and understand the steps in the tutorial.	76	3.87	.82

There were significant positive correlations found between doing the tutorial and enjoying the use of the simulation, control over the game play and understanding of the interfaces. This means that a tutorial is a valuable addition for introducing the simulation and allowing players to become acquainted with the tool.

6.5 Reflection on game design for understanding complexity

The development of a game to simulate complex adaptive systems has an inherent tension. On the one hand, Complex Adaptive Systems are open systems where a small element could have significant consequences for the system behaviour, if it is a sensitive element. Studying complex systems calls for broad system boundaries in which all elements are taken into account. On the other hand, development of simulations in general and games specifically is often driven by setting clear boundaries, just large enough to take relevant elements into account. From an outside perspective these simulation and games are closed systems, even when different environmental scenarios are part of the simulations. Furthermore, deciding what is inside the boundaries and what is outside is difficult to validate. Consequently, game development has a significant impact on the value of the game. In this section, the boundaries of the game due to the development process are discussed.

6.5.1 Focus on strategic processes

An important content-related design choice is the focus in the game on the strategic processes of contracting clients and constructing the area. This choice was inspired by objectives for the development of the game given by the Port of Rotterdam. The decision makers for the Port of Rotterdam wish to gain greater insight into the effects of their strategic choices and the robustness of these strategies when the actors are faced with unexpected events or conflicts. The focus on strategies consequently means that other aspects are outside the scope, such as the strategic management of actors outside the Port of Rotterdam, or the negotiation process.

This means first of all that the negotiation with clients has a maximum of three steps: contact, reaction to offer, and the decision to sign a contract. The players also do not have to write reports or detailed contracts, they only have to decide upon some indicators such as price, size, location and delivery date. Second, the participants do not have to deal with contractors regarding the construction design, approach and materials. The participants determine when different building processes have to begin and they also decide in which order the Maasvlakte 2 is built. The game does not deal with the consequences of different construction methods or negotiations with contractors.

6.5.2 Game development as a co-evolving system

The process of development can be seen as a co-evolving system, starting with some basic elements, which are extended and adapted based on the feedback of the players and game play. The reason for this approach is that we first want to prove that the concept works. The intention was to start with a working prototype. Based on the reactions to this prototype the game can be expanded with additional subsystems, decisions, and feedback. That is why a tutorial was eventually added and performance criteria were extended.

A disadvantage of this approach is that the structure of the simulation has to be flexible enough to constantly adapt to new elements. This was a reason for the developers to rebuild SIMMV2 into a more flexible environment, SimPort-MV2. This change makes it not only possible to adapt the Maasvlakte 2 game, but it also provides a basis for developing other comparable games.

6.5.3 Socio-technical system set-up

For the purposes of the game, a hybrid version of a computer and a social/interactive game was used. It was decided not to develop a total immersive 3-D environment, where the participants could walk around. An important reason is that in the real-world system, the place where discussions take place – the office – is different from the area that is the subject of the discussions, Maasvlakte 2. Simulating a 3-D office is not relevant for our objectives. Simport-MV2 is played with a group of participants sitting together in their simulated office consisting of a table with three laptops, running a simulation of the Maasvlakte 2 area. The current state of Maasvlakte 2 is constantly projected on a wall, so players are continuously aware of the developments of the area.

There are several other reasons to choose this set-up. This set-up has the advantage that the participants are free to choose and change their ways of communication. They are not bound to computer interfaces but have the option of using a planning board, a white board, a flip-over or post-its for their communication. This freedom also allows more space for self-organizing behaviour.

In addition to the interaction between individual participants, participants interact with the computer simulation in two ways. First, the decisions about strategies, reactions to clients and commencement of building activities are the input of the computer simulation. Second, the simulation provides feedback on the reactions of the system based on the input of the participants. This interaction between decisions and feedback on the development and performance of the Maasvlakte 2 project provide insights into the interactions in the system.

The game leaders have some possibilities for playing the outside world, by influencing the economy, adapting client offers or sending messages to the players. This socio-technical set-up provides a game environment in which complex adaptive system behaviour is expected to emerge.

6.5.4 Double function of serious games

Special attention has to be given to the design choices related to the function of the game. Serious games are used in many different contexts of learning, research and intervention. The different uses call for different requirements related to the validity of the game. The game SimPort-MV2 has two functions: system understanding and individual learning. These two functions have different criteria for the level of abstraction, feedback structure and embedding of the game. These criteria are not necessarily conflicting, although this is possible.

For learning purposes it is recommended that the game be embedded within a context, for example, with lectures about project management or port design. In that case the game is played primarily as part of a theoretical course. Feedback on the actions of the players is also important for learning. After 10 simulated years, the game was paused to allow some time for reflection. Facilitators could use this moment to support reflective thinking. These two criteria are less relevant if the game is used for system understanding.

For system understanding, the abstraction and level of detail of the game are relevant. In order to draw valid conclusions about the patterns of behaviour, the game and simulation used in the game have to be valid. This could conflict with the learning objectives if complicated models are used. Complicated models are expected to increase the validity, but this makes the game more of a black box, where cause and effect relationships are no longer clear and learning decreases. For the purposes of the research, it was decided to find a level of abstraction which was simple enough to discover the cause and effect relationships and detailed enough to search for relevant patterns of behaviour. To make the influence on the building and negotiation process and the final lay-out of the system clear, elements like environment and hinterland transportation were left outside the scope of the system, because they could distract players' attention from the message.

In addition to these two learning objectives, learning about the system also takes place during the development. As Kafai (Kafai, 2006) said, 'the greatest learning benefit remains reserved for those engaged in the design process, the game designers, and not those at the receiving end, the game players' (p.39). This was also observed by Lee with respect to the developers of large-scale models (Lee, 1973). Although this is not proven, there is an argument in favour of this statement. Game developers need a clear understanding of the system elements and behaviour in order to make well-founded design choices. This understanding is created by exchanging information during discussions and by developing conceptual maps and models, which makes the designer's knowledge explicit. On the other hand, patterns of emergent behaviour as a consequence of the social and technical interaction in the system cannot be designed. Learning about emergent system behaviour only occurs after playing the game multiple times with 'real participants'.

6.6 Conclusion

In this chapter the development of the game SimPort-MV2 was explained. In each step, several decisions were made to abstract the real-world situation into a realistic and playable game. Finally, a game was developed in a co-evolving process, which focuses on the construction and exploitation of the Maasvlakte 2. In the game, groups of four to six players have the possibility to decide about the strategies, the building and negotiation, with the objective of realizing a valuable port area.

Because the usability of the game is related to the validation, we tested the game in different ways. From the validation analysis it can be concluded that the game is valid for the learning purposes of understanding complex systems and for observing general system patterns. The players agree that the level of detail and the realism were sufficient. Furthermore, the players enjoyed playing and using the computers in the game.

However, the game cannot be used as a decision support system. The outcomes are only valid for this abstract representation of the Maasvlakte 2. The outcome of the choices could have other consequences in the real-world system due to the influence of elements which are outside the scope of the game. Two examples of relevant elements are the influence of actors outside the Port Authority and the safety aspects of infrastructure, the chemical industry and traffic on the water.

In the next chapter, the use of SimPort-MV2 for understanding complex systems is analysed. The individual learning effects of the game are discussed in Chapter 8.

7. LOOKING INTO THE FUTURE: COMPLEX SYSTEM BEHAVIOUR

Introduction

It is argued that simulation games are useful for understanding the complexity of the system (Duke & Geurts, 2004; Klabbers, 2006b). However, less research exists on what is meant by understanding complexity and how this emerges in a game. Based on the framework of complex adaptive systems, the complexity in a game can be analysed as well as the understanding of the complexity of the system. In this chapter, we research the contribution of the game SimPort-MV2 in understanding the complexity of Maasvlakte 2.

As explained in Chapter 6, SimPort-MV2 simulates a socio-technical system in which the social elements of the system are simulated by the participants and by computer agents. The technical elements are implemented in a computer simulation. Second, we concluded that SimPort-MV2 fulfils the design requirements to create an environment in which a complex adaptive system could emerge. So far, we have not analysed whether the complex behaviour also occurs.

This chapter shows that SimPort-MV2 simulates a Complex Adaptive System, by comparing the game output with the properties of a complex system. If we want to enhance understanding of the complexity of infrastructures, the game has to simulate this complexity. Next, this chapter analyses whether or not the objectives of the game are reached and if it is possible to gain a better understanding of the dynamics of the Maasvlakte 2 system.

For the analysis, we took the game output of 82 teams, from games played since 2005. The game output provided information about the end state after 30 simulated years and the key decisions during the session. This chapter starts with defining the solution space as it appeared in the game. After that, the outcomes are explained based on the decisions made in the game. In section 3, the game is considered as a Complex Adaptive System. Section 4 describes the lessons which can be drawn for the Port of Rotterdam, based on the outcomes of the game.

7.1 Solution space: large diversity in Maasvlakte 2 areas

Each team ends up with a future picture of Maasvlakte 2. This picture consists of financial, spatial and process indicators. These indicators define the performance of Maasvlakte 2, and they are therefore used for defining the solution space of a SimPort-MV2 gaming session.

The solution space of the game is the area of all possible game outcomes. Just as in complex adaptive systems, the solution space is based on a series of decisions and interactions. Theoretically, the solution space of the game is determined by the rules of the game and the decisions players can make during a session. However, for an open game like SimPort-MV2, the models, rules and creativity that the participants bring with them should also be taken into account. Because of the large number of decisions and consequences in the game, it is not possible to calculate the total number of outcomes or to calculate boundaries of possible outcomes. However, the large number of sessions and the more than 80 teams building the Maasvlakte 2 area made it possible to define the solution space based on the diversity of the outcomes of the game. This solution space was able to give an indication of the future of the real Maasvlakte 2.

7.1.1 Financial performance

The most important factors for a successful port area are the financial indicators consisting of total costs, total income and profit after 30 simulated years. These indicators determine whether or not the port area is profitable.

Based on the results of 74 teams, we observe that the total costs of the construction and exploitation of Maasvlakte 2 lie between 2.1 and 3.1 billion euros (Table 7-1). These differences are caused by the choices of different building strategies and speeds of building.

Table 7-1. Financial performances of simulated MV2 areas

	N	Minimum In K €	Maximum In K€	Mean In K €	Std. Deviation
Total Costs	74	2,145,482	3,136,269	2,620,950	164,818
Total Revenues	74	559,821	4,418,423	2,627,205	757,206
Profit	74	-2,133,798	1,670,508	5,854	735,546

The revenues of the teams show more variety and lie between 559 million euros and 4.4 billion euros. The low score was caused by a lack of clients – only 772 ha were rented – and by the low average income of the container terminals, which made up 85% of the clients. The team with the highest score had a fully occupied area and a high income per hectare per client.

The profits of the simulated Maasvlaktes also show large differences. The team with the greatest loss, 2.1 billion euros, was the same as the team with the minimum income, which directly explains this loss. The team with the best financial performance had a profit of 1.6 billion euros, caused by its high income.

Furthermore, the results show that 54% of the teams made a profit after 30 years and that 46% did not reach a break-even point. On average, the simulated Maasvlakte 2 made a profit of 6 million euros. Due to the large variety, this is not statistically significant from zero. That means it is possible to reach the break-even point within 30 simulated years. Some teams even reached this point within 25 years, while others were still far from making a profit after 30 years.

7.1.2 Spatial performance

The second group of indicators is the spatial performances. The spatial division of clients has consequences for the zoning plan, hinterland transportation and emissions. Spatial indicators are construction progress, division of clients and rented areas over time.

The fastest construction took place in 10 years, which means the area was finished in 2016. All working packages were built in as rapid a succession as possible. At the other extreme, there was a team which had not finished construction in 2037 because of insufficient client demand. On average, the first parcels were finished in 2015 and the total area was finished around 2023.

If we look at the rented area, we see that the minimum rented was 720 ha in 2037, which means 280 ha were still vacant. The maximum rented area was 1,288 ha, which meant that this team had to disappoint clients, because no space was left.

Another spatial criterion is the division of the clients. The largest part of the area was used for container terminals, at an average total of 623 ha (Table 7-2). The total area of distribution and chemical industry was significantly lower: 133 ha and 184 ha respectively. Conversely, a new group with alternative clients occupied on average 51 ha of area.

Table 7-2. Average area of each type of client

	N	Minimum in Ha	Maximum In Ha	Mean In Ha	Std. Deviation
Area Distribution	78	49	362	133	60.86
Area Chemical	78	28	493	184	88.16
Area Alternative	78	0	115	51	32.79
Area Container	78	381	880	623	101.96

A different distribution of types of clients gave a completely different lay-out, as can be seen in Figure 7-1 and Figure 7-2. The left figure (7-1) shows a team which focused on the chemical industry, which is indicated in green. In this example, less space is used for container terminals (indicated in red) and distribution (indicated in yellow). The figure on the right (7-2) shows the lay-out of the area with a focus on the container sector. In this example, there is more distribution and less chemical industry and alternative clients (indicated in blue).

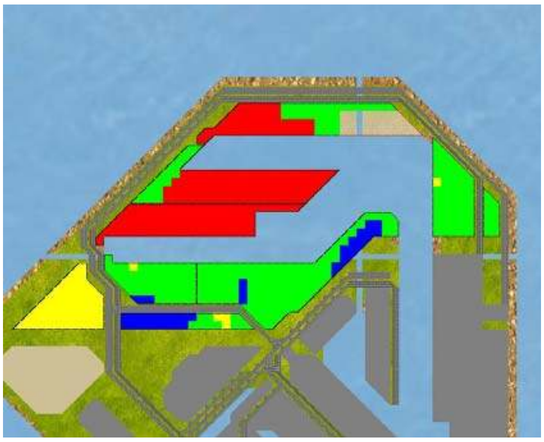


Figure 7-1. Focus on chemical market (Team Speed Port)

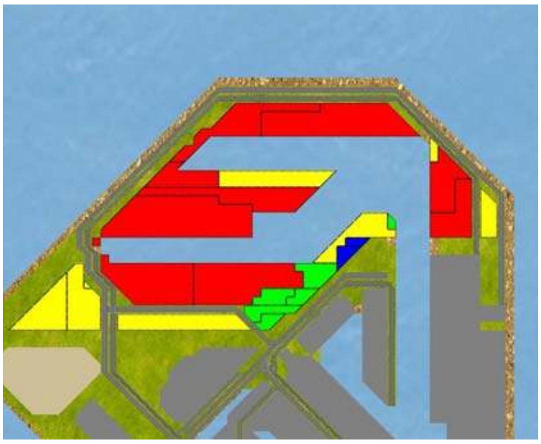


Figure 7-2. Focus on container market (Team Bright Port)

The maps also provide information about the clustering of clients. This clustering has exploitation advantages (Port of Rotterdam, 2003). For example, they use the same type of quays and exchange raw materials. Figure 7-3 shows a nicely clustered design for Maasvlakte 2. The cluster of the chemical industry is placed next to the existing chemical area on Maasvlakte 1. A completely different design can be found in Figure 7-4, where different types of clients are juxtaposed. From the 74 valid maps of the situation in 2036, 35 showed a clustered design, and the others showed an unstructured division of clients. Players gave two reasons for not producing a clustered lay-out. First, they did not focus on clustering, and second, the clients wished to be placed on another parcel and the players complied with their request.

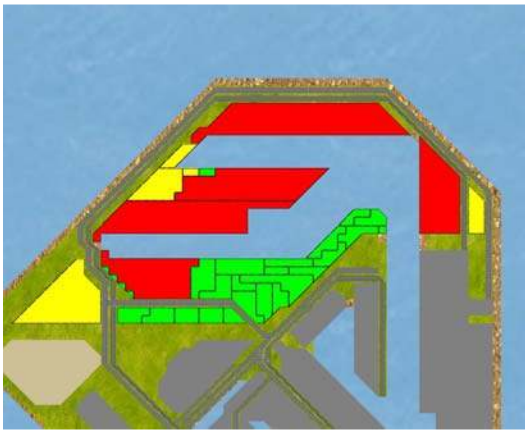


Figure 7-3. Nicely clustered design of MV2 (Team IPS)

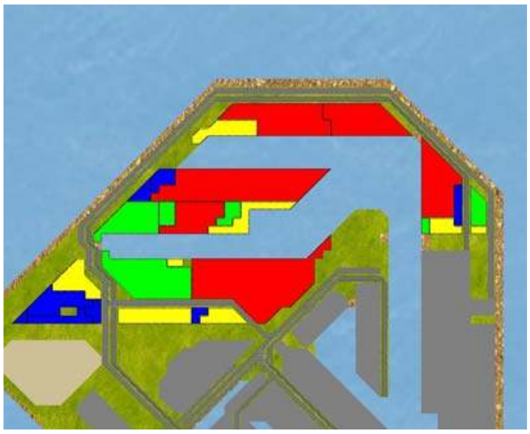


Figure 7-4. Unstructured division of clients on MV2 (Team Porter)

7.1.3 Process performance

Finally, the performance of a team is based on the decision-making process. The indicators are the internal communication and client satisfaction.

Internal communication

The team consists of three to six participants divided over three different roles, with their own responsibilities and without any hierarchy (Figure 7-5). The commercial director is responsible for the negotiations with clients, the building director is responsible for the construction, and the general director is responsible for the coordination and finance. Communication between the players is necessary for the coordination between the construction and exploitation of Maasvlakte 2.

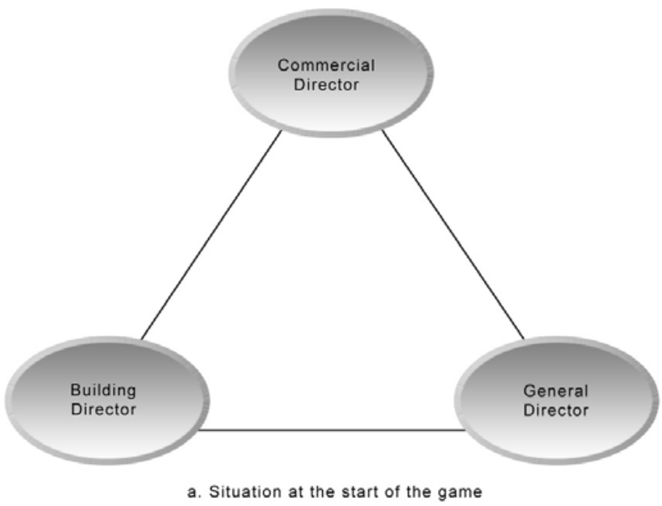


Figure 7-5. Division of roles at the start of the game

Observations of the sessions showed that the participants needed some time to structure the communication processes. Many teams restructured the responsibilities after a period of 10 simulated years. In general, three different networks can be observed. The first shows only a small change as compared to the starting situation, where the general director supports the other directors in contracting clients and building MV2.

The second structure, which emerged during the game, is the division of the participants over the type of clients (Figure 7-6 b). In this situation, participants are responsible for the processes of one type of clients: negotiation, contracting and placing clients on the map. Based on the allocation plan, each role knew the number of hectares and parcels for his type of client.

The third structure shows a hierarchical structure. One of the participants, not always the general director, heads the team and coordinates the entire process (Figure 7-6 c). All decisions have to be communicated to the coordinator, who writes everything down. In this way, each team member has an overview of when certain areas are built and how much area is left for new clients.

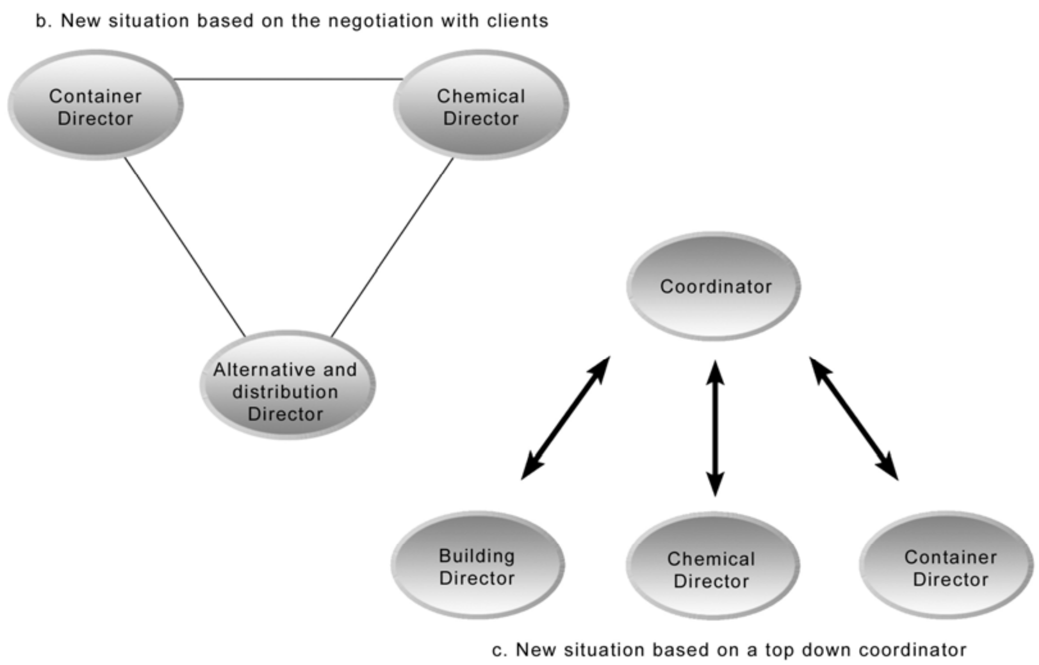


Figure 7-6. Roles divided by the type of client (b) and roles divided in a hierarchical structure (c)

Client satisfaction

The second indicator of the quality of the process is client satisfaction. The satisfaction of the client is based, among other things, on the speed of the negotiation process and whether the team adheres to the contract. In the redesign of the game, the calculation of satisfaction was improved. This makes the satisfaction of the two versions incomparable. The results are therefore split between teams of SIMMV2 and SimPort-MV2. The satisfaction score is based on a percentage, where the higher the percentage, the higher the satisfaction. Client satisfaction was on average 82% for the SIMMV2 game and 64% for the SimPort-MV2 game (Table 7-3).

As can be observed, the percentages of SimPort-MV2 are lower. In SimPort-MV2, the model checked whether or not the client received enough space and the correct length of the quay as stipulated in the contract, a feature which was not implemented in SIMMV2. When an area was rented twice and a conflict arose surrounding the use of space, this became visible in the client satisfaction.

Table 7-3. Average score of the client satisfaction after 30 years

Satisfaction	N	Minimum In %	Maximum In %	Mean In %	Std. Deviation
SIMMV2	26	61	94	82.96	9.13
SimPort-MV2	50	44	78	63.86	8.42

Client satisfaction was not constant over time. Therefore, we show the satisfaction over the 30-year period for the teams with the minimum and maximum scores in 2037 (Figure 7-7 and Figure 7-8). The team *SimCity* started with an increasing satisfaction; however, satisfaction soon declined to a percentage below 30 in 2015. The most important reasons for this were that areas were not delivered on time, the size of the area was too small, the length of the quays was too short or negotiation time was long – in one case 9 years! After 2015, the team recovered and satisfaction increased to 44%.

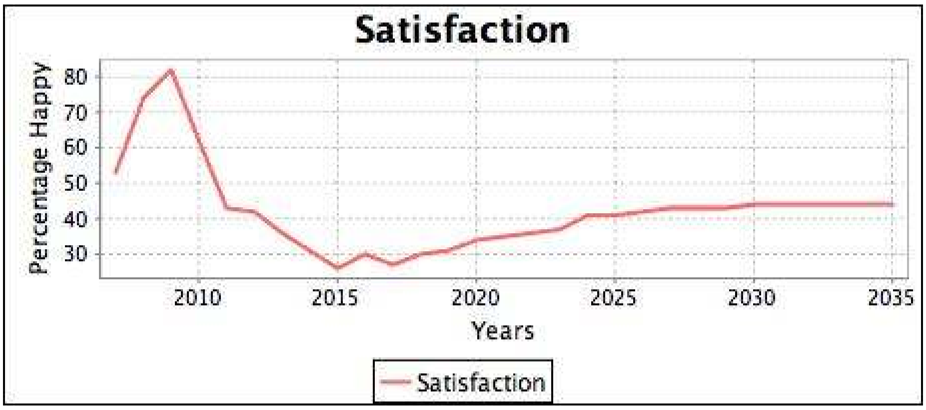


Figure 7-7. The client satisfaction of the team with the lowest satisfaction after 30 years (Team SimCity)

The second example is that of *Team 1*. After a couple of years, the client satisfaction of Team 1 grew to 95% in 2016. Thereafter satisfaction decreased slightly but remained around 80%. The reason for this high level of satisfaction was that there were no delays in building the areas for large customers. Furthermore, they gave the clients what they agreed to in the contract.

Figure 7-8. The client satisfaction of the team with the highest satisfaction after 30 years (Team Team 1)

7.1.4 The solution space

The results of the performance indicators showed that there is a large variety of possible outcomes. There are large differences in revenues and profit, in the lay-out of the Maasvlakte 2 area and in the satisfaction of the clients.

It is also observed that a high score on one performance indicator did not necessarily mean that the other performance indicators were also high. Consequently, the winning teams were not the ones with the highest score on a single indicator, but on the average of the indicators revenue, profit and satisfaction at three moments in time (2017, 2027, and 2037). In this way, the players had to balance the different objectives.

This can be illustrated by the top scores of two teams, one of the SIMMV2 competition and one of the SimPort-MV2 competition (Table 7-4). As we can see, the best teams scored above average on the three indicators, but no score was the highest of all teams. This shows that focusing on one indicator is not enough to win and that the teams have to deal with multiple criteria at several moments in time in order to achieve the best score after 30 years.

Table 7-4. Strategy and performance of the two winning teams

Winner SIMMV2 Boom Havens Int	Winner SimPort-MV2 Maasdwazen
Building strategy: Maximum flexibility Commercial strategy: On top of things	Building strategy: Fast Forward Commercial strategy: On top of things
Revenue: 3,737,468 K € (average 2,722,091 k €) Profit: 897,494 K € (average 104,695 k €) Client satisfaction: 90% (average 82%)	Revenue: 3,618,736 K € (average 2,627,205 k €) Profit: 1,188,857 K € (average 5,854 k €) Client satisfaction: 73% (average 64%)

7.2 Explanation of the solution space

The teams started on an equal basis; they had the same information, the same starting situation and the same tasks. The differences in the outcomes can only be explained by the choices of the teams and the response from the simulation. Although each gaming session was unique, some general patterns and considerations are observed. These observations are the emerging properties of the game play, which is divided into the consequences of the strategic choices, game processes and sensitivity of the system.

7.2.1 Consequences of strategic decisions

The outcomes as presented in the previous section are emergent outcomes. They are all based on the combining effects of players' decisions and the responses of the system. In this section, the consequences of the strategic decisions are discussed.

Commercial strategy

Of the 88 teams, 70 chose the 'on top of things' commercial strategy. Despite the intentions to set strict requirements, many teams did not manage to follow their criteria. This frequently led to unstructured lay-out of operating clients. The three explanations mentioned most frequently were:

- potential clients asked for different parcels,
- there was no other area available, and

- other companies than those desired contacted the teams.

Towards the end of the game, the lay-out became further unstructured, because participants had to fill in the gaps (empty spaces between clients) with a variety of small companies. Alternative clients paid enough and needed only a small area; they fit nicely in the unoccupied areas. Therefore, the number of alternative clients was high in several teams. However, they did not fit the deep-sea related criterion.

Building strategy

Another observation is that many teams chose a flexible building strategy. The teams selected the alternatives to build the area based on client demand, as we learned from the motivations:

> 'Maximum flexibility gives us the possibilities to adapt the building of the port to the market situation of that moment without losing too much money' (Team Boom Haven Int.)
>
> 'This strategy gives us enough flexibility while still maintaining a good construction time.' (Team The Outsiders)
>
> 'Gives more flexibility in order to address the clients' needs as more information becomes available.' (Team GTS Consultants)

However, the results show that this flexibility was hardly used. In 23% of the teams there was no flexibility at all, and in 41% the flexibility was hardly used. If the demand was high enough, then this flexibility was needed. However, results of the teams show that building as quickly as possible was not a result of the number of contracted clients.

Table 7-5. Overview of the teams made use of the flexibility of phased building process, where 'as fast as possible' means that all working packages are started immediately when possible and 'maximum flexibility' means that the working packages are started independently of each other

	Frequency	Valid Percent
As fast as possible	17	23.0
Hardly use flexibility	30	40.5
Average use of flexibility	19	25.7
Maximum use of flexibility	8	10.8

Flexibility is important for dealing with uncertainties in systems with high path-dependency, like the construction of Maasvlakte 2. Once the construction of a parcel is begun, it cannot be stopped or removed. Next, three examples are given of teams that built the port area as quickly as possible, and the different outcomes are shown.

The consequence of inflexibility can be seen in the process of *Barval Ports*. Figure 7-9 shows the amount of area which was reclaimed, built and contracted. This team had chosen the ‘fast forward’ strategy, which consists of two building phases. The Maasvlakte 2 area was finished in 2020, but the client demand was not high enough to fill the area. In 2036, the total area contracted was around 720 ha in 2035, and 280 ha of area was still unused. Because of the lower flexibility, the team could not respond to the lower demand. Consequently, parts of Maasvlakte 2 remained vacant (Figure 7-10).

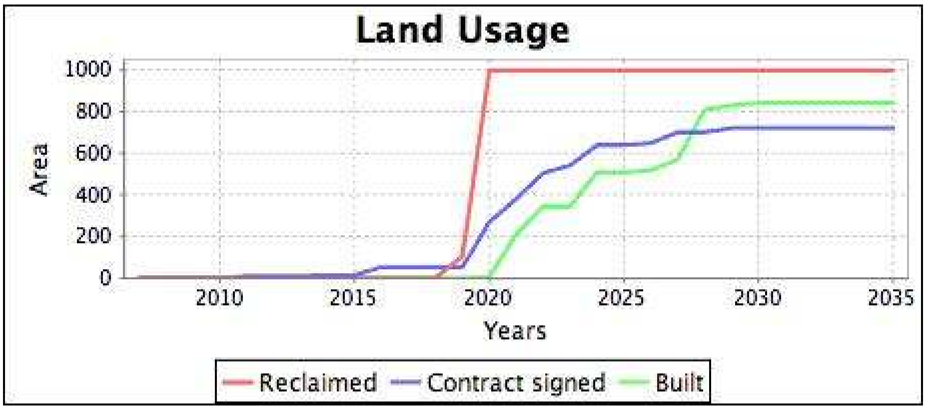


Figure 7-9. Land usage of the team Barval Ports with the building strategy ‘Fast Forward’

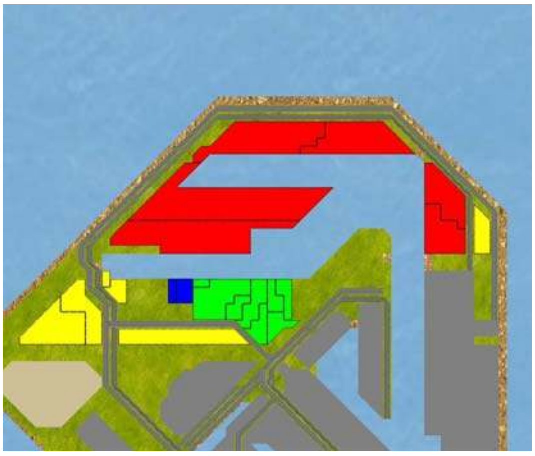


Figure 7-10. Map of team Barval Ports 2036, with lots of space left

Another example is that of *Team 1*, who chose the ‘all in one go’ strategy. This team had the possibility of building the port area flexibly, in accordance with demand. However, they did not use the flexibility of this strategy. As can be seen in Figure 7-11, after 2015 the team continued building Maasvlakte 2, while contracts lagged behind. Based on the contract, the last two working packages were able to be started seven years later, without delays in delivery of parcels. Many teams had similar figures.

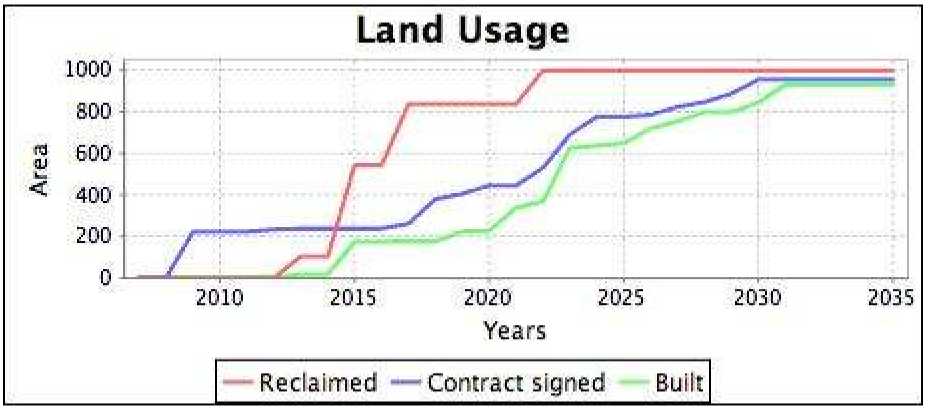


Figure 7-11. Land usage of Team 1 with building strategy 'All at one go!'

A third example of a team who built the area 'as fast as possible' is *Evian* (Figure 7-12). They had to build the area because they contracted many clients. This meant vacant areas were scarce.

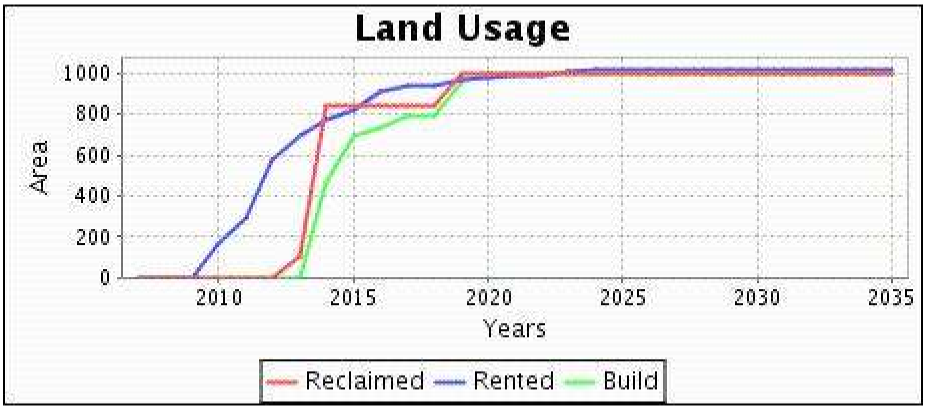


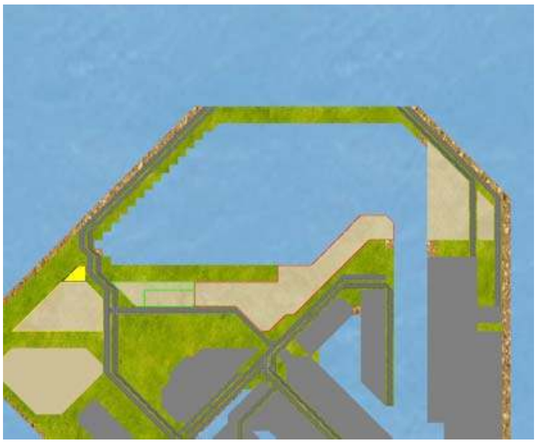
Figure 7-12. Land usage of team Evian with building strategy 'Carrying on but not rushing it'

Negotiation process

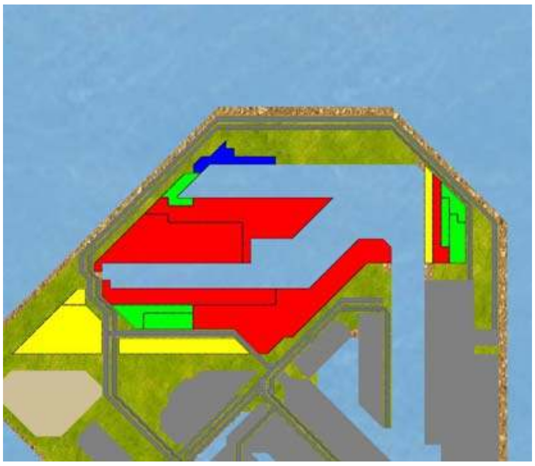
The building process is an example of a path-dependent process. Another path-dependent process is contracting clients. In the game, it is not possible to change or break signed contracts. Each new contract changes the structure of the system, because a certain area and quay length is assigned to a client and less area is available for future contracts.

Several times teams had conflicting situations because two clients were assigned the same parcel or the length of the quays was too short. The players dealt with this conflict in different ways, with varying consequences for client satisfaction. This was also observed by one of the players on the team *Op naar MV3*. He said, 'if your start is not good, you will lag behind'. One example of this growing process is shown in Figure 7-13, where the Maasvlakte 2 area is illustrated at four moments in time.

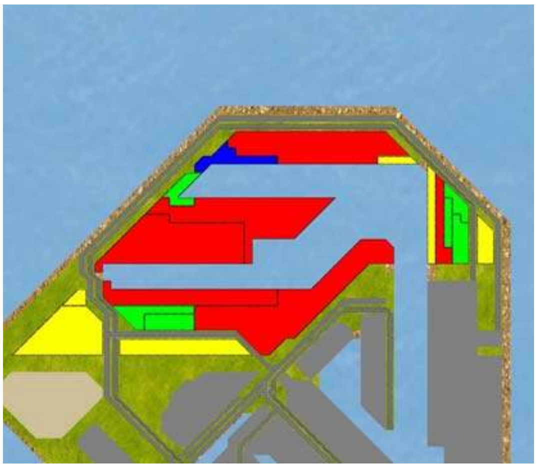
Maasvlakte 2 in 2007 (Team FFHP)



Maasvlakte 2 in 2016 (Team FFHP)



Maasvlakte 2 in 2026 (Team FFHP)



Maasvlakte 2 in 2036 (Team FFHP)

Figure 7-13. Evolution of the Maasvlakte 2 of team Fast Forward Harbour Planners. The dark grey area is the current Maasvlakte 1, the light grey area is the area under construction, green indicates the area which is finished and the light green, red, yellow and blue areas are clients.

7.2.2 Game play processes

Most sessions followed the same pattern of playing. In general, a session consisted of three different phases of structure: the chaos phase, the organized phase and the last-minute phase. The length of each phase differed per team, as did the level of chaos and organization.

After the strategy phase, where the players tried to get an overview, the time started. Almost immediately the teams entered the 'chaos phase'. In this phase, the process was characterized by an unstructured situation. Players did not know what they had to do, nor what the other team members were doing. They faced communication problems and an information overload. This phase resulted in vacant areas, an unstructured lay-out and low client satisfaction.

During the game, the players changed processes and entered the 'organized phase'. This change was especially obvious after the first break, when the teams had

had some time for reflection. In the first place, participants made agreements about which information was relevant, and several teams changed the structure and roles of the organizations, as described in 0. In the second place, players learned each other's language and developed a standard for communication. Players grew accustomed to concepts in the game. At the beginning, nobody had any idea what a 'work package' was or where 'parcel 131' lay. After one hour of playing, all players were acquainted with these concepts. Third, agreements were made between the players on how to exchange information. Groups developed different protocols for exchanging information, for example, with post-its, notes on a piece of paper or on the white board. These changes are examples of the self-organizing property of this system.

In the organized phase of the game, players entered a flow of building and negotiation. In this phase, most of the working packages were started and discussions about planning changed to discussions about optimizing the negotiation process. Due to path-dependencies, the freedom of decisions decreased. This made coordination and decision making easier.

The third type of process was observed at the end of the game, when most of the work was done: the Maasvlakte 2 area was built, most of the parcels were rented, and there were only small parts left. In this 'last-minute phase', some players of the team contacted clients and rejected them based on area size, while others adopted the stance of 'wait and see'.

7.2.3 Robustness and instability

If the solution space is determined by the individual players, and if the system shows emergence, self-organization and path-dependencies, then we would like to know which parameters make the system instable and for which parameters the system is robust. Although robustness and instability are two separate properties of a complex adaptive system, they are described together in this section.

The parameters discussed are: 1) choice of building strategy, 2) choice of commercial strategy and 3) economy. The different choices are compared in terms of financial performance and client satisfaction.

Building strategy

The first choice discussed is the building strategy. Table 7-6 shows the costs of the construction per building strategy. The cost of the 'all in one go' strategy was lower, because the outer contour and the infrastructure did not have to be replaced. The costs of the areas built with the 'Maximum flexibility' strategy were higher than those of the other strategies. The flexibility made the construction more expensive, because activities were not combined efficiently.

Table 7-6. The costs of building the Maasvlakte 2 area per building strategy

Strategy	N	Minimum	Maximum	Mean	Std. Deviation
Fast Forward	5	2,154,661 K	3,136,269 K	2,515,701 K	366.763
Carrying on but not rushing it	51	2,333,627 K	2,935,473 K	2,633,582 K	105.212
Maximum Flexibility	6	2,595,102 K	2,971,499 K	2,857,282 K	140.646
All in one go	12	2,145,482 K	2,693,619 K	2,492,948 K	133.940

As can be seen in Table 7-7, the building strategy also influenced the income. The 'all in one go' strategy generally had a lower income than the other chosen strategies. One explanation is the delay before starting to build due to procedures related to the compensation project. Consequently, the income from rented areas and port dues also started later.

Table 7-7. The income of the Maasvlakte 2 area per building strategy

Strategy	N	Minimum	Maximum	Mean	Std. Deviation
Fast Forward	5	1,892,540 K	3,618,736 K	3,029,671 K	757.437
Carrying on but not rushing it	51	911,320 K	4,418,423 K	2,679,562 K	746.181
Maximum Flexibility	6	2,178,592 K	3,737,468 K	2,853,673 K	550.342
All in one go	12	559,821 K	3,078,031 K	2,123,757 K	732.854

If the costs and income were the lowest in the 'all in one go' strategy, then the question is what the combined effect was on the profit. From Table 7-8 it can be deduced that for all strategies, teams suffered a loss or earned back their investments.

Table 7-8. The profit of the Maasvlakte 2 area per building strategy

Strategy	N	Minimum	Maximum	Mean	Std. Deviation
Fast Forward	5	-545,148 K	1,188,857 K	513,969 K	715.869
Carrying on but not rushing it	51	-1,517,889 K	1,670,508 K	45,399 K	718.009
Maximum Flexibility	6	-759,570 K	897,494 K	-3,608 K	620.235
All in one go	12	-2,133,798 K	518,317 K	-369,191 K	779.607

The client satisfaction after 30 years did not differ among the different building strategies (See Table 7-9).

Table 7-9. Satisfaction of the clients after 30 years per building strategy

Strategy	N	Minimum (%)	Maximum (%)	Mean (%)	Std. Deviation (%)
Fast Forward	5	50	88	69	13.67
Carrying on but not rushing it	52	46	94	71	12.87
Maximum Flexibility	6	54	90	71	13.88
All in one go	13	44	90	69	11.44

In conclusion, the choice of building strategy influences the costs, the income and the profit after 30 years. The costs of the 'all in one go' strategy seem to be lower, because the outer contour does not have to be replaced. At the same time, the income after 30 years is also lower, because the first container can be loaded later in time. The building strategy does not make any difference for client satisfaction after 30 years.

Commercial strategy

The second strategic choice is the commercial strategy. From Table 7-10 it can be concluded that there is no significant difference in costs, revenues and profit caused by the different commercial strategies. The commercial strategy also does not affect client satisfaction (Table 7-11).

Table 7-10. The costs, the revenues and the profit after 30 years per commercial strategy

Strategy	N		Minimum (K€)	Maximum (K€)	Mean (K€)	Std. Deviation (K€)
Come as they may	14	Total costs	2,333,627	2,938,162	2,634,772	170,497
		Total revenues	1,152,661	3,851,115	2,585,926	733,419
		Profit	-1,438,907	1,124,071	-50,989	733,121
On top of things	60	Total costs	2,145,482	3,136,269	2,617,724	164,772
		Total revenues	559,821	4,418,423	2,636,836	768,370
		Profit	-2,133,798	1,670,508	19,118	714,644

Table 7-11. Satisfaction of the clients after 30 years per commercial strategy

Strategy	N	Minimum (%)	Maximum (%)	Mean (%)	Std. Deviation (%)
Come as they may	14	49	84	69	11.15
On top of things	62	44	94	70	12.92

The outcome of the system described in financial performance and satisfaction is robust for the choice of the commercial strategy. A possible explanation is that contrary to the building strategy, the commercial strategy can be adapted. This is what we also observed in the game, where people started with the 'on top of things' strategy but switched to the 'come as they may' strategy in order to increase the number of contracts and earn as much money as possible.

Economy

The starting situation was a growing economy, which indicates that demand for space was high and transhipments were high and growing: a perfect situation for the start of this project. To experience the consequences of changes in the economy, the economic situation worsened over six sessions.

For two teams, the economy declined in the last period. Because the Maasvlakte 2 area was already built and most of the contracts with clients were already signed, the consequences for the profit were minor. The results of these teams, Casco and SimCity, are given in Table 7-12.

The other four teams observed a declining economy in the second period. As can be seen in Table 7-12, this had consequences for the outcome. Negotiations with clients become more difficult, and contracted rents were lower. This had consequences for the entire period, even when the economy improved after some time. Other effects were the lower number of transhipments, which led to a decrease in port dues. After 30 years, the revenues were lower than average and the teams did not make a profit.

Table 7-12. Financial results of the teams with a low economic growth

Team name	Period of economy decline	Revenues (K€)	Profit (K€)
Casco	3	3,586,192	1,166,182
SimCity	3	2,686,157	89,479
Havenbaronnen	2	1,401,416	-1,251,018
Maaskoning	2	2,362,647	-204,421
Speedport	2	1,892,540	-545,148
Havenkoning	2	2,346,819	-272,393

From this small number of teams, we see that the system is unstable for the economy during the design and in the negotiation phase. However, as soon as Maasvlakte 2 is built and clients are settled, the system is more robust for economic fluctuations.

7.3 SimPort-MV2 as a complex adaptive system

Based on the characteristics of Complex Adaptive Systems as defined in Chapter 2, we analyse whether SimPort-MV2 simulates a complex adaptive system. The game can be considered a system which consists of agents, network, and aggregate system. The properties on this level can be pointed out in the structure and the behaviour of the game.

Several design criteria are defined to create an environment in which complexity can emerge. For example, the agents are determined by the developers, as are the starting rules and initial reference system. However, this does not completely justify the system's being complex: we also have to compare the dynamics of the game with properties of Complex Adaptive Systems.

7.3.1 SimPort-MV2 at the agent level

Playing the game with different participants provided a variety of agents in the system. Each participant differed in terms of past experiences, knowledge and motivation. The difference between the participants led to a variety of game play. Some teams were proactive and decided on the strategy without thinking of the consequences within 5 minutes. Other teams had more problems and had to be forced to decide on their strategy after one hour of weighing the pros and cons. There are players who made decisions without informing other team members. On the other hand, there were teams in which decisions were only made when everyone agreed.

We observed during sessions that a unified language and communication protocol is developed to communicate within the team and to coordinate the MV2 project. For example, the concepts of the building strategies and the names of the parcels became familiar to the players in the team. This is a known strength of games in the literature (Duke, 1974; Duke & Geurts, 2004).

We also observed that the participants adapted continuously to new situations and new events. Some teams adapted their initial strategy in order to increase the speed of contracting. That meant that all properties at the agent level were present (Table 7-13).

Table 7-13. Properties of the agent level in SimPort-MV2

Agent level: properties	
Property	Game operationalization
Adaptiveness	Changing commercial strategies
Agent diversity	Different people, different clients
Interface and protocol similarity	Learning the game language

With gaming it is possible to explore the diversity and the adaptation of the players due to the changing environment. Sometimes it is even possible to extract some internal rules of the players. This means that gaming can be used to analyse the behaviour of the key actors in the real-world system and their personal intentions and objectives related to the observed system.

7.3.2 SimPort-MV2 at the network level

Table 7-14 presents the game operationalization of the properties at the network level. We observe network dynamics in the flow of information from one component to another. This is information between individual participants, between participants and the formalized system, and between building and finances.

Network evolution is visible in two ways. The first is the emerging port area. Due to the construction of the area and contracting clients, elements and relations change. Each action changes the structure and flow of information in the system. The game starts with water and ends with an industrialized area.

In the game, the possibility of changing the topology is limited, due to the choices in the design. However, the freedom of players to change their internal organization is often used. Many teams redistributed the responsibilities and tasks among the players. In the course of the game, the flexibility of the choices decreased. More and more fixed relations were formed.

Table 7-14. Properties of the network level in SimPort-MV2

Network level: properties	
Property	Game operationalization
Network dynamics	Information exchange about signed contracts Exchange of money and construction
Network evolution	Changing structure of the team Growth of the area

In a game like SimPort-MV2, network dynamics and evolution are observable. However, the changes in the physical system are less surprising, because most of the rules are set. The use of a computer model makes it possible to show these dynamics and influence the decision making. The evolution in the social system shows that multi-player games can be used to explore different types of organizations and the consequences of these structures. The outcomes of the game did not significantly differ between the structures, but that is only valid for this game. Serious gaming can be used to illustrate different paths of growth and evolution of new structures in the actor system.

7.3.3 SimPort-MV2 at the system level

The outcome of Simport-MV2 depends on the individual decisions of participants and the response of the formalized simulation. The combination gives an emergent outcome in a broad solution space. During game play, several properties of CAS have been found that can explain the outcomes.

First, self-organization was observed. After the start of the game, no intervention from outside was required to keep the processes going. The participants were free to structure their processes, and they organized these themselves. Fewer examples of self-organization in the physical system were found because a large part of the model is deterministic.

Second, there were two examples of path-dependency. These were the construction process of MV2 and the contracting process with clients. Both processes consisted of irreversible decisions, with consequences for future steps. Changes in the environment could not be compensated for by removing buildings or breaking contracts.

Finally, analysis of all outcomes showed that the system is robust for the commercial strategy and allocation plan chosen, because these are more flexible and open to change. The economic climate and building strategy are parameters which can make the system unstable. Table 7-15 summarizes how the system-level properties of CAS are operationalized in the game.

Table 7-15. Properties of the system level in SimPort-MV2

System Level: properties	
Property	Game operationalization
Self-organization	Communication and coordination within the team
Path dependency	Construction of MV2 Contracting clients
Robustness	Commercial strategy
Instability	Economy during construction phase Building strategy

Finally, the observations on the system level show that gaming can be used to explore emergence, self organization, path dependency, robustness and instability. The outcomes of the game can be explained based on these properties.

When we consider the game SimPort-MV2 as a system in and of itself, we observe the properties of a CAS at each level of the game. That means SimPort-MV2 can be seen as a complex adaptive system. Based on the requirement that a game has to simulate complex adaptive system behaviour to analyse the dynamics of the system, we can conclude that the game SimPort-MV2 can be used to analyse the dynamics of the MV2 system.

7.4 Implications for the Port of Rotterdam

The objective of the game was to gain better insight into any unforeseen, undesirable or unintentional effects of one or more development strategies for the performance of Maasvlakte 2. The results of the sessions played provide insight into this behaviour. We use the expectations of the Port of Rotterdam as defined in the key planning decision, business case and other documents for comparison. Differences between the outcomes are explained. We describe the performance of Maasvlakte 2, sensitivity of the strategic choices, and synchronization of the processes.

7.4.1 Performance of Maasvlakte 2 in 2037

There are three criteria for comparing the expectations of the Port of Rotterdam with the game output. These are the construction time, the division of clients and finance.

Construction time

After several delays, the objective of the Port of Rotterdam is to finish the first parcels in 2013 (Van Haastrecht, 2008; Keuning, 2009). The total construction has to be finished in 2028.

The results of the game showed that on average the first parcels are finished in 2015, a couple of years later than desired. These delays are caused by delays in the building process or the long negotiation for nature compensation. On average, the area is constructed around 2024, a couple of years sooner than planned. The most important reason is that many teams build the area as quickly as possible without reckoning with customer demand.

Division of clients

The Port of Rotterdam has defined three main types of clients: container terminals, chemical industry and distribution (Port of Rotterdam, 2003). They expect that the container terminals will be the largest group, with a planned area of 625 ha. The chemical industry and the distribution are planned for 210 ha and 165 ha, respectively.

The results of the game showed many different lay-outs for MV2. On average, a Maasvlakte 2 lay-out consists of 625 ha of container terminals, 182 ha of chemical industry and 132 ha of distribution area. This means that the amount of container terminals is comparable with the expectations of the Port Authority, while distribution and chemical industry occupancy is lower than planned.

This is caused by 51 ha of alternative clients (among others, a home for the elderly, a shrimp farm and a gold treasury), which are implemented in the game. These alternative clients are added to show the behaviour of the team to clients who deviate from the criterion in the key planning decision (PKB). In the PKB an appointment is made to develop the area for deep-sea related activities (*Ministerie van Verkeer en Waterstaat, Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, Ministerie van Financiën, Ministerie van Economische Zaken, & Ministerie van Landbouw Natuur en Voedselkwaliteit*, 2003).

The players show that it is difficult to refuse signing contracts with alternative clients. They are interesting when the demand for area of the industry lags behind or when only relatively small parcels are left. Then economic reasons become more important than the strict requirements of the team.

Finance

The Port of Rotterdam wants to reach a break-even point in 30 years, assuming a contribution from the government (Port of Rotterdam, 2003).

The financial situations of the simulated areas showed great diversity. This shows the large uncertainties of costs, income and profit over a 30-year period. In the game, 54% of the teams broke even before the end of the game (after 30 simulated years). Several other teams were close to breaking even. If we look at the profit of the teams, this was on average 6 million euros. However, the variety in the profit makes this average not significantly different from zero.

According to the outcomes of the game, it is possible to make a profit, but there is no guarantee of this. The income shows a large variety. One important remark must be made about these numbers, namely that in the game only direct costs and income are taken into account. Indirect income from transportation to the hinterland, employment in the area and other sources are outside the scope of the game and will need to be taken into account in the real-world situation.

7.4.2 Sensitivity of strategic choices

A second point for reflection is the sensitivity of the strategic choices of the Port Authority for the outcomes over the medium term. As described in section 7.2.3, the outcome in the game is sensitive to economic fluctuations and building strategy.

The financial results of the teams that had to build Maasvlakte 2 in a worse economic scenario were significantly lower than that of other teams. Client demand was lower and contracting was more difficult.

The results show that the system is unstable for the building strategy. Once building starts, it is difficult to stop the construction process or change the speed of the process. Choosing a flexible building strategy is preferred. However, this is only useful when building is postponed when new areas are not needed. In the game, the participants selected the flexible strategy, but they built as fast as possible.

The performances of the simulated areas further show that the outcome is robust for the commercial strategy and allocation plan. This does not mean that different commercial strategies and allocation plans do not give different outcomes. The team is more flexible in adapting their strategy, however.

In the course of the game, the final lay-out diverges from the allocation plan, because clients prefer other parcels than planned or other industries are more interesting than expected beforehand. In addition, the negotiations between the team and clients are not strictly conducted according to the strategy.

7.4.3 Synchronization of parallel processes

The Port of Rotterdam has taken on the challenge of synchronizing the construction and exploitation process in order to avoid unnecessary investments. This challenge was also made to the participants in the game. We observed that following the strategy ‘contracting clients before building’ is difficult, independent of the building strategy. Participant gave as reasons that clients prefer areas other than the ones which were built or they have another time frame. Closer to the end of the game, it also seemed more difficult to continue following the strict requirements, because there was not much space left and the players wanted to fill these areas as quickly as possible.

Even more important is the communication within the team. Synchronization requires good communication and coordination. In the game, this communication was problematic. Participants were not aware of the information they needed from each other or the information was unclear. After some time, this process improved significantly; however, by then many decisions had already been made.

Two teams showed that it is possible to first contract clients and then start building. The land usage of team Delfia Ports and Mosselhaven are given in Figure 7-14 and Figure 7-15. In both teams, there were hardly any empty areas in MV2, which means that cost and income were close to each other.

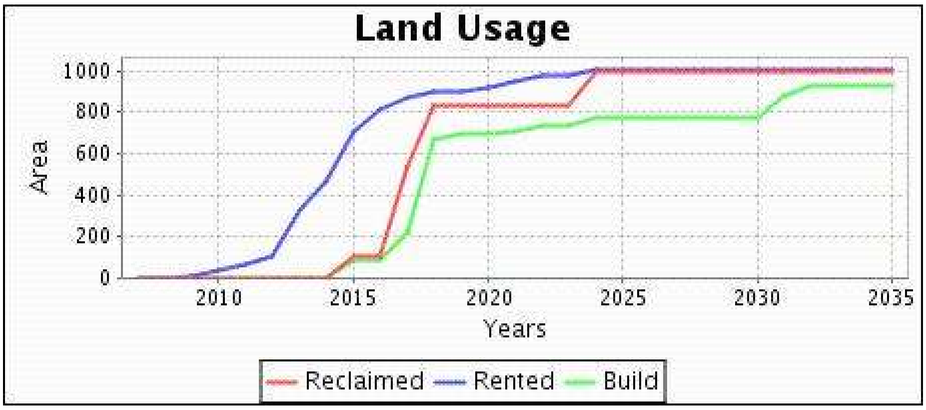


Figure 7-14. The land use of Delfia Ports over the time period. The blue line indicates the number of ha rented, the red line is the number of ha reclaimed, which follows the blue line, and the green line indicates when the clients finished building their parcel.

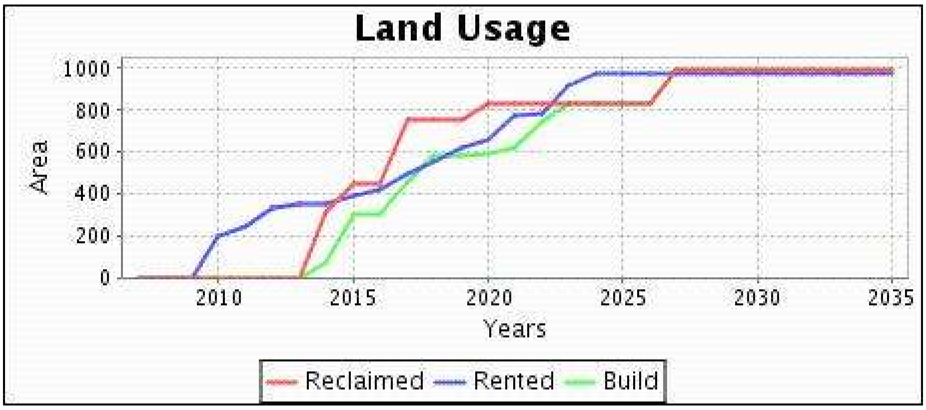


Figure 7-15. Another example of first contracting clients then building, from Mosselhaven (bs = maximum flexibility)

From the results of the game, we learn that it is difficult to follow a pre-defined plan. Even in the simplified environment of the game, with a limited number of decisions and performance indicators, it is difficult to follow the defined strategies. Planning is still useful for setting a goal for the future and defining the steps which have to be taken. However, especially in long-term projects, the planning has to be flexible and the actors involved have to adapt to changing situations.

7.5 Conclusion

This chapter had two objectives. The first objective was to analyse whether Simport-MV2 simulates a complex adaptive system and which properties of complex adaptive systems can be observed. Because we concluded that SimPort-MV2 simulates the complexity, the second objective was to derive some lessons from the dynamics in the game applicable to the real-world Maasvlakte 2 project. These are based on the objectives of the game at the start of the development.

7.5.1 SimPort-MV2 as a complex adaptive system

Based on the characteristics of complex systems as defined in Chapter 2, we can conclude that SimPort-MV2 simulates a Complex Adaptive System. The game can be considered a system which consists of agents, a network, and an aggregate system. The properties of each level can be observed in the game play. Based on the requirement that a game has to simulate complex adaptive system behaviour to analyse the dynamics of the system, we can conclude that the game SimPort-MV2 can be used to analyse the dynamics of the Maasvlakte 2 system.

To analyse the game output for conclusions about the real-world situation, we have to be aware of the limitations of the game. SimPort-MV2 represents a limited model of reality, where many aspects are ignored. These boundaries are set by the designer as a consequence of the choices made in the design process. This means, for example, that dynamics as observed in Complex Adaptive Systems are limited in the game. The freedom of choice is restricted in order to make the game playable. In SimPort-MV2, pre-defined building packages and boundaries for the parcels are given. In reality, the combined building activities and boundaries of the parcels are open. The lay-out of the area is changed several times over the years, as explained in Chapter 5. That makes the solution space even broader than the outcomes of the game.

Another limitation is that the decision-making process is simplified. As explained in Chapter 6 about the design of the game, the negotiation in SimPort-MV2 takes place in three steps, while in reality a research team is formed and several negotiation steps are taken. The tendering of the construction is also limited to defining a start date. Consequently, the outcomes of the real negotiations are open to greater flexibility and balancing between different objectives and different situations.

In conclusion, the game SimPort-MV2 simulates a Complex Adaptive System and shows patterns of complex behaviour. This shows that gaming can be used to simulate Complex Adaptive Systems when an environment is created in which complexity can emerge. Just as in SimPort-MV2, all games simulate a certain aspect of complexity. In reality, more diversity in elements and network is present than what is possible to take into account in a game. Consequently, the solution space in reality is even broader, but the system is also more flexible than in the game. By playing a game, it is possible to gain greater insight into the actors' adaptations and their internal (hidden) rules, the network evolution, emergence, path dependency, self-organization, robustness and instability.

7.5.2 From game world to real world

Based on the validation of the game and the analysis of the complexity of the game, we can conclude that SimPort-MV2 simulates the complexity of the real Maasvlakte 2 in a simplified way. The outcomes of the game can be used to expand the insights into the complexity of Maasvlakte 2. Patterns of system behaviour can be derived which could be used in the policy making process.

- The game showed that the planning as proposed by the Port Authority is feasible under normal circumstances. The results also showed that direct income and profit from Maasvlakte 2 is uncertain and depends on the number of contracted clients.
- The final outcome is sensitive for the chosen building strategy and economic climate. The economy especially influences the outcome when it declines during the building and exploitation period. In this period, it is necessary to contract clients, whereas they are less interested before construction is complete. The outcome is robust for the commercial strategy and allocation plan, because these are flexible.
- Furthermore, it is a challenge to follow a synchronized process of construction and exploitation. Building processes takes a number of years, and clients want to extend in the short-term. Communication between different departments can also lead to coordination problems, yet two teams showed that synchronization is possible.

Besides the limitation of validity, the game SimPort-MV2 contributes to an improved understanding of the complex adaptive system of Maasvlakte 2. This understanding is especially related to the interaction between the social behaviour of the decision makers and the physical consequences for construction and land use.

Gaming is different from decision support systems. Whereas in gaming, long-term processes and interactions have a central place in the analysis of the system, decision support systems (DSS) are focused on the optimal outcomes of decisions. A related difference is that gaming supports the understanding of cause and effect relationships, whereas DSS is often a black box. Finally, gaming is a reason to start a discussion about the outcomes and the way the outcomes are reached, whereas in DSS the objective is to define the 'optimal' solution. Which strategy is best and how to avoid miscommunication cannot be answered with this game. The game experience and the outcome of the game can serve as a starting point or stimulation for the discussion about the effects of different choices and how to avoid bottlenecks in the process.

8. PLAYING SIMPORT-MV2 AND LEARNING ABOUT COMPLEX SYSTEMS

Primary problems of internal cooperation, negotiation and decision-making seem terribly true. (Resp. nr. 12, SIMMV2)

I found new insights into the synchronization of the demand and planning of the building process. (Resp. nr. 112, SIMMV2)

I think that such tools have the potential to improve policy making, as long as they take into account all the important concepts of the system. (Resp. nr. 193, SimPort-MV2)

Introduction

So far, the story of Simport-MV2 has described the complexity of the real-world system Maasvlakte 2, the evolving design of the game SimPort-MV2, and the evaluation of the system behaviour from an outside observer perspective. However, the objective of these steps has been to gain new insights into the complexity of the system by playing a serious game like SimPort-MV2. The individual learning that takes place from playing SimPort-MV2 and the variables which influence the learning outcome are analysed in this last empirical chapter. This chapter answers two questions:

1. What do the players learn about the complexity of the system, and does this differ between different player groups?
2. What input and process variables influence this learning outcome?

To answer the first question, we analysed which learning outcomes were perceived by the players. The six different learning outcomes, which are derived in Chapter 3, were used for this analysis. For each learning outcome, we analysed which results were reached and whether they differed between different groups of players. We used descriptive analyses like means and percentages to analyse the data. Differences in learning between groups of players were analysed with a Bonferroni test.

To answer the second question, that of which variables influenced this outcome, we used the input, process and outcome model as deviated from the theory-oriented evaluation framework of Hense and Kriz (Kriz & Hense, 2006) in Chapter 4 (see Figure 8-1). In this model, we took the input variables game, player and embedding, and process variables computer interaction, personal interaction and engagement into account. We used explanatory factor analysis, principle component analyses and varimax rotation to define some factors out of the indicators (Hair, Anderson, Tatham, & Black, 1998). The results of the factor analyses can be found in Appendices C and D. The factors were used in a bivariate correlation analysis to search for correlations between input, process and learning outcome.

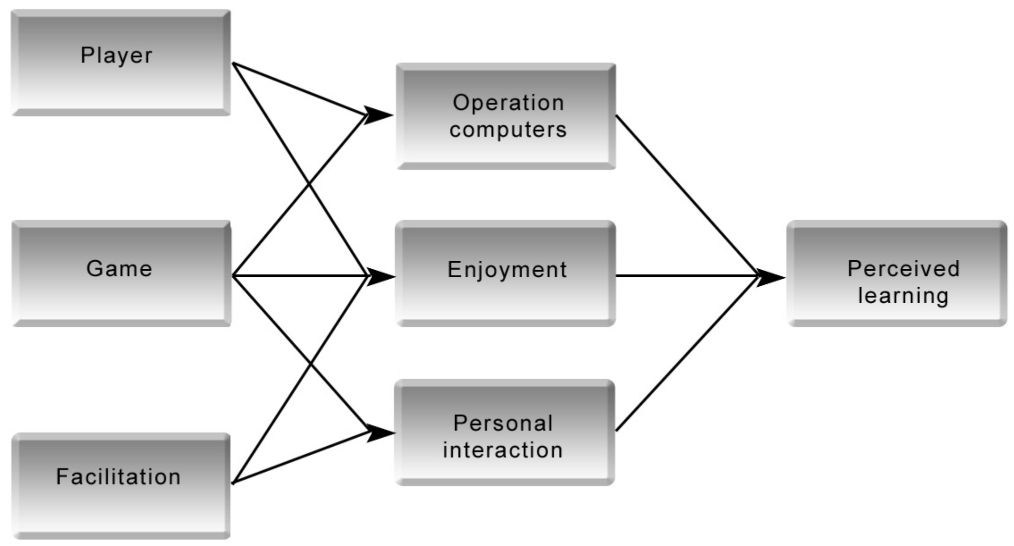


Figure 8-1. Relations between the input, game play and output variables, which will be analysed with the game SimPort-MV2

Before answering the main questions, we wanted to know who the players were and why they played the game. These questions are answered in Section 1. In Section 8.2, the results of the learning experiences are presented. These experiences are divided into declarative knowledge, procedural knowledge and strategic knowledge related to different perspectives of understanding complex systems and Maasvlakte 2. In Section 8.3, the influence of the input and process variables on the learning outcome is analysed.

8.1 Introduction of the players

The objective of this section is to describe the data set and give a summary of the collection and analysis of the data. Furthermore, we answer the question: who are the players?

8.1.1 General data set

The data for the analysis of the individual learning effects were the questionnaires filled in by the participants of the game, supplemented with the observations of the facilitators. The first version of the game, SIMMV2, was played eight times between August 2005 and June 2006. Each time, 2 or 3 teams played the game in parallel, which gives a total of 31 teams and 190 players. The version SimPort-MV2 was played 16 times between September 2006 and October 2009. To date, SimPort-MV2 has been played by 60 teams and 239 participants.

Each participant was asked to fill in a questionnaire before and after the gaming session. The questionnaires consisted of multiple questions with different items. Most of the questions were statements about experiences, preferences and expectations, which we asked the participants to score on a 5-point Likert scale from 'totally disagree' to 'totally agree'. Furthermore, there were some questions about personal characteristics and some open questions for further comments (See Appendices A and B).

The questionnaire changed slightly over the years. Several learning objectives were added. We also decided to make a separate pre-questionnaire for the professionals. There were some small differences between the surveys for the professionals and those used for the students. These differences were related to the questions about the embedding of the game in education.

In total we received 248 pre-game questionnaire surveys (58%) and 418 post-game questionnaires (97%). The high response on the post surveys was reached by asking the players to fill in the questionnaire directly, before they left the location. The lower response on the pre-game questionnaire has two reasons. The first reason is that not all participants were asked to fill in a questionnaire because the pre-survey was introduced later in the process, for example, for the professionals. The second reason is that for large groups of players, the pre-questionnaire was administered via the Internet, which gave a lower response rate.

The game was played by different types of players. In total, 136 professionals, 275 students, and 25 teachers participated in a SIMMV2 or SimPort-MV2 session. There was an unequal division of men and women; 79% of the participants were men. The average age of the players was 28 years ($\sigma = 8.88$ years), with the youngest participant being 19 and the oldest 61 years old.

8.1.2 Different groups of players

Different groups of participants took part in a gaming session. This offered opportunities to compare different settings and the effects of the game. The game was played by professionals in the field of Port Management or Port Design, students of Delft University of Technology and teachers from different educational institutes.

The main focus group was the professionals of the Port of Rotterdam, for whom the game was developed. We can compare the results of this group with those of a different group of professionals who are also in the field of port management and design but not involved with Maasvlakte 2.

A second comparison can be done between the current managers and the future managers of complex projects, who are now students. Although not all students will become port managers, they represent the managers of the future. These students have grown up in a different social and educational setting which, as expected, will influence their way of managing large projects and using support methods and tools. The student group consisted of students of Civil Engineering, specializing in ports and waterways, and students of Technology, Policy and Management, likely to become project managers – both groups were from the Delft University of Technology.

Finally, the outcomes can be compared with a group of teachers involved with neither port management nor project management. This group was used as a control group.

The general set-up is visualized in Figure 8-2. The results can be compared between professionals of the Port of Rotterdam and professionals in the same field, the professionals can be compared with the students, and both can be compared with the teachers.

Professionals				
	Professionals Port of Rotterdam	Xp1v	→	Yp1v
	Other Port Professionals	Xp2v	→	Yp2v
Students				
	Students of Port Design	Xs1v	→	Ys1v
	Students of Project Management	Xs2v	→	Ys2v
Teachers				
	Teachers	Xtv	→	Ytv

Figure 8-2. Scheme of research set up of four comparable groups of players

The groups played the game in different settings and with different purposes. Therefore, a short background is given to the different groups of players. A summary of the groups can be found in Table 8-1.

Group 1: Professionals at the Port of Rotterdam

The professionals of the Port of Rotterdam work in different departments and are more or less involved in the Maasvlakte 2 project. There were six gaming sessions between August 2005 and July 2009, with 17 teams. These sessions took place at the Port of Rotterdam Authority and took about 5 hours each. The game was played by 69 participants (50 men and 19 women), having an average age of 36 years (σ=9.1). These participants were to some extent involved in the project (μ=1.23, σ=1.17), and are reasonably well informed (μ=2.00, σ=1.18).

In this case, the objective was to gain greater insight into the long-term effects on the construction and use of Maasvlakte 2 caused by the strategic decisions made by the port authority. These new insights were intended to support the decision-making process of Maasvlakte 2.

Group 2: Participants of the Port Seminar

The second group of professionals took part in one of the port seminars; they also worked in the field of port design or port management. The first of these was an International Port Seminar, organized by UNESCO-IHE, for people with some working experience in management positions in port management, planning and development and consultancy. The other seminar was a post-academic course about port planning, organized by the Faculty of Civil Engineering of Delft University of Technology.

SimPort-MV2 was played four times by a total of 50 participants. Most of the players were men (53 men and 14 women), and the average age was 33.8 years (σ=6.48). The participants of the Port Seminar were less involved (μ = 0.54, σ = 0.76) and less well informed (μ = 1.36, σ = 0.88) about Maasvlakte 2 than the participants of the Port of Rotterdam.

In both seminars, the game was played at the end of the seminar as a practical exercise in port planning and management. The game session took up one day, i.e., seven hours of playing, including the briefing and debriefing. The objective of playing the game was to learn about the project management of Maasvlakte 2 and to experience this process.

Group 3: Students of Port Design

The professionals can be compared with the future professionals, today's students. Students of two different courses played the game SimPort-MV2. The first student group was taking a course in Ports and Waterways as a part of their Master studies in Civil Engineering. This is a theoretical course about the development of water-related infrastructures and functional designs of port terminals. The game was played at the end of the course as an integration of all concepts explained in the course. The duration of the game was one day, starting with an introduction to the Maasvlakte 2 project.

The game was played three times between March 2006 and October 2008, with 14 teams and 61 students of which 70% were men. The average age was 23.7 years (σ = 2.8). This group was younger than the professionals.

Group 4: Students of Project Management

The other student group was taking theoretical courses about project management within a multi-actor setting at the Faculty of Technology, Policy and Management at the Delft University of Technology. Over a period of eight weeks, students attended lectures, studied literature and had to complete several assignments. The game was played at the end of the course and took one day. The role of the game was to bring theory into practice and to experience the difficulties of managing large, technical projects.

Between December 2005 and October 2009, 214 students played the game SIMMV2 or SimPort-MV2. The average age was 23.0 years (σ=2.9), and 79% of the population were men. From the first surveys, we learned that the students were not involved with the Maasvlakte 2 project (μ=0.17, σ=0.47) and felt somewhat informed (μ=0.95, σ=0.74). This group of players was younger than the professionals and less informed about Maasvlakte 2 than the professionals of the Port of Rotterdam.

Group 5: Teachers

The last group of participants consisted of teachers from different educational institutes in Rotterdam and the surrounding area. In some sense, this was a special group, because their intention was not to improve their knowledge about project management or Maasvlakte 2. They wanted to experience whether this game could be useful for education. This group was used as a control group.

In total, 24 teachers played the game, 79% being male. The average age was 43 years (σ=14.7). The variance was high because the age of the participants lay between 19 and 61 years. The teachers were not involved in the Maasvlakte 2 project (μ=0.45, σ=0.60) and were somewhat informed (μ=1.71, σ=0.91). The teacher group was older than the four other groups and better informed about Maasvlakte 2 than the students and professionals of the port seminars.

Table 8-1. The background characteristics of the five different groups of players

	Total	Group 1	Group 2	Group 3	Group 4	Group 5
Name		Professionals Port of Rotterdam	Professionals Port Seminar	Student Port Design	Students Project Management	Teachers
Setting		Individual session	Part of 3 weeks seminar	Part of 8 weeks course	Part of 8 weeks course	Individual session
Course		n.a.	International Port Seminar	Port design	Functional and policy design	n.a.
Focus		Insights in the long term effects of strategic decisions	Port management	Functional design	Project management	Use of SimPort-MV2 for education
Duration	5 to 7 hours	5 hours	5/7 hours	7 hours	7 hours	5 hours
Number of players	418	69	50	61	214	24
Average age	28 σ= 8.88	34 σ=9.1	34 σ=6.48	24 σ = 2.8	23 σ=2.9	43 σ=14.7
Informed MV2		Reasonably well	Somewhat	n.a.	Somewhat	Somewhat

8.2 Perceived learning by playing SimPort-MV2

The first question is 'What do the players learn about the complexity of the system and does this differ between different player groups?' To answer this question, we developed the following sub-questions:

a. What are the general learning experiences?
b. Do the participants increase their declarative knowledge?
c. Do the participants increase their procedural knowledge?
d. Do the participants increase their strategic knowledge?
e. What are the differences between professionals of the Port of Rotterdam and the professionals of the Port Seminar?
f. What are the differences between the professionals and the students?

Gaming is used for multiple learning objectives. In this research we attempted to find out if playing SimPort-MV2 can increase the understanding of the complexity of the system. This understanding was divided into three types of objectives, based on Garris et al. (Garris, Ahlers, & Driskell, 2002): 1) declarative knowledge, 2) procedural knowledge and 3) strategic knowledge (see also Chapter 3). With sub-question a, we identified the educational value in general, and with questions b – d, the different learning results were specified.

Furthermore, we explored whether the learning results differed between the groups of players in order to determine if gaming is valuable for policy-making processes. If it is not, is gaming valuable for other groups of players? For that purpose, questions e and f had to be answered.

8.2.1 General learning experiences

The first indication of the value of SimPort-MV2 is the general learning experiences. These give an indication of the value of gaming for the Port of Rotterdam and for education in general. The question is:

a. What are the general learning experiences?

The questionnaire had four indicators for the general learning experiences. One was related to the value of SimPort-MV2 for the Port Authority and the other three were related to serious gaming in education. These last statements were only part of the student questionnaires.

As can be seen in Table 8-2, statement 1 shows that SimPort-MV2 is seen as worthwhile to the Port Authority. The professionals of the Port of Rotterdam agreed with this statement ($n=64$, $\mu=3.9$, $\sigma=.71$), as did the professionals from the port seminar ($n=48$, $\mu=4.1$, $\sigma=.68$).

The student participants found that they improved their learning (statement 2), and they would like to play other games in the course of their education (statement 3). Furthermore, the game SimPort-MV2 is educationally valuable (statement 4).

Table 8-2. General learning experiences of all participants

		N	Mean	Std. Deviation
1. The use of SimPort-MV2 is worthwhile to the Port Authority	Port of Rotterdam	64	3.9	.71
	Other port professionals	48	4.1	.68
2. It improves my learning to work on this serious game.		233	3.8	.72
3. I would very much like to play other serious games in education.		233	4.0	.76
4. The use of SimPort-MV2 in education is valuable.		250	4.0	.62

The indicators show that SimPort-MV2 is, according to the professionals, worthwhile for the Port Authority. Second, students agreed that SimPort-MV2 improved their learning, that the game is valuable for education and that they would like to play other games as well. However, these indicators do not answer the question of what the participants learned. These questions are answered in the next sections.

8.2.2 Declarative knowledge

This section shows the results of the first group of learning objectives related to declarative knowledge. The question is:

b. Do the participants increase their declarative knowledge?

As explained in Chapter 3, declarative knowledge is divided into theory-based notions, understanding the theory of the course in which the game took place and, in domain-specific concepts, the content of the game, the Maasvlakte 2 project. This sub-question has two parts:

B1 Do participants increase their understanding of theory-based notions?

B2 Do participants increase their domain-specific concepts?

B1. Do participants increase their understanding of theory-based notions?

Gaming is used to explain theoretical concepts (Laurillard, 1992). In this case, the students and professionals of the Port Seminar also played the game as part of a theoretical course. Therefore, the hypothesis was that students and the professionals of the Port Seminar would increase their understanding of theory-based notions.

The survey contained two indicators of theory-based learning. The results are shown in Table 8-3. With both indicators, the participants scored neutral. The mean score on statement one is 3.0 and on statement 2 even lower, 2.6.

Table 8-3. Theory-based learning of students and professionals at the Port Seminar

	N	Mean	Std. Deviation
1. I have gained (theoretical) knowledge.	280	3.0	.93
2. The theory from formal lectures and books became more understandable.	224	2.6	.87

The results show that the participants of SimPort-MV2 did not increase their theory-based knowledge.

B2. Do participants increase their domain-specific concepts?

Because the participants played the game around the subject of the Maasvlakte 2 project, it is expected that they would increase their knowledge about Maasvlakte 2. Furthermore, the professionals of the Port of Rotterdam were already more informed about the Maasvlakte 2 project. Their score is probably lower on this indicator. The hypothesis was that students, teachers and professionals of the Port Seminars would increase their domain-specific concepts.

Table 8-4 gives the results of the three indicators which represent the subject-related knowledge. In general, all groups increased their knowledge about the Maasvlakte 2 project. On the more general statement (number 1 in Table 8-4), the score is neutral.

Table 8-4. Domain-specific learning of all participants

	N	Mean	Std. Deviation
1. I have gained content-related (subject) knowledge.	280	3.2	.94
2. Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte.	415	3.7	.94
3. SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	412	3.6	.89

The answer to the question is that the participants learned about the subject Maasvlakte 2.

To test the hypothesis that students, teachers and professionals of the Port Seminars increase their domain-specific concepts and that the score of the professionals of the Port of Rotterdam is lower, we did a Bonferonni Multiple Comparison Analysis. The results are shown in Table 8-5.

These results show that on the statement ‘I've gained a number of new insights about the real 2nd Maasvlakte’, the professionals scored significantly lower than the students (.776 and .631) and the other professionals (.824). On the statement ‘SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte’, no significant difference was found except for the other professionals.

Table 8-5. Results of the Bonferroni Multiple Comparisons

Dependent Variable	(I) GRPSET	(J) GRPSET	Mean Differen-ce (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	Prof PoR μ=3.4	Student PM	-.256	.123	.376	-.60	.09
		Student PD	-.051	.169	1.000	-.49	.39
		Prof PS	-.647(*)	.165	.001	-1.11	-.18
		Teachers	.002	.208	1.000	-.59	.59
I have gained a number of new insights about the real 2nd Maasvlakte.	Prof PoR μ=3.1	Student PM	-.776(*)	.124	.000	-1.13	-.43
		Student PD	-.631(*)	.157	.001	-1.08	-.19
		Prof PS	-.824(*)	.167	.000	-1.30	-.35
		Teachers	-.260	.212	1.000	-.86	.34

* The mean difference is significant at the .05 level.

These results correspond with the Pearson Correlation Analysis. This analysis shows that there is a significant negative correlation between 'informed about MV2' and 'gaining new insights about Maasvlakte 2' (n=162, corr. = -.411, p = .000). There is no significant correlation between 'the long-term effects and pitfalls' and 'informed about Maasvlakte 2' (n=161, corr. = -.139, p = .079).

Based on this analysis, we conclude that playing SimPort-MV2 increased the subject-related knowledge for the participants who were less informed about Maasvlakte 2 before playing the game. This does not hold true for the insights about the long-term effects and pitfalls of Maasvlakte 2.

The answer to the question *Do the participants increase their declarative knowledge?* is both yes and no. No, because the participants did not increase their understanding of theory-based notions. And yes, because the participants increased their knowledge about Maasvlakte 2, except for the professionals of the Port Authority. Their score was lower because they were already informed about the project before playing the game.

8.2.3 Procedural knowledge

The second group of learning outcomes is related to the procedural knowledge. The main question in this section is therefore:

c. Do the participants increase their procedural knowledge?

In Chapter 3, procedural knowledge was specified as understanding of the linear processes of a complex system and understanding the complex processes. Linear processes are the processes within a subsystem, like the building or commercial process. The complex processes are the relations between the different subsystems and processes. This leads to 2 sub-questions:
C1. Do participants increase their understanding of the linear processes?
C2. Do participants increase their understanding of the complex processes?

C1. Do participants increase their understanding of the linear processes?

The measure for understanding linear processes contains four indicators. The results show that the participants agreed with statements 2 and 3 in
Table 8-6. That means the game provided insights into the 'strategic' and 'commercial and economic' complexity. On the other two indicators, insights into technical complexity and underlying cause and effect relationships, the participants scored lower, although still above an average of 3. The lower score on the increasing insights into technical complexity can be explained by the limited attention to technical choices, for example, different methods for construction and material use.

Table 8-6. Linear process learning of all participants

	N	Mean	Std. Deviation
1. SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	411	3.4	.99
2. SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	415	3.9	.75
3. SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	414	3.9	.76
4. The underlying cause-effect relations became clear enough during the course of the game.	416	3.5	.82

In conclusion, the participants increased their understanding of the strategic, commercial and economic complexity of the Maasvlakte 2 system.

C2. Do participants increase their understanding of the complex processes?

The question of whether participants increased their understanding of complex processes was based on four indicators. The results of understanding complex processes show a difference between the outcomes directly related to the Maasvlakte 2 project (statements 1 and 2 in Table 8-7) and general outcomes (statements 3 and 4 in Table 8-7). The participants agreed that the game provided a clear picture of the 2nd Maasvlakte and about why the processes have to be geared together. On the other hand, thinking beyond disciplinary boundaries or seeing the relations between the processes gave a neutral score (see Table 8-7).

Table 8-7. Complex process learning of all participants

	N	Mean	Std. Deviation
1. SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	412	3.7	.80
2. SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	394	3.8	.74
3. I have learned to think beyond disciplinary boundaries.	278	3.3	.86
4. I have learned to see the relations between different subject areas.	280	3.2	.96

In conclusion, we can say that the game SimPort-MV2 provided insights into some aspects of the procedural knowledge. This was especially related to the strategic, commercial complexity, the picture over the long term and why processes have to occur in synchronization.

8.2.4 Strategic knowledge

The third cognitive perspective of learning is strategic knowledge, which is related to the management of complex adaptive systems. The main question here is:

d. Do the participants increase their strategic knowledge?

Infrastructure systems contain a technical and social component. Therefore, the question is divided in two sub-questions:
D1. Do participants increase their knowledge of managing the technical system?
D2. Do participants increase their knowledge of managing the social (multi-actor) system?

D1. Do participants increase their knowledge of managing the technical system?

Two indicators were used to determine if playing SimPort-MV2 contributes to a better technical realization of Maasvlakte 2. As can be seen in Table 8-8, statement 1, the participants slightly agreed that playing the game could contribute to a good realization of Maasvlakte 2. The participants neither agreed nor disagreed on the role of the game for the preparation of professional practice.

Table 8-8. Dealing with the physical systems of all participants

	N	Mean	Std. Deviation
1. I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	392	3.4	.86
2. I have prepared myself for later professional practice (in an internship, traineeship, work, etc.).	228	3.2	.91

In conclusion, SimPort-MV2 does not significantly contribute to an increased knowledge of how to manage the technical system.

D2. Do participants increase their knowledge of managing the social (multi-actor) system?

The perceived learning outcome related to dealing with the social system showed that the participants agreed that the game SimPort-MV2 can promote better communication and cooperation between the different departments and individuals (see statements 1 and 2 in Table 8-9). This was also the result of the professionals of the Port of Rotterdam, who scored $\mu=4.0$ ($\sigma=.78$) on statement 1 and $\mu=4.0$ ($\sigma=.69$) on statement 2.

The other skills, such as communication, discussion, negotiation, working together and professional skills, scored close to 3, which means the participants neither agreed nor disagreed with the statements.

For the indicators ‘learned to communicate’ and learned to ‘discuss and reason’, the results showed that teachers (n=24) and professionals (N=54) of the Port of Rotterdam scored significantly lower, respectively $\mu=2.4$ ($\sigma=1.10$) and $\mu=2.5$ ($\sigma=1.06$) for the teachers and $\mu=2.4$ ($\sigma=1.\ 04$) and $\mu=2.4$ ($\sigma=1.02$) for the professionals. They were probably already more experienced in communication and discussions in teams, and the game did not challenge them to improve these skills, while the other participants were challenged.

Table 8-9. Dealing with the social network of all participants

	N	Mean	Std. Deviation
1. I think that SimPort-MV2 can promote cooperation between different departments and individuals.	408	4.0	.70
2. I think that SimPort-MV2 can promote better communication between different departments and individuals.	406	4.0	.71
3. I learned to communicate	347	3.0	.97
4. I learned to discuss and reason.	346	3.0	.96
5. I have learned to work better together with others in a team.	279	3.4	.84
6. I have learned to negotiate better.	277	3.1	.89
7. I have improved relevant (professional) skills.	278	3.2	.93

The results show that the game does not provide practice in social skills specifically, but that the participants found that the game promotes cooperation and communication between the different departments of the Port of Rotterdam.

Finally, the results show that increasing the strategic knowledge is limited to the expectation that SimPort-MV2 increases communication and cooperation between different departments and individuals.

8.2.5 Comparison between the professionals

The game was played with two groups of professionals: the professionals of the Port of Rotterdam and the professionals of the Port Seminar. Both groups were working in the field of port management or port planning. By comparing these two groups, we can analyse whether there is a difference in learning results for participants who were informed about the Maasvlakte 2 and those who were not. The next question is:

e. What are the differences between the professionals of the Port of Rotterdam and the professionals of the Port Seminar?

To answer this question we had to know if there is a difference in knowledge about Maasvlakte 2 before playing the game. An Independent Sample T-test showed that the professionals of the Port of Rotterdam were significantly better informed about Maasvlakte 2 than the other professionals ($t = -3.376$).

If we compare all the indicators of the different learning outcomes, we see that there is a significant difference in outcome between professionals of the Port of

Rotterdam and professionals of the Port Seminar on 6 indicators. These indicators can be found in Table 8-10.

The Port of Rotterdam professionals scored lower on all indicators, which means their increase was limited. Furthermore, in Table 8-10 we observe that 5 out of 6 indicators are directly related to the project Maasvlakte 2. From this result, we can conclude that the game contributes to explaining the project Maasvlakte 2 to the people who were less informed.

Table 8-10. Differences between professionals of the Port of Rotterdam and of the Port Seminars

Statement	Mean of PoR	Mean of PS	t-value	Sig. (2-tailed)
1. Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte.	μ=3.1 σ=.97	μ=3.9 σ=.87	4.820	.000
2. SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	μ=3.4 σ=1.03	μ=4.0 σ=.63	3.905	.000
3. SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	μ=3.1 σ=1.10	μ=3.7 σ=.79	3.432	.001
4. The underlying cause-effect relations became clear enough during the course of the game.	μ=3.3 σ=.91	μ=3.7 σ=.68	2.982	.003
5. SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	μ=3.5 σ=.84	μ=3.8 σ=.81	2.229	.028
6. I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	μ=3.1 σ=.83	μ=3.8 σ=.84	4.033	.000

There were no significant differences found between the two professional groups on the other indicators. Both groups agreed that SimPort-MV2 is worthwhile, the game provided insights into the strategic and commercial complexity, the game showed why and how processes have to be synchronized, and the game can promote communication and cooperation between different departments.

8.2.6 Comparison between professionals and students

Another difference was to be expected between the professionals and the students. The students belong to the 'game generation', and it is to be expected that they learn differently and therefore need other learning tools. Gaming is a tool which fits this new way of learning. When students increase their learning more, it could mean that gaming will be more useful in the future. The question to be answered in this section is:

f. What are the differences between the professionals and the students?

The assumption behind this question is that the professionals are on average older than the students. First, this assumption was tested with an Independent Sample t-test. This showed that there was a significant difference in age (t = -13.198). The professionals were on average 36 years old and the students 23 years.

There are five learning indicators which show a difference between the professionals and students. These are summarized in Table 8-11. As we can see, the professionals had a higher score on all statements except statement 2 about the new insights. This means that professionals graded SimPort-MV2 as more worthwhile for the Port Authority than the students did. They also thought that the game will increase communication and cooperation between departments at the Port of Rotterdam more than students expected.

Table 8-11. Differences between professionals and students

Statement	Mean of Profs	Mean of Students	t-value	Sig. (2-tailed)
1. The use of SimPort-MV2 is worthwhile for the Port Authority	μ=4.0 σ=.70	μ=3.8 σ=.76	-2.511	.012
2. Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte.	μ=3.4 σ=1.01	μ=3.8 σ=.88	3.936	.000
3. SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	μ=3.9 σ=.78	μ=3.7 σ=.69	-3.089	.002
4. I think that SimPort-MV2 can promote cooperation between different departments and individuals.	μ=4.1 σ=.75	μ=3.9 σ=.69	-2.097	.037
5. I think that SimPort-MV2 can promote better communication between different departments and individuals.	μ=4.1 σ=.69	μ=3.9 σ=.72	-2.640	.009

The other indicators did not give a significant difference between the students and professionals. Based on these learning results we conclude that on average the game was more useful for increasing knowledge for the professionals than for the students.

8.2.7 Conclusions about learning experiences

In general, SimPort-MV2 was seen as a worthwhile and educational experience. However, this does not say anything about the learning objectives reached. Therefore, we also analysed several different types of possible learning outcomes. Table 8-12 shows the main conclusions drawn regarding the contribution of playing SimPort-MV2 to the six different learning outcomes.

Table 8-12. Perceived learning outcome of playing SimPort-MV2

Perceived learning outcome	Increase?	Comments
Theory based notions		
Domain specific content	✓	Except for the professionals of the PoR
Understanding linear processes	✓	Only strategic and commercial complexity
Understanding complex behaviour	✓	Only related to project Maasvlakte 2
Management of the physical environment		
Management of the social environment	✓	Only related to project Maasvlakte 2

The results show that the game did not increase theory-based knowledge. This could indicate that transfer of knowledge about theoretical concepts will be better achieved by other types of games, for example abstract games about one pattern, or other learning methods. The game did increase knowledge about the Maasvlakte 2 project.

In answer to the question of whether participants increase their procedural knowledge, the results show that participants agreed that they increased their perceived knowledge about the commercial and strategic complexity, about getting a clear picture and about the relevance of why and how to combine the different processes. On the more general learning indicators and insights into technical complexity, players neither agreed nor disagreed with the statements.

Finally, the results show that the participants did not increase their understanding of dealing with the physical system. Participants agreed that the game can promote cooperation and communication between the different departments. More general social skills are not increased.

We found some differences between the professionals of the Port of Rotterdam and the professionals of the Port Seminar. These differences were related to the subject of the Maasvlakte 2 project, which were caused by the differences in the knowledge about Maasvlakte 2 at the start of the game. Participants of the Port of Rotterdam were already more knowledgeable about the Maasvlakte 2 project, and they did not receive new information related to this knowledge. SimPort-MV2 contributed to the dissemination of information about Maasvlakte 2 to the participants who were less informed.

Several differences were found between professionals and students. On average the scores of the professionals were equal to or higher than the scores of the students, except for gaining new insights into Maasvlakte 2 (Figure 8-3).

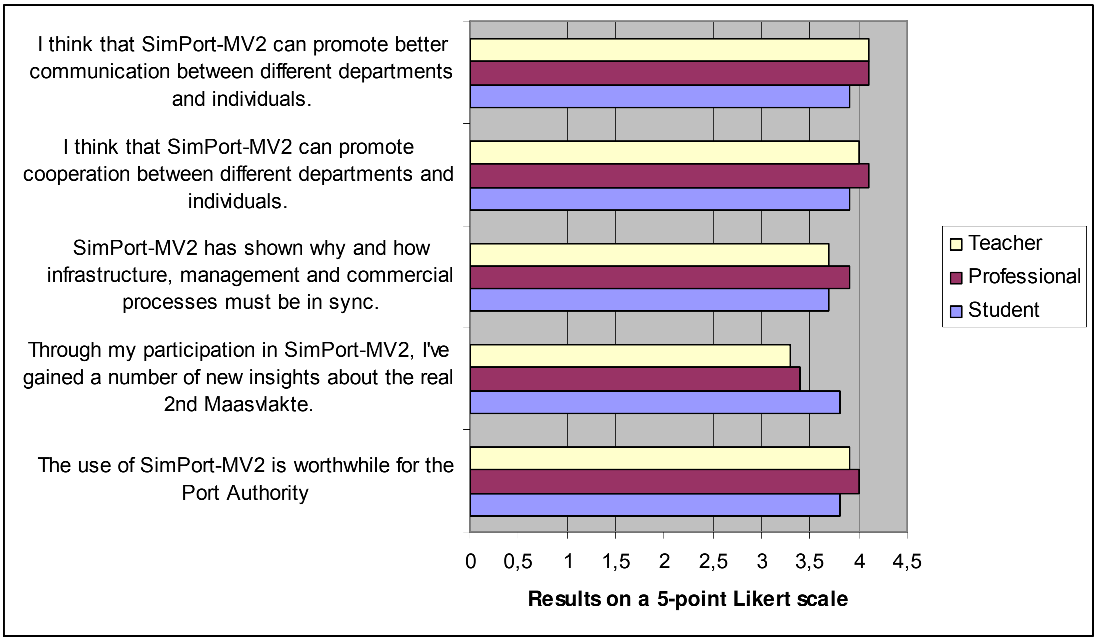


Figure 8-3. Differences between students, professionals and teacher on five learning outcome indicators

Based on the results of the learning outcome, SimPort-MV2 was successful in four out of six learning outcomes. We have also shown that being informed about Maasvlakte 2 leads to less learning on the indicators directly related to the subject and that students did not increase their knowledge more than the professionals. The next question is: which variables influence this learning outcome? Further, if we know which variables affect the outcome, can this be used to increase the learning outcomes?

8.3 Relations between input, process and outcome

According to the theoretical framework of Kriz and Hense adapted by Mayer et al. (Kriz & Hense, 2006; Mayer, Jager, & Bekebrede, 2007), input, process and outcome variables are related. In Chapter 4, we identified several of the relevant variables and relations which are tested in this chapter. The variables taken into account are the perceived learning outcomes as discussed in the previous section, the process variables computer interaction, engagement and personal interaction, and the input variables game, player and embedment of the game. The direct relationships between these variables are shown in Figure 8-4. The main question of this section is:

What input and process variables influence the learning outcome?

This question was answered in three steps. We started with an analysis of the values of the indicators, which provided insights into the input of the session and the game process. After that, we executed several factor analyses to reduce the number of indicators for the correlation analyses. Based on this limited number of factors, we were able to analyse how large the relationships, if any, were between the variables. This was done by means of a bivariate correlation analysis.

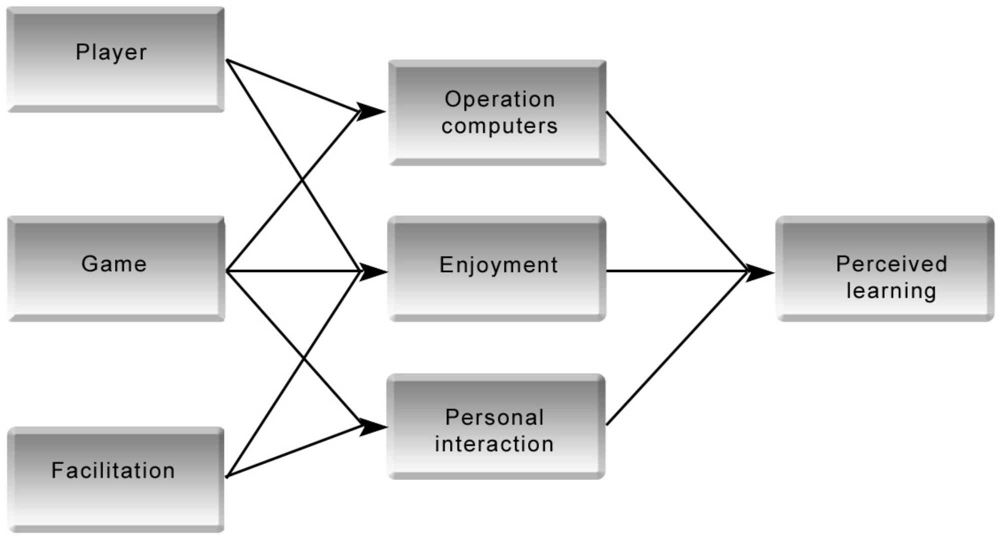


Figure 8-4. Relations between the input, game play and output variables, which will be analysed with the game SimPort-MV2

This section starts with an analysis of the process variables, followed by the relationship between process factors and the perceived learning outcome. In 8.3.2, the input variables are discussed and the relations between input and process are explored. Finally, in 8.3.3 direct correlations between the input variables and perceived learning are discussed.

8.3.1 Relations between process and outcome

Based on the adapted framework of Kriz and Hense (Kriz & Hense, 2006) as described in Chapter 4, the game play or the game session is based on interactions. These variables are computer interaction, engagement and personal interaction. To answer the question of whether there is a relation between process variables and learning outcome, we have to answer several sub-questions:

a. What is the opinion of the players about the computer interaction?
b. Is it possible to extract one factor which represents the computer interaction?
c. What is the opinion of the players about the engagement?
d. Is it possible to extract one factor which represents the engagement?
e. What is the opinion of the players about the personal interaction?

f. Is it possible to extract one factor which represents the personal interaction?
g. What is the size of the correlation between computer interaction, engagement and personal interaction?
h. What is the size of the correlation between computer interaction and learning outcome?
i. What is the size of the correlation between engagement and learning outcome?
j. What is the size of the correlation between personal interaction and learning outcome?

Analysis of the process variables

We start with an analysis of the process variables, computer interaction, engagement and personal interaction. For each variable we try to reduce the indicators by executing a factor analysis and give the opinion of the players. We therefore answer sub-questions a to f. We start with the analysis of the computer interaction.

Computer interaction

The computer plays an important role in the game. It is the simulation which provides the feedback about the development of the Maasvlakte 2 area and the consequences of the decisions. This feedback is given in the form of maps, figures and messages. The input of the simulation comes from the decisions of the players. Therefore, the design of the computer simulation and the user-friendliness of the interfaces could be relevant for the game play and learning.

a. What is the opinion of the players about the computer interaction?

In general, the participants were positive about the use of the computer and the quality of the interfaces (see Appendix C, Table C-1 for all indicators). The participants enjoyed using the computer simulation (n=415, μ=4.1 σ=.70), they found the computer screens attractive (n=412, μ=3.8 σ=.72), and the screens gave a sense of changes in the port area (n=410, μ=3.6 σ=.80). According to the participants, the computers were easy to operate (n=415, μ=3.9 σ=.85) and the need for help was on average neutral (n=412, μ=2.7 σ=1.12). The high variance shows that opinions were diverse. This is comparable with the observations made during the sessions. Some participants did not have any questions; others needed more help with filling in the decisions in the computer.

b. Is it possible to extract one or two factors which represent the computer interaction?

Based on a factor analysis, two factors can be extracted: enjoyment of using the computer simulation (ENJCOMP) and quality of the interfaces (QUAINT). See Appendix C, Tables C-2 and C-3 for the details of the factors. The mean of the factor ENJCOMP is 3.9 ($n=414$, $\sigma=.65$) and factor QUAINT is 3.7 ($n=401$, $\sigma=.57$). In general, the players were satisfied with the quality of the interfaces and they enjoyed using the simulation.

Engagement

The second process variable is the engagement during the sessions. When participants are more engaged, they have a higher motivation and are more seriously involved (Garris et al., 2002).

c. What is the opinion of the players about the engagement?

In the first place, the results of the surveys show that the tasks in the game were not too easy ($n=412$, $\mu=2.6$ $\sigma=.80$) nor too difficult ($n=412$, $\mu=2.7$ $\sigma=.80$), and game play was not too slow ($n=396$, $\mu=2.1$ $\sigma=.76$) (See Appendix C, Table C-4 for detailed information). This gives an indication that the activities fell within the boundary of flow (Csikszentmihalyi, 1975).

In the second place, the players enjoyed playing the game ($n=416$, $\mu=4.3$ $\sigma=.65$) and had fun taking part ($n=233$, $\mu=4.2$ $\sigma=.59$), and they think the game is educational ($n=414$, $\mu=4.0$ $\sigma=.68$). Finally, the players strongly agree that their performance will be better if they play it again ($n=415$, $\mu=4.4$ $\sigma=.79$).

d. Is it possible to extract one or two factors which represent the engagement?

The indicators of ‘educational to take part in’, ‘enjoyable to take part in’, ‘would like to play again’ and ‘fun working together’ are significantly correlated. This group of indicators is called the fun factor (See Appendix C, Table C-5). The mean value of the fun factor is 3.9 ($\sigma=.53$).

Personal interaction

The third process variable is the personal interaction: the effort and cooperation within the team.

e. What is the opinion of the players about the personal interaction?

From the results we observe that in general the players made a good effort (n=394, μ=4.3 σ=.64), had good discussions (n=396, μ=3.7 σ=.77) and worked well together (n=396, μ=3.8 σ=.81) (see Appendix C, Table C-6 for more details). These results are supported by our observations of the behaviour of the players. For example, during the lunch break they were still discussing the strategy or they were already waiting to start after the lunch. These indicators show that the participants were involved in the game and became part of the system.

f. Is it possible to extract one two factors which represent the personal interaction?

The six different indicators of personal interaction can be represented by one factor PERSINT (See Appendix C, Table C-7). The players are satisfied with the personal interaction during game play (μ=3.9 n=389, σ=.55).

The game play process is described based on three types of variables: the interaction with the computer, interaction between the players and the enjoyment of playing the game. To conclude, we observe that the quality of the interaction with the computer and between the players was good. Furthermore, the game was not too difficult or too easy to play, which means the game was within the boundary of boredom and anxiety and the participants enjoyed playing the game.

The factor analysis gave four factors which can be considered the process variables: Enjoyment of using the computer simulation, quality of the interfaces, the fun factor and personal interaction.

Correlations between process variables and learning outcome

The next question is: can we find correlations between the process indicators and the learning outcome? We start with the correlations between the process variables.

g. Is there a correlation between computer interaction, engagement and personal interaction?

From the correlation analysis (Table 8-13) it can be observed that the four process factors are significantly correlated. The personal interaction, the enjoyment of using the computers, the user screens and the fun factor are dependent on each other. There is a strong correlation between enjoying the use of the computer simulation and the quality of the interfaces. The quality of the interface is important for the enjoyment of the game play. When the quality of one factor is low, this affects other factors.

Table 8-13. Correlation matrix of the process variables

		FUNFACTOR	ENJCOMP	QUAINT	PERSINT
FUNFACTOR	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	231			
ENJCOMP	Pearson Correlation	.257**	1		
	Sig. (2-tailed)	.000			
	N	230	414		
QUAINT	Pearson Correlation	.270**	.458**	1	
	Sig. (2-tailed)	.000	.000		
	N	223	399	401	
PERSINT	Pearson Correlation	.398**	.313**	.345**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	228	386	398	389

**. Correlation is significant at the 0.01 level (2-tailed).

h. What is the size of the correlation between computer interaction and learning outcome?

There are many significant correlations between the enjoyment of the computer and the quality of the interfaces with the perceived learning outcome (see Appendix C, Table C-8 through C-11). For example, there are significant, relatively strong correlations between the quality of the interfaces and the learning indicators 'seeing long term effects/pitfalls of Maasvlakte 2' (corr=.300, p=.000, n=397) and 'SimPort-MV2 provided a clear picture of Maasvlakte 2 over the long term' (corr=.324, p=.000, n=397).

This correlation was also found in research on edutainment games in K-12 education. Those games lack high-quality graphics and interfaces (Dempsey, Rasmussen, & Lucassen, 1996) and incorporate drill-like activities which are boring for students and therefore fail to improve learning (Kirriemuir & McFarlane, 2004). The interfaces and graphics are received well, which one would expect to lead to higher learning outcomes. This also supports the idea that using high quality computer visualizations could give an added value to the learning outcome.

i. What is the size of the correlation between engagement and learning outcome?

An important element which is often mentioned as one of the added values of games is the engagement. Research has shown that the motivation of the player increases when he or she likes the activity, and this increases the learning experiences (Garris et al., 2002; Hannafin & Hooper, 1993; Wideman et al., 2007).

Our results support this idea. The indicators of the fun factor are significantly correlated with the perceived learning outcome (See Appendix C, Tables C-8 through C-11). This holds true for the general learning indicators. For example, for the statement 'It improves my learning to work on this simulation game', the correlation was .499 (p=.000, n=230). For other learning indicators as well, there are significant correlations between the fun factor and learning, although not all are of very high value. Two correlations are interesting to mention because they have a high correlation. These are the correlations between the fun factor and 'promoting cooperation between individuals and departments' (corr=.432, p =.000, n=225) and 'promoting communication between individuals and departments' (corr=.408, p=.000, n=225).

j. What is the size of the correlation between personal interaction and learning outcome?

From the bivariate correlation analysis, we can conclude that there are some significant correlations between personal interaction and perceived learning outcome (see Appendix C, Tables C-8 through C-11). One of the explanations is that higher motivation is important for learning (Wideman et al., 2007). It is remarkable that there is no significant correlation between personal interactions and general social skills (communication: corr=.107, p=.049, n=339, discussing and reasoning: corr=.080, p=.142, n=338 and negotiation: corr=.121, p=.046, n=271).

Conclusions of process variables

We conclude that the process variables computer interactions, engagement and personal interaction are correlated with each other and the learning outcome. This corresponds with the theory that learners who are engaged, more motivated and have to work together in the learning process will have better learning results.

Because we cannot visualize all learning indicators in a figure, we defined a factor 'general learning' based on the general learning indicators (see Appendix C, Table C-12) as an example to show the relations in the model. The correlations between the process variables and between process variables and general learning are presented in Figure 8-5.

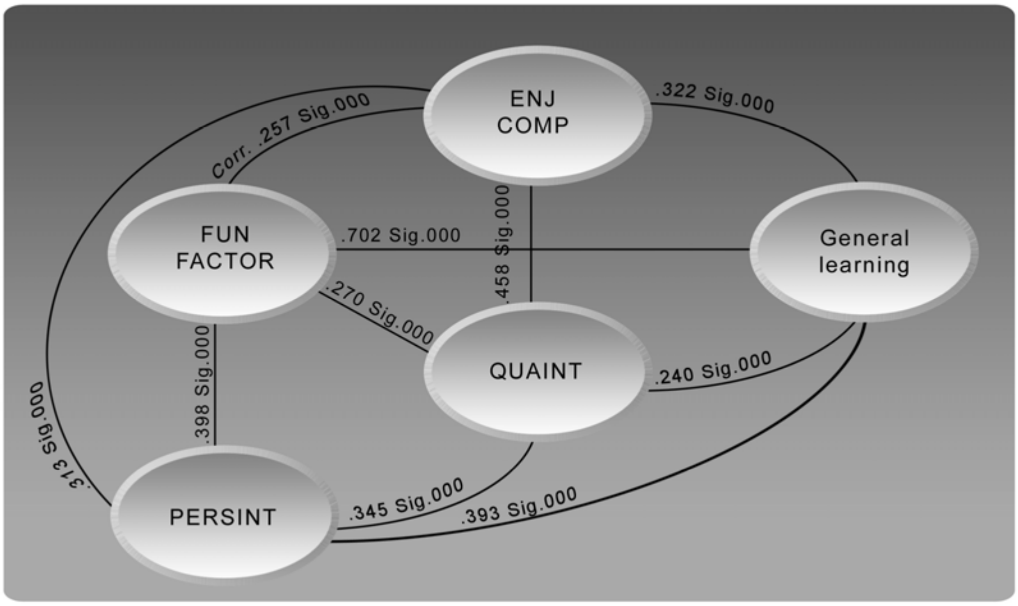


Figure 8-5. Correlations between the process variables and general learning outcome

8.3.2 Relations between input and process

The process variables, computer interaction, engagement and personal interaction are influenced by the input of the game. This game input consists of the participants, the game and the facilitation of the game. For finding the relations between the input and process variables we have to answer the following questions:

k. What are the experiences of the players with computer simulations and gaming?
l. What are the expectations and learning preferences of the players of the game?
m. Is it possible to extract a couple of factors which represent the players?
n. What is the opinion of the players about the quality of the game?
o. Is it possible to extract one factor which represents the quality of the game?
p. What is the opinion of the players about the facilitation and embedding of the game?
q. Is it possible to extract one factor which represents the facilitation and embedding of the game?
r. What is the size of the correlations between the input factors?

s. What is the size of the correlations between the player factors and the process variables?
t. What is the size of the correlations between the game factor and the process variables?
u. What is the size of the correlations between the facilitation factor and the process variables?

Analysis of the input variables

We start with an analysis of the input variables (questions k to q).

Player

Differences between players lead to different starting positions and frames of reference. This frame of reference influences learning as we have already analysed based on the knowledge about Maasvlakte 2 and age (see section 8.2.6). In this section, we analyse the game and computer experiences, and the learning preferences, game and learning expectations, since these variables affect game play as well.

k. What are the experiences of the players with computer simulations and gaming?

There are two types of experience which could influence the game play: the experience with using computer simulations and digital learning environments, and game experience.

The hypothesis behind the decision to use a computer game is that the participants are expected to be familiar with using computer simulations or digital environments. The results show that most of the participants were acquainted with using digital learning environments and computer simulations (Figure 8-6 and Appendix D, Table D-1). A comparison between the player groups shows that there were no differences in computer experience.

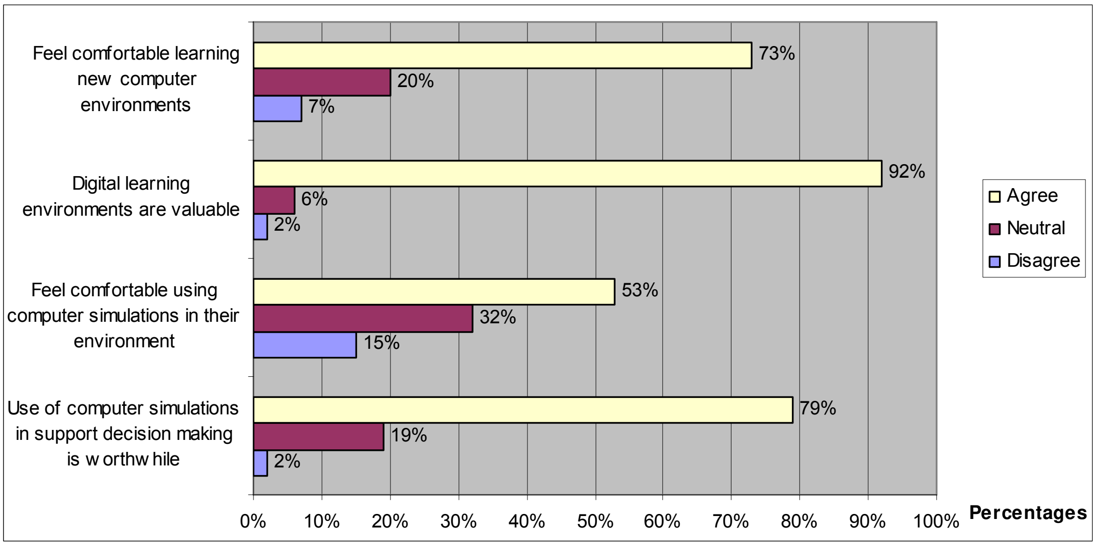


Figure 8-6. Computer experiences of the players

Many researchers talk about the digital natives or the game generation (Prensky, 2001, 2006; Veen, 2006). The assumption behind this idea is that youth play games regularly (see Chapter 1). The results from our set of participants show something different. More than 50% hardly ever play games or computer games in private (see Appendix D, Table D-3). Also, if we look at participants with an age below 25, 63% play games less than once a month, and for computer games this is 42%. Egenfeldt-Nielsen also experienced a large group of students with little or no computer game experience (Egenfeldt-Nielsen, 2005 p.166).

Except for the participants in the Port Seminar sessions (40% never), most of the participants had played simulation games before: 98% of the Project Management students, 61% of the Port Design students, 54% of the professionals of the Port of Rotterdam and 80% of the teacher participants.

This means the participants are experienced with using digital environments and feel comfortable learning new environments. The participants do not play (computer) games often.

I. What are the expectations and learning preferences of the players of the game?

There are two expectations of the players and one preference which influence the starting position of the individuals: expectation of serious gaming, expectation of learning outcomes and preferred learning style.

From the results of the survey, we can conclude that the attitude towards serious gaming was positive. Players found that serious games add something to other forms of teaching (n=290, μ=4.0 σ=.68) and that it was fun to take part in a serious game (n=290, μ=3.9 σ=.70). More indicators can be found in Appendix D, Table D-4.

The players also started with some learning expectations. These expectations were based on the introduction of the teachers in the lectures and the information provided about the game before the session. In general, the learning expectations were positive. The highest expectations found were related to the real world system: to increase the knowledge about the strategic (n=289, μ=4.0 σ=.62) and commercial complexity (n=288, μ=3.9 σ=.64), to see some pitfalls and long-term effects (n=289, μ=3.9 σ=.70) and to gain a number of new insights (n=288, μ=3.8 σ=.75). These expectations are close to the objectives of the game. The other values of the learning expectations can be found in Appendix D, Table D-6.

Third, the preferred learning style influences the start situation. These learning styles determine the way people prefer to learn (Kolb, 1984; Myers, McCaulley, Quenk, & Hammer, 1998)[14]. Some people feel more comfortable attending lectures and studying literature, others prefer learning-by-doing. From the results as shown in Appendix D, Table D-8, we see that the student participants on average prefer to work in groups (n=233, μ=3.9 σ=.79) and that they do not prefer formal lectures (n=231, μ=2.7 σ=.86) or studying textbooks (n=232, μ=2.2 σ=.93).

The participants of SimPort-MV2 have a positive attitude towards serious gaming; they expect to learn about the strategic and commercial complexity and gain new insight in the project and the long-term effects. On average, the students prefer to work in groups and do not prefer lectures or studying literature.

m. Is it possible to extract a couple of factors which represent the players?

If we want to analyse the relations between the player characteristics and process indicators, we have to reduce the number of indicators. Therefore, a factor analysis was performed on the experiences and expectations.

The indicators of computer experience can be represented by two factors (see Appendix D, Table D-2). The first factor is the value of the digital environment (VALUEDL, n=205, μ=4.2 σ=.59), and the second factor is the value of learning new computer applications (VALUENC n=359, μ=3.8 σ=.83).

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[14] Kolb's learning types are divided into pragmatics, theorists, reflectors and activists. The Myers-Briggs types are based on four characteristics: Extraversion vs. introversion attitude, sensing vs. intuition, thinking vs. feeling functions and judging vs. perceptive life style. Both researchers state that persons do not fit within one of these types, but that persons have all styles in them and they prefer some styles to others.

The expectations of serious games can be reduced to one factor called EXPSERGAM (n=276, μ=3.9 σ=.53).

The learning objectives can be summarized in four factors, representing the subject Maasvlakte 2 (n=286, μ=3.9 σ=.58), social skills (n=282, μ=3.7 σ=.63), theoretical knowledge (n=227, μ=3.4 σ=.66), and professional skills (n=224, μ=3.4 σ=.75).

The learning preferences are correlated and can be further analysed as one factor LRNPREF (see Appendix D, Table D-9 for the factor analysis). The mean value of the learning preference is 3.6 (n=230, σ=.63), which means the participants prefer to work together on a project.

This means that, based on the pre-survey (see Appendix A), we derived eight factors which describe the player characteristics (Table 8-14 and Appendix D.1). Apart from these factors, there are two indicators about game experiences, age and gender.

Table 8-14. Excluded factors about player characteristics

Factor	Number of items	Cronbach´s Alpha
Value of digital learning environments (VALUEDL)	3	.745
Value of learning new computer programs (VALUENC)	2	.754
Learning preferences (LRNPREF)	5	.776
Expectations Serious Games (EXPSERGAM)	5	.798
Subject Maasvlakte 2 (SUBMV2)	5	.873
Social skills (SOCSKILLS)	5	.830
Theoretical knowledge (THRKNOW)	4	.759
Professional skills (PROFSKILLS)	2	.739

Game characteristics

The second input variable of a gaming session is the game. We identified two game characteristics, the version of the game and the game quality. There are two versions of this game: SIMMV2 and SimPort-MV2. These versions differ in lay-out of the interfaces, while the concepts, objectives and activities are the same. The differences in the validation of the game are discussed in Chapter 6.

According to literature, there are two aspects of the quality of the game related to the learning environment: content quality and game quality (Feinstein & Cannon, 2002; Gosen & Washbush, 2004). In Chapter 6, we concluded that SimPort-MV2 was realistic and detailed enough for the purpose of the game. Now, the question is:

n. What is the opinion of the players about the quality of the game?

The participants of the game were positive about the aim of the game (n=417, μ=4.0 σ=.72) and the relevance of the topic (n=253, μ=3.8 σ=.91), and agreed the game was built in an interesting way (n=417, μ=4.2 σ=.61). More information about the quality of the game can be found in Appendix D, Table D-10.

o. Is it possible to extract one factor which represents the quality of the game?

We also analysed whether the nine indicators of the quality of the game can be reduced to one factor. The factor analysis extracts two factors (Appendix D, Table D-11), the quality of the game (QUAGAME) and the relevance of the game (RELGAME). The average score for the quality of the game is 3.8 (n=404, σ=.55) and for the relevance of the game 3.8 (n=251, σ=.70).

Embedment and facilitation

Based on Kolb's extended learning cycle as described in Chapter 3, two variables are relevant for reflecting on the activities: the embedment of the game and the facilitation of the game.

p. What is the opinion of the players about the facilitation and embedment of the game?

The results show that it is not easy to embed the game in the lectures. The students neither agreed nor disagreed that the game was well embedded in this particular course (n=243 μ=3.2 σ=.89).

The role of the facilitator was to motivate the players, brief and debrief the gaming session and help them with questions (see Chapter 3). The participants were satisfied with the quality of the facilitation of the game. They agreed that the instructions were clear (n=411 μ=3.7 σ=.85) and that good feedback was provided (n=396 μ=3.9 σ=.70) (Appendix D, Table D-12).

A significant correlation was found between the quality of the facilitation and the alignment with lectures. This seems logical, because in the introduction and debriefing relations have to be made between the game and the courses.

q. Is it possible to extract one factor which represents the facilitation and embedding of the game?

The different indicators of the quality of the facilitation are significantly correlated, but these cannot be represented by one factor.

Based on the pre- and post-surveys, we can conclude that participants of SimPort-MV2 are not hardcore gamers; even those from the 'game generation' do not often play games, including computer games. On the other hand, the participants are acquainted with the use of digital learning environments and computer simulations and have a positive opinion about serious gaming.

The participants prefer to work together and they expected to increase their knowledge and insights about the Maasvlakte 2 system through the game experience. The participants gave a high score for the quality of the game. They agreed that the objectives were relevant, the game was interesting and the materials were available and understandable. Finally, the embedment of the game in the course is difficult; the students did not agree that the game was aligned with the lectures or the literature. According to the participants, the quality of the facilitation was high.

Correlations between input variables and process variables

The second group of relations are those between the input and process variables. Based on factor analysis, we identified 14 factors of the input variables which can be used for further analysis (Table 8-15). We start with the correlation between the input factors. Then we analyse the correlation between the player characteristics on the three process variables, followed by the game quality and the facilitation.

Table 8-15. Input variables based on the factor analysis

Player characteristics	Game characteristics	Context
Value of learning new computer programs (VALUENC)	Version of the game	Embedding of the game
Value of digital learning environments (VALUEDL)	Duration of the game	Facilitation of the game (three indicators)
Expectations Serious Games (EXPSERGAM)	Quality of the game (QUAGAM)	
Learning preferences (LRNPREF)	Relevance of the game (RELGAM)	
Theoretical knowledge (THRKNOW)		
Subject Maasvlakte 2 (SUBMV2)		
Social skills (SOCSKILLS)		
Professional skills (PROFSKILLS)		

The first question is:

r. Are there correlations between the input factors?

The bivariate correlation analysis gives many significant correlations between the input variables, but many correlations are low. The complete table can be found in Appendix D, Table D-13. Figure 8-7 is an illustration of the higher correlation between the input variables. The most interesting conclusions are summarized.

Related to the game generation, there are many assumptions about the players' way of learning. They are acquainted with using computer technology, prefer learning-by-doing and playing games. If this is true, several player characteristics have to be correlated, for example, playing computer games and age with the other input variables. There is no significantly high correlation between playing computer games and the other input variables, only age (corr = -.327, p=.000, n=278). The age is also not correlated with the other input variables. This means that computer experience, serious game expectations, learning expectations and learning preferences are independent of age and playing computer games.

Another expectation is that serious gaming is interesting to people who are comfortable using simulation and digital environments and prefer learning-by-doing. The results show that serious game expectations are significantly correlated with the other input variables. Participants who are more positive about serious games are also more positive about the value of digital learning environments (corr=.368, p=.000). These participants also have a higher preference for working in groups on a project (corr=.295, p=.000), and a higher learning expectation of the subject Maasvlakte 2 (corr=.322, p=.000), social skills (corr=.357, p=.000), theoretical knowledge (corr=.275, p=.000) and professional skills (corr=.337, p=.000).

Furthermore, correlations are found between the value of digital learning environments and learning preferences (corr=.308, p=.000), which means that people who prefer to work in groups on a project also give a higher value to digital environments. These correlations support the assumptions that gaming fits with other types of learning preferences and greater familiarity with digital environments and simulations.

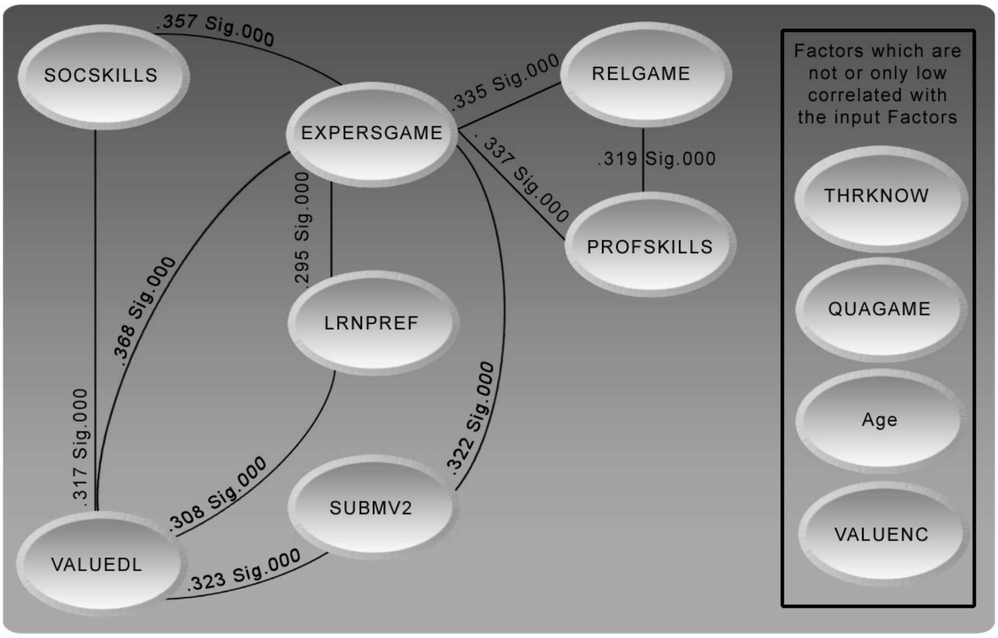

Figure 8-7. Correlations between the input variables

s. What is the size of the correlations between the player factors and the process variables?

The outcome of the correlation analysis can be found in Table D-14 of Appendix D. The correlation analyses showed that previous game experience (corr=.093, p=.150), learning preferences (corr=.133, p=.059), and attitude towards serious games (corr=.078, p=.190) are not significantly correlated with the computer interaction indicators. This means that gamers and non-gamers have the same experience with the interaction with the computer. There is a positive significant correlation between the value of learning new computer simulation and enjoyment of using computer simulation (corr=.238, p=.000).

The personal interaction is not significantly correlated with the learning expectations: value of digital learning environments (corr=.097, p=.168), enjoyment of learning new environments (corr=.106, p=.047), expectations of serious games (corr=.069 p=.302), learning preferences (corr=.157, p=.026). This means that, based on these characteristics, all players interact with each other with the same intensity. There is a correlation between playing computer games and personal interaction (corr=.231, p=.000).

There are significant correlations between computer experience (corr=.210, p=.003), computer game experience (corr=.235, p=.001), learning preferences (corr=.375, p=.000), and expectations of serious games (corr=.344, p=.000) with the enjoyment of the game. This means, for example, that people who prefer to work together or on a project have more fun playing SimPort-MV2. This supports the expectation that gaming fits in the learning-by-doing learning preferences. Participants who are positive about serious gaming also have more fun during the game. There is no correlation between the learning expectations and the fun factor.

t. What is the size of the correlations between the game factor and the process variables?

As Table D-15 (see Appendix D) shows, there are many correlations between the quality of the game and the process variables.

The quality of the game is significantly correlated with the enjoyment of using computer simulations (corr=.362, p=.000) and the quality of the interfaces (corr=.428, p=.000). This is also true for the relevance of the game on the enjoyment of using computer simulations (corr=.271, p=.000) and quality of the interfaces (corr=.262, p=.000).

Second, there is a significant correlation between personal interaction and the quality of the game (corr=.364, p=.000) and relevance of the game (corr=.287, p=.000). This means that participants who consider the game of a higher quality or more relevant also have a higher level of interaction with the other players. This indicates that participants are more motivated when the quality is high and the game is relevant.

Finally, there is a significant correlation between the quality of the game (corr=.356, p=.000), the relevance of the game (corr=.418, p=.000) and the engagement.

u. What is the size of the correlations between the facilitation indicators and the process variables?

There are significant correlations between the quality of the facilitation and the enjoyment (corr=.321, p=.000) and quality of the interfaces (corr=.311, p=.000). This could imply that the facilitators are necessary to explain the basic use of the system and the interpretation of the information on the interfaces. There is also a significant correlation between the facilitation of the game and the personal interaction (corr=.340, p=.000) and engagement (corr=.199, p=.002). Again, this supports the idea of the importance of the facilitator in these gaming processes.

The embedment of the game is not significantly correlated with any of the process factors. This could mean that for the game play factors, the game can be played as a stand-alone intervention.

Conclusions of input and process variables

There are many significant correlations between the player characteristics and process variables. For example, there is a significant correlation between the value of learning new computer simulations and the enjoyment of using computer simulations. The enjoyment of the game is correlated with the personal characteristics: computer experience, computer game experience, learning preferences, and expectations of serious games.

The quality and relevance of the game is also significantly correlated with the enjoyment of using computer simulations, the quality of the interfaces, personal interaction and engagement. This indicates that not all games are worthwhile. The game has to have a certain quality and has to be relevant for the course.

Finally, there are correlations between the facilitation of the game and process variable. Thatcher (1990) also shows the relevance of the facilitation. This outcome again shows the relevance of the facilitator to make the participants enthusiastic and support the process.

8.3.3 Relations between input and outcome

Although it is expected that the input variables affect the outcomes via the process, we also analysed the correlations between the input and the perceived learning outcome directly.

v. What is the size of the correlations between player characteristics and learning outcomes?

The attitude towards serious games has a positive relation with the perceived learning outcome (See Appendix D, Tables D-17, D-19, D-21, D-23). For example, there is a correlation between expectation of serious games and agreement that the use of SimPort-MV2 in education is valuable, with a value of corr .329 (n=205, p=.000). It is possible that this is a desired outcome of the believers in serious games. On the other hand, it could be that the attitude towards serious games is determined by the learning preferences and value of computer simulations and therefore positively influences the learning outcome.

Many significant correlations are found between the learning expectations and perceived learning; however, these are low (see Appendix D, Tables D-18, D-20, D-22, D-24). This can be the result of a self-fulfilling prophecy, where people want to learn something and therefore say that they reached that objective. This could also imply that participants were supported in focusing on specific learning objectives by the facilitators in the introduction and debriefing.

w. What is the size of the correlations between game quality and learning outcomes?

The quality of the game and the relevance of the game are significantly correlated with the perceived learning outcome (see Appendix D Table D-25 through D-28). The relevance of the game is correlated with 'the use of the game is educationally valuable' with a value of corr .507 (n=245, p=.000). These correlations support the hypothesis that the quality of the game is important for the learning experience (Feinstein & Cannon, 2002; Gosen & Washbush, 2004).

x. What is the size of the correlations between the facilitation of the game and the learning outcomes?

The alignment of the lectures with the game is significantly correlated with the learning outcome 'theory from formal lectures and literature became more understandable' (corr=.312, p=.000, n=219). When the objective of the game is to gain greater insight into the theory, it has to be well embedded in the course.

The quality of the facilitation is significantly correlated with the general learning indicators as well as with several specific learning indicators. The highest correlations were found with the learning indicators concerning the subject Maasvlakte 2 (see Table D-29 through D-32 of Appendix D). This could be caused by the attention paid to the Maasvlakte 2 project in the game. For example, in the debriefing, many relationships are found between the activities in the game and the real-world system. These results show the relevance of the role of the facilitator in the learning process.

Several player characteristics have a positive correlation with the different perceived learning outcomes; however, these are low. There are strong correlations between serious gaming expectations and learning expectations. This means that the personal characteristics influence the learning experiences.

Another conclusion, based on the significant correlations between the quality and relevance of the game and facilitation with the learning outcome, is that both are relevant. The indicator of the alignment of the game with the course was only correlated to the understanding of lectures and literature.

8.4 An inside perspective on understanding complex adaptive systems

The added value of gaming for understanding complex adaptive systems is explored from two perspectives, namely that of the observer (outside the game) and that of the player (inside the game). This chapter has described the added value of gaming from the player's perspective. From the enthusiasm of the players and the positive atmosphere during the sessions, the game SimPort-MV2 appears to be a successful learning intervention. However, this does not answer the questions of whether gaming improves the understanding of complex adaptive systems in a multi-actor context.

Based on 26 learning indicators, the perceived learning of the participants was analysed. The differences in learning outcome between the professionals of the Port of Rotterdam and Port Seminar and the differences between students and professionals were researched. After that, we identified which process and input variables affect the outcome. In this section, the conclusions are summarized.

8.4.1 Perceived learning of playing SimPort-MV2

The first main question of this chapter was: What do the players learn about the complexity of the system and does this differ with different player groups?

In general, the players were positive about gaming as a learning intervention for education as well as for the Port of Rotterdam. However, the results show that learning did not take place for all six defined categories of learning outcomes. Four main contributions are identified.

1. The game was successful in increasing the knowledge about the Maasvlakte 2 project. This result was especially observed with participants who were less informed about Maasvlakte 2.
2. The results show an increase of perceived knowledge about the commercial and strategic complexity.
3. The participants also agreed that the game provides a clear picture of the MV2 area and that the game showed why and how the different processes have to be integrated.
4. Participants agreed that the game can promote cooperation and communication between different departments and individuals.

The game SimPort-MV2 did not increase the theory-based knowledge about complex adaptive systems or other theories explained in lectures, except for the professionals at the Port Seminar.

In the second place, the game did not contribute to a better understanding of dealing with the physical system. This result does not mean that games in general are not suitable for this learning objective. The game SimPort-MV2 does not focus on the detailed, technical aspects of the construction of Maasvlakte 2. This lack of focus on the technical aspects explains this limited learning effect. The game also has a limited effect on general social skills such as communication, discussion and negotiation. The lack of attention to these general skills in the debriefing could cause the low learning score on these indicators.

The perceived learning is closely related to the subject, Maasvlakte 2. A possible explanation for this outcome is that the objectives of the game and the discussions focus on Maasvlakte 2, and at the time of the surveys no reflection on other systems could be done. It is possible that transferring knowledge to other comparable systems is not easy and additional interventions are needed.

The results of the survey showed differences in learning outcomes between the different groups of players. The professionals of the Port of Rotterdam scored lower on the indicators about the subject Maasvlakte 2 because they were already informed about this project. The professionals scored higher on four learning indicators than the students. From the professional perspective, playing SimPort-MV2 is more valuable than from the students' perspective. Professionals may have had more comparable experience and thus possibly better developed learning competencies with which to abstract the perceived learning. This cannot be proven, because the learning competencies and their relation to the perceived learning were not part of the survey.

Finally, it can be concluded that playing SimPort-MV2 contributes to a better understanding of the Maasvlakte 2 system and contributes less to an increased theoretical understanding.

8.4.2 Influence of input and game play variables on the learning outcomes

The second main question was: which input and process variables influence this learning outcome? The schematic of the relations between input, process and outcome variables is tested (Figure 8-1). Figure 8.8 is based on the derived factors and the correlation. The figure shows only the correlations between input, process and outcome with a value higher than .300 and not the correlations between the input variables and process variables.

The correlation analysis shows that VALUEDL, VALUENC and age are not correlated with the process factors and general learning outcome. Also, the learning expectations SUBMV2, THRKNOW and SOCSKILLS are not highly correlated with the process factors and general learning. Earlier we showed that there are correlations for the more specific learning outcomes. The embedment of the game is also not correlated with the process factors and general learning outcome.

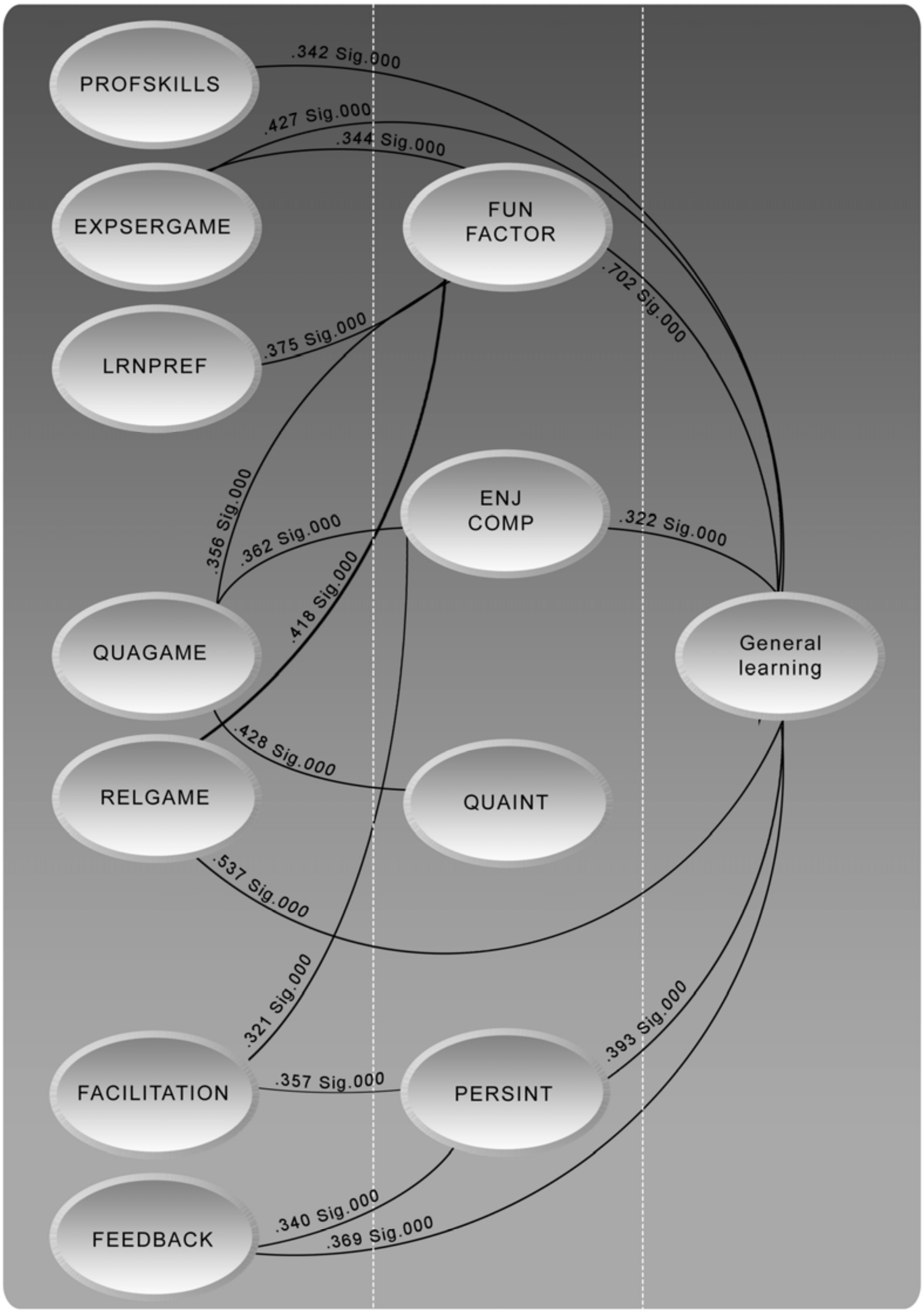

Figure 8-8. The highest correlations between the input, process and general learning outcome

Input variables on process variables and learning outcome

We found significant correlations between the personal characteristics, the quality of the game and the facilitation, and the process factors.

Players with a more positive attitude towards serious games scored higher on the learning outcome. Earlier game experience and computer experience were not correlated with the learning outcome. Finally, the learning expectations were significantly correlated with the perceived learning outcome.

We found a positive correlation between the relevance of the game and facilitation and perceived learning. This means that if the participants were more satisfied with the game and facilitators, they scored higher on the different learning outcomes. This outcome supports the theories and experience that gaming itself is not sufficient for learning. The relevance of the game is important, and facilitators are needed to support the learning process. If the objective of the game is to increase the theoretical knowledge of the course, then the game has to be well aligned with other lectures and assignments.

Process variables on learning outcome

From the correlation analysis between the game process indicators and perceived learning, we conclude that the process indicators are correlated with the outcome. Because the process variables also significantly correlated with each other, we do not know if there is a direct relation between the process variable and the outcome. If we assume that there is a direct relation, then we find the following relationships.

In other studies, the importance of engagement in games on greater motivation and learning has already been discussed (Garris et al., 2002; Sandford, Ulicsak, Facer, & Rudd, 2006). Our analysis, based on the correlations between the fun factor and learning outcomes, supports this relationship.

In multi-player games, personal interaction between players is unavoidable. This was also the reason for developing a multi-player game to simulate social interaction. The correlation analysis showed that the personal interaction is related to the learning indicators. Because the discussions and collaboration in the game are about the Maasvlakte 2 system, this stimulates learning. Greater involvement in the game also results in better perceived learning. However, in the debriefing other signals are also given. For example, one team (Linda’s Choice) explicitly said that during the game they were busy playing and did not have time to think about the relationship with reality. This was also observed by Zagal and Bruckman (2008), who found that gamers have difficulty stepping back from ‘gaming’ to learning.

Finally, we assume that using a computer simulation integrated into the game increased the learning about the physical dynamics of the system. The correlation analysis between enjoyment of using the computer and the quality of the interfaces and the learning outcome illustrates this. The highest correlations are found between the interfaces and learning indicators related to Maasvlakte 2. This indicates that the interfaces are useful for explaining the changes in the system. That also means that using a computer simulation to visualize the physical system is valuable. The correlation between the enjoyment of the computer and quality of the interfaces with the fun factor indicates that computer simulations can be an added value for game play.

In conclusion, learning experiences are mainly related to the subject of the MV2 project. This indicates that SimPort-MV2 supports understanding the complexity of the Maasvlakte 2 systems and is less supportive in transferring general notions and skills about complex adaptive systems.

These results also show that simply playing a game is not enough to achieve good learning results. The quality and relevance of the game directly and indirectly influence the outcome. This also applies to the role of the facilitators, who also influence the game play and outcome. Personal characteristics also influence the game play, and learning and gaming will not be a success for all types of participants, for example for those who prefer lectures and literature studies. Finally, the atmosphere based on the interaction with the computer, each other and engagement are relevant for a positive effect.

In this chapter, we analysed the relation between different variables. Caution should be exercised when using this outcome to make predictions about effectiveness. Just as Wilson et al. (2009) remark, it is possible that variables in combination lead to the results, or that one variable has more impact on the outcome than the other. More research is needed to analyse these combined effects on the outcome.

9. IS IT ONLY A GAME? CONCLUSIONS AND RECOMMENDATIONS

Introduction

'To what extent can serious gaming simulate complex infrastructure systems, and how can serious gaming be used for understanding complex infrastructure systems?' This was the main question posed in the introduction of this dissertation. After a long journey, guided by several sub-questions, it is time to reflect on the results and come to the conclusions. What did we discover? And which questions are still open or have emerged over time?

Before answering the research questions in detail, we start with a short overview of the content of the previous chapters, which can be found in Section 9.1. The answers to the defined sub-questions are presented in Section 9.2. This section is divided into a theoretical exploration and an empirical exploration. A reflection on the research limitations is given in Section 9.3, and implications for the use of serious gaming can be found in Section 9.4.

9.1 Overview of the research

Policy makers and designers face several challenges when planning and designing interventions in infrastructure systems. These challenges are caused by the complexity of these infrastructure systems. In this research, we explored the ways in which serious games[15] support the understanding of this complexity. The working hypothesis was: *Serious gaming is a useful tool to simulate complex, socio-technical infrastructure systems and supports policy makers and designers in understanding the complexity of the planning and design of these systems.* The accompanying main research question was:

[15] In this research serious games are described as simulation games that use gaming concepts and technology from the entertainment video game industry (see Chapter 1.3).

To what extent can serious gaming simulate complex infrastructure systems, and how can serious gaming be used for understanding complex infrastructure systems?

The research done to answer this question was based on the research framework as presented in Figure 9-1. This research consisted of two parts. The first part was a theoretical exploration in which the relationships between the design of infrastructures, complex adaptive systems and serious gaming were analysed, and requirements and expectations for the development and use of serious games were derived.

The second part was the empirical exploration, in which the requirements and expectations based on the theory were tested in a case concerning the development of the land reclamation project Maasvlakte 2 in the Port of Rotterdam, The Netherlands.

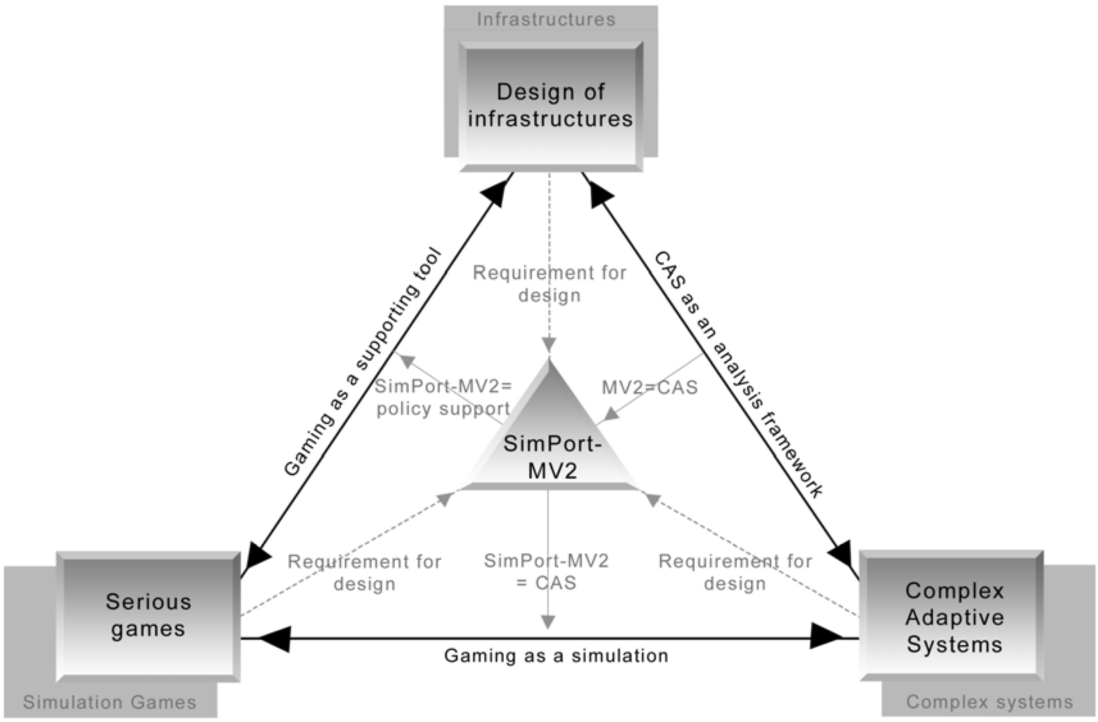

Figure 9-1. Research framework showing the relationships between the key concepts and the function of the game SimPort-MV2

The relationships between the theoretical concepts and the effects of the development and use of gaming were translated into six research sub-questions.

RQ1: What are complex systems, and in what way does complex systems theory contribute to the understanding of infrastructure systems?

RQ2: What properties make serious gaming suitable for simulating complex adaptive systems?

RQ3: In what way can serious gaming support the policy-relevant understanding of complex infrastructure systems?

RQ4: What are the lessons learned from the development of a serious game about complex infrastructure planning?

RQ5: What lessons learned about the complex system behaviour in gaming can help us to improve our understanding of complex infrastructure systems in reality?

RQ6: What knowledge and skills do players gain about complex infrastructure systems from being involved in and part of the system?

With this research, we showed that serious gaming is a useful tool that can increase the understanding of the dynamics of a complex adaptive system such as infrastructures, from an outside observer's perspective as well as from an inside player's perspective. Furthermore, we provide recommendations for improving the effects of serious gaming on the policy-making process in the future. In the next sections, detailed answers will be given to the research questions.

9.2 Answering the research questions

In this section, the results are discussed, based on the six sub-questions. We start by answering RQ1, RQ2 and RQ3 related to the theoretical exploration. Next, the questions RQ4, RQ5 and RQ6 of the empirical exploration are answered.

9.2.1 Theoretical exploration

The objective of the first part of this research was to explore the relationships between the design of infrastructures, complex adaptive systems and serious games based on theory. We had to answer the questions 'What do we mean by these concepts?' and 'How are these concepts related to each other?' The theoretical exploration started with the relation between infrastructures and complex systems. Next, we researched the relation between complex systems and serious gaming. Finally, the relation between serious gaming and infrastructures was studied.

Infrastructures as complex adaptive systems

The research began with the question about the relation between CAS and infrastructures.

> RQ1. What are complex systems, and in what way does complex systems theory contribute to the understanding of infrastructure systems?

The history of thinking about complex systems has shown that there are different perspectives which have emerged from different research fields and which have been inspired by different developments. Therefore, several complex systems theories exist alongside one another, such as General Systems Theory, Systems Thinking and Complex Adaptive Systems. Each has its own perspective for describing and analysing complex systems.

Currently, the Complex Adaptive Systems theory is leading in the field of understanding complex systems. One important reason is that Complex Adaptive Systems assume that the structure of the system is dynamic, and therefore a bottom-up perspective is needed which allows for changes in the structure of the network. Other theories, such as Systems Thinking and Cybernetics, assume that flows over the network are dynamic and that the structure of the system is fixed.

Taking into account the social and physical characteristics of systems, the following description of Complex Adaptive Systems was used: Complex Adaptive Systems are open, adaptive systems, situated in a dynamic environment, consisting of heterogeneous agents and actors that are related in a network structure, and consequently, the result of these networked interactions is the observed system behaviour.

The theoretical classifications to define Complex Adaptive Systems are not sufficient for the analysis of real-world systems. Therefore, based on the observable characteristics of Complex Adaptive Systems, a conceptual framework was designed consisting of an agent, an interaction and a system level (see Figure 9-2).

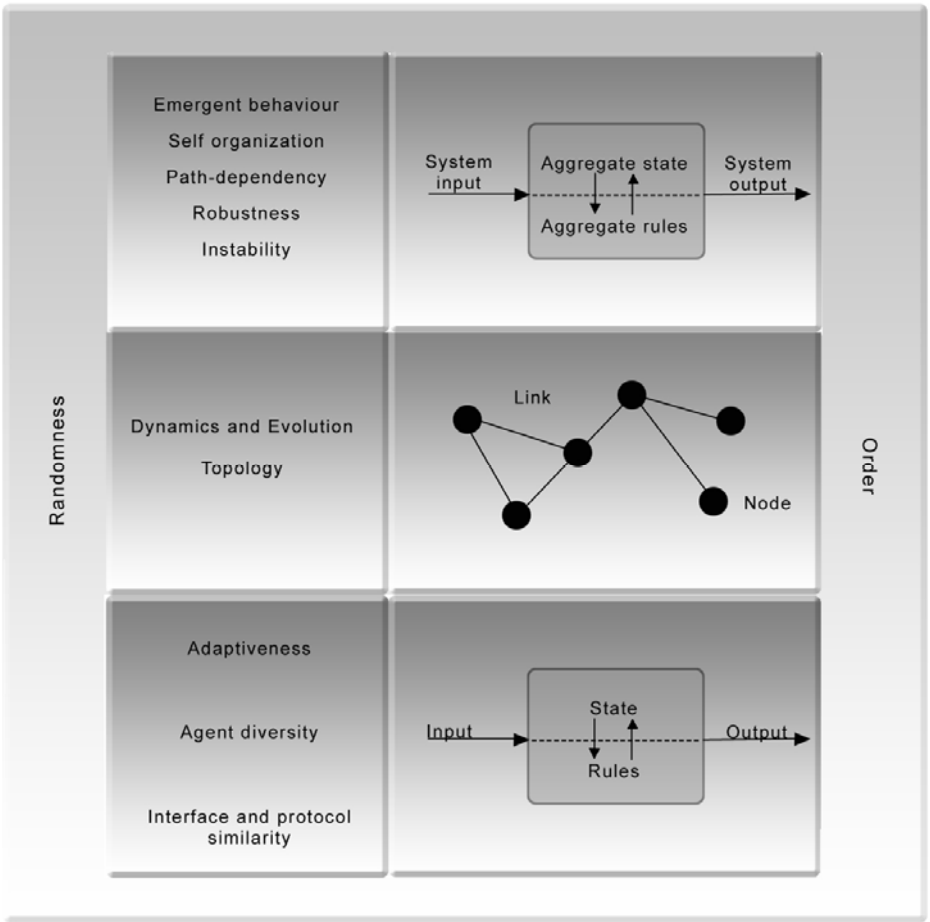

Figure 9-2. Conceptual framework of complex systems

This framework has proven to be useful for describing the characteristics of urban and spatial infrastructures (Van der Lei, Bekebrede, & Nikolić, [forthcoming]). Infrastructures consist of multiple diverse elements, physical assets and social actors that are related in a network based on rules and regulations. The combined interaction of the elements' activities could result in emergent behaviour, such as traffic jams, power black-outs or price increases after liberalization.

This framework can be used to analyse the complexity of infrastructure systems by comparing characteristics of infrastructures with the properties of complex systems. The framework can also support the understanding and explanation of unexpected, emergent behaviour.

For the direct support of design and management of infrastructure systems, this framework lacks forecasting capabilities; it is only descriptive. Future dynamics and unexpected consequences cannot be derived.

In order to explore the possible future situation of the dynamics of the system or the effects of interventions in the system, dynamic tools or instruments are needed. To research the aggregate behaviour, we need the help of computer-based exploration models (Holland, 1997). These models can have different functions to show the correctness of their prediction of the real world situation, to demonstrate that something is possible or to suggest new ideas about complex situations (Holland, 1997). The framework can be used to understand and explain the observations in the computerized environment or to clarify the consequences of the limitations of the simulation.

Serious gaming for simulating Complex Adaptive Systems

In this research, serious gaming was introduced as a tool to simulate the dynamics of a complex adaptive system and as an intervention to increase the understanding of this system. To explore these assumptions, we first had to know under which circumstances serious gaming can simulate complex adaptive systems. Therefore, the following question had to be answered.

RQ2: What properties make serious gaming suitable for simulating complex adaptive systems?

Serious games are games with a serious purpose for education, policy and training, but also for health, politics and advertising. They employ technology and gaming concepts from the video game industry. In this dissertation, the focus lay on serious games as a sub-set of simulation games. These serious games are interesting because they offer new possibilities for simulating socio-technical systems, and they also offer the possibility of integrating large-scale simulation models.

Serious games contain several elements of complex adaptive systems. When a game is divided into players, rules and interaction, and game output, it shows levels comparable to those used for analysing Complex Adaptive Systems. From a comparison of these levels, we concluded that serious games can simulate this complexity if they consist of multiple players and/or multiple adaptive agents, flexible rules and dynamic interaction, and an open game outcome. These requirements have to be incorporated into the game design process to develop a game in which such complex properties as similarity, diversity and adaptation of agents, evolution of the system and self-organization, path-dependency, robustness and instability can emerge.

At the same time, a game needs to fulfil the following game requirements: the game has to be reliable, usable and realistic, but it must also contain players, rules, resources, challenges, competition and other game characteristics. Finally, to have educational value, the game has to be embedded in a learning context or policy process, there has to be sufficient opportunity for reflection after the game, and it has to be a motivating experience.

Serious gaming for understanding relevant to policy

The third question was about the relation between gaming and the design of infrastructures.

> RQ3: In what way can serious gaming support the policy-relevant understanding of complex infrastructure systems?

Understanding complex systems has been an important objective of simulation games for many years. Based on the characteristics of games as a semi-bounded complex system, games are a safe environment in which to experiment and test policies, ideas and actions which may be too expensive, dangerous or time-consuming (Barreteau, 2003; Klabbers, 2006) to conduct in real-world situations. Furthermore, games are a motivating activity (Malone, 1981), and research has shown that they improve learning retention (Egenfeldt-Nielsen, 2005). Serious gaming increases these characteristics by simulating a more realistic and immersive environment and by including motivating game concepts, such as levels and challenges.

Gaming is used for many purposes and in many different situations (Duke & Geurts, 2004; Egenfeldt-Nielsen, 2005; Meijer, 2009). One of the purposes is to gain insights into the complexity of a system, without analysing how or for what type of complexity gaming is useful (Duke & Geurts, 2004; Klabbers, 2006). We argue that serious gaming can be used in two ways to support the understanding of infrastructures.

The first is by analysing the socio-technical system behaviour of the players interacting with the simulated physical environment. Each game session explores one possible future path. Observers can analyse the strategic behaviour of the players in the game, the dynamics in the social and physical network and their interaction, and the emergent system behaviour. If the game is played multiple times, the outcomes show patterns of self-organization and path-dependency, and it can be analysed for which parameters the system is instable or robust.

The second way in which gaming supports the understanding of infrastructures relates to the individual learning of the participants. By using games in the right social context, they can be used for all types of learning, but in relation to understanding complexity this research focused on the cognitive learning outcome. On the individual level, games can be used to increase subject-related content and theory-related notions; they can be used to understand linear and complex processes within complex systems; and finally, games can be used to practice the management of the physical and social network. An important element in this learning process is the reflection on the game play process. This reflection is facilitated by the feedback in the game, the facilitator and the embedding of the game in a richer learning or policy-making context.

9.2.2 Empirical exploration

The second step of this research was to explore the relations between the design of infrastructures, complex adaptive systems and serious gaming in reality. Therefore, we decided to take an example of a complex infrastructure project, Maasvlakte 2 (MV2), and develop a serious game around the design and development of this system.

The game SimPort-MV2 was developed to gain insights into the consequences of different strategic choices over the long term and to improve communication and coordination between different departments of the Port of Rotterdam in order to synchronize the construction and negotiation process. The objective of this multi-player game is to *make appropriate planning and implementation decisions, individually and collectively, that will lead to a satisfactory design and exploitation of the Second Maasvlakte (1,000 ha) over a 30-year period.*

In this section, we draw conclusions about the design and use of the game. We start with the lessons learned from designing a serious game, followed by an evaluation of increasing understanding of system behaviour and the learning of the individuals.

Lessons learned from the development of a serious game

Because developing a serious game from a complex adaptive systems perspective is relatively new, this development was also a learning process, and our experiences may be useful for developing serious games in the future. The fourth question was therefore:

> RQ4: What are the lessons learned from the development of a serious game about complex infrastructure planning?

One of the objectives was to develop a realistic simulation of a real-world system with social and technical system characteristics. For the purpose of the game, a hybrid version of a computer game and social game was used. We decided against developing a total immersive 3-D environment in which the participants could walk around. An important reason for this was that in the real-world system, the place where discussions take place (the office) is different from the area that is the subject of the discussions (Maasvlakte 2). This set-up has the advantage that the participants are free to choose and change their ways of communication. They are not confined to using computer interfaces alone, but they have the option of using a planning board, a white board, a flip chart or post-its in their communication. This freedom also allows more space for self-organizing behaviour.

The design process was based on the policy exercise design process of Duke and Geurts (Duke & Geurts, 2004). The process starts from a real-world system and devotes attention to the conceptualization of the real-world system and its translation into a game. However, the development of the virtual environment is not part of the approach of Duke and Geurts. Therefore, elements of simulation and interface design were integrated into the design approach. For a good integration of the social interaction between the players and their interaction with the simulated physical environment, the design of this virtual environment had to be taken into account from the start of the design process. For the development of the virtual environment, developers could use existing game engines, but these did not always fit the requirements. Therefore, SimPort-MV2 was developed from scratch.

The process of development can be considered a co-evolving system; it started with some basic elements which were extended and adapted based on the feedback of the players and game play. A disadvantage of this approach was that the structure of the simulation had to be flexible enough to constantly adapt to new elements. This was a reason the developers rebuilt SIMMV2 into a more flexible environment, SimPort-MV2.

There is an inherent tension between the development of a game and simulating a Complex Adaptive System. On the one hand, Complex Adaptive Systems are open systems in which a small change in one element can have significant consequences for the system behaviour as a whole. On the other hand, the development of simulations in general – and games specifically – is often driven by setting clear boundaries that are just large enough to be able to take relevant elements into account. The boundaries have to be carefully chosen, and these define the validity of the model. A serious game therefore does not provide certainty about the future dynamics of the system or promise that the strategy of the winning team will give the best results in reality.

Special attention has to be paid to the design choices related to the function of the game. The game SimPort-MV2 has two functions: system understanding and individual learning. These different uses call for different requirements related to the validity of the game. Both functions have different criteria for the level of abstraction, feedback structure and embedment of the game. For system understanding, the level of abstraction, detail and validity of the game is relevant for drawing valid conclusions about the patterns of behaviour. This could conflict with the learning objectives if complicated models are used. It is expected that these models increase validity, but on the other hand, such models can be a black box, where cause and effect relations are no longer clear and learning decreases. Cannon describe this as the complexity paradox (Cannon, 1995).

Besides the two learning objectives mentioned, learning about the system also takes place during the development phase. Game developers need a clear understanding of the system elements and behaviour in order to make well-founded design choices. This understanding is created by exchanging information during discussions and by developing conceptual maps and models which make the designer's knowledge explicit. On the other hand, patterns of emergent behaviour as a consequence of the social and technical interaction in the system cannot be designed. Learning about emergent system behaviour only occurs after playing the game multiple times with 'real participants'.

Increasing understanding of complex system behaviour by observing game play

The first use of serious gaming is to observe the system behaviour of the simulated socio-technical system and to search for patterns of behaviour based on multiple gaming sessions. The question related to the value of serious gaming as simulation was thus:

> RQ5: What lessons learned about the complex system behaviour in gaming can help us to improve our understanding of complex infrastructure systems in reality?

By comparing the characteristics of complex systems as defined in Chapter 2 with the observations and outcomes of the gaming sessions, we conclude that SimPort-MV2 simulates a Complex Adaptive System. The defined properties on each level can be observed in the game play. This is an important requirement if the game is used to analyse the dynamics from a complex adaptive systems perspective.

In the first place, we learned that the output shows a large variety of possible outcomes for the port area. Each team ended up with a different situation after 30 game years. Even within a relatively closed system, i.e., without any major influence from (inter-)national politics or other stakeholders, a large solution space can be observed. The results show that steering towards a single outcome seems impossible, and flexibility in the design is necessary to adapt to the changing environment.

Although the outcomes show a large variety, several patterns of system behaviour can be derived. These patterns could be used as points of discussion in the policy-making process.

- The game showed that the planning as proposed by the Port Authority is feasible under normal circumstances. The results also showed that direct income and profit from Maasvlakte 2 is uncertain and depends on the number of contracted clients.
- The final outcome is sensitive to the chosen building strategy and economic climate. Especially when the economy declines during the building and exploitation period, this has major effects on the outcome. During this period it is necessary to contract clients to avoid vacant areas, while clients, on the other hand, are less interested. The outcome is robust for the commercial strategy and allocation plan, because these are flexible.
- Furthermore, it is a challenge to follow a synchronized construction and exploitation process. Building processes takes a couple of years, and clients would like to begin exploitation within a shorter time period. Communication between different departments can also lead to coordination problems, yet two teams showed that synchronization is possible.

The limitation of a serious game is that the game outcome does not provide optimal solutions or point out the decisions which bring the system to this optimal state. However, the outcomes give patterns of behaviour showing how the system can evolve and what parameters largely affect this evolution. This knowledge can be taken into account in a decision-making process and in the planning of large infrastructure projects.

From the example of SimPort-MV2, we were able to conclude that gaming can support the understanding of complex systems on each level of perspective. At the agent/actor level, the differences between elements can be observed, as well as the behaviour of agents. At the network level, the evolution of the system can be analysed. At the system level, the emergent behaviour, path dependency, self-organization, and the robustness and instability of the system can be analysed.

Participants increase their knowledge and skills by being involved in and part of the system

The second way of using serious games is to teach the participants knowledge and skills about the subject of the game and about concepts of complex adaptive systems.

RQ6: What knowledge and skills do players gain about complex infrastructure systems from being involved in and part of the system?

From the enthusiasm of the players and the positive atmosphere during the sessions, the game SimPort-MV2 appears to be a successful learning intervention. The participants enjoyed playing the game, and they agreed with the general learning indicators, which means that they found the game a worthwhile experience and thought that it improved their learning.

More specifically, we observe that the game was especially successful in increasing knowledge about and insights into the Maasvlakte 2 project (Table 9-1). The results show an increase of perceived knowledge about the commercial and strategic complexity. The participants also agree that the game provides a clear picture of the Maasvlakte 2 area and that the game showed why and how the different processes have to be integrated. Finally, participants agreed that the game can promote cooperation and communication between different departments and individuals.

The participants who were already informed about the Maasvlakte 2 project did not increase their knowledge about the system, while the participants who were less informed did increase their insight into the project. On the indicators related to the future dynamics of the system, such as 'how to synchronize the construction and exploitation' and 'promotion of cooperation and communication between individuals and departments', the professionals scored significantly higher.

Table 9-1. Perceived learning outcome of playing SimPort-MV2

Perceived learning outcome	Increase?	Comments
Theory-based notions		
Domain-specific content	✓	Except for the professionals of the PoR
Understanding linear processes	✓	Only strategic and commercial complexity
Understanding complex behaviour	✓	Only related to project Maasvlakte 2
Management of the physical environment		
Management of the social environment	✓	Only related to project Maasvlakte 2

Correlation analysis showed that there are direct and indirect correlations between the input and process variables on the learning outcome. See Chapter 8.4.2 for the details.

- There is a significant correlation between the fun factor, the enjoyment of using computers in the game and personal interaction with the learning outcome. The fun factor in particular is highly correlated. This means that engagement is important for learning, which supports the idea that enjoyment is an important element for learning (Garris, Ahlers, & Driskell, 2002; Sandford, Ulicsak, Facer, & Rudd, 2006). Positive cooperation and interaction between players also increase learning outcome.

- High correlations are found between the interfaces and learning indicators related to Maasvlakte 2. This indicates that the interfaces are useful for explaining the changes in the system. That also means that using a computer simulation for visualizing the physical system is valuable.
- The different process indicators, the fun factor, the enjoyment of using computers in the game, personal interaction and the quality of the interfaces are significantly correlated with each other. These factors could have mutual influence. This means that difficulties with computers could have a negative effect on the engagement. Likewise, if participants do not actively participate, this could influence the personal interaction and level of engagement.
- The learning preferences and serious game expectations of the players are correlated with the level of engagement in playing and the general learning outcome. Gaming is most valuable for participants who prefer to work together on a project and expect gaming to be valuable.
- The quality of the game and the relevance of the game are positively correlated with the game process (fun factor, enjoyment of using the computer and the quality of the interfaces) and the learning outcome. When participants are more positive about the quality of the game and/or see the relevance of the game, they are more engaged in the process and have a higher perceived level of learning.
- The embedment of the game in a course is significantly correlated with learning theory-based notions. The quality of the facilitation and feedback is highly correlated with the personal interaction and learning outcomes. This supports the importance of the role of the facilitator in the use of serious gaming.

9.2.3 Conclusions about serious gaming for understanding complex infrastructure systems

The main research question was:

To what extent can serious games simulate complex infrastructure systems, and how can serious gaming be used for understanding complex infrastructure systems?

The main answer to this question is as follows:

Serious games can simulate properties of complex adaptive systems when several design requirements are taken into account. In addition to simulating this complexity, they also simulate the social and technical system characteristics integrally. On the other hand, the simulation is on a higher level of abstraction. Details in the system are not taken into account, because this distracts participants from the gaming experience. Consequently, gaming output is useful in analysing patterns of the system's future behaviour, but the output is not sufficiently detailed to yield the optimal design.

Serious gaming can contribute in two ways to the understanding of complex infrastructure systems: by simulating the dynamics of a complex adaptive socio-technical system (observer's perspective) and by allowing one to experience the complexity of being part of the system (player's perspective).

1. By analysing the dynamics and outcomes of multiple gaming sessions, policy makers can learn about the behaviour of the system and the players, the variables for which the system is robust or instable, and which bottlenecks can be observed en route to the desired end state. The results of SimPort-MV2 show that gaming can be used to simulate different paths into the future and to analyse the emergent behaviour and other properties on the system level, as well as to show the network dynamics and increase insights into the behaviour of adaptive agents.

2. Participants of the game go through a learning experience. Players act and react in a complex environment and experience the dynamics of the system. By participating in this learning experience, they increase their cognitive knowledge about the complexity of the system. The case showed that SimPort-MV2 increased the participants' knowledge and insights into long-term effects of the Maasvlakte 2 system. This learning is influenced by the engagement in playing the game, the relevance and quality of the game, the enjoyment of using a computer simulation and the quality of the interfaces and facilitation.

In conclusion, we can assert that managers of complex infrastructure systems need to play serious games. By playing serious games, unexpected or undesired behaviour of interventions can be observed. Gaming also provides new insights into the relations and possible dilemmas of parallel processes. These new insights, as viewed from an observer's perspective as well as from the experience of being part of the system, could support discussions in the policy- or decision-making process.

9.3 Reflection

The validity of the outcomes of the research has to be placed within the context of several research limitations. In this section, several limitations and their consequences on the outcome are discussed. The limitations are discussed from three perspectives: the research perspective, the game developer's perspective and the policy/learning perspective.

9.3.1 Critical remarks from a research perspective

`In this research you use one game to support your theoretical framework; you cannot compare the results with other games, so what does that mean for the generalization of the results?´

It is true that our empirical conclusions are based on the development and evaluation of a single game, namely SimPort-MV2. We are aware that this is just one example of a complex infrastructure system and that we evaluated only one type of serious game. Other infrastructure systems with different characteristics could require another game design or even another intervention tool. Consequently, based on these results we cannot conclude that gaming is more or less effective than other tools or that this design is the most appropriate design for all types of infrastructure projects.

Being aware of this limitation, we decided nevertheless to analyse a single game, for two reasons. The first reason is that this study is an explorative study in which we try to show different ways of using serious games for understanding complexity. Second, research requires making choices as to what is taken into account and what is not. One must also make a choice between evaluating a single aspect of multiple games or multiple aspects of one game. With respect to the explorative question, we chose to analyse one game in multiple ways: on the design, observer and individual levels.

Generalization of the research outcome is therefore difficult. The expectation is that projects with characteristics comparable to Maasvlakte 2, e.g., a large spatial impact, a long decision-making and construction process, many uncertainties as to costs and revenues and strong path-dependencies in a socio-technical setting, can derive similar advantages from using serious gaming for increasing understanding of the complexity. However, this is a question for further research.

´If a researcher has been involved in the design, the facilitation and the evaluation of the game, does this influence the outcome?'

The limitation of using a design research approach is the research bias. We were aware of this from the beginning. The researcher was actively involved in the development and evaluation of the game. However, the development was not accomplished alone. The development team consisted of people from the Port of Rotterdam who had knowledge about the system, people from Delft University of Technology for the game concept and people from Tygron Serious Gaming for their knowledge of programming. In this sense, the personal research bias was reduced. In addition, the facilitation of the game employed different persons. The influence of the research was compared for the different facilitators and showed no differences.

'In order to measure the learning effects, you used a survey and asked the participants to score on what they think they have learned. Does that give reliable learning outcomes?'

The measurement of the learning was done with a questionnaire containing statements about the opinion of the participants regarding their learning. This is a subjective measurement. Self-reported learning is a good first indicator to measure if players increase their insight into complex systems. More objective methods could be used for testing the increase of insight; however there are few good methods to measure different types of learning. An increase in theory-based notions and domain-specific knowledge could be measured using knowledge tests, but other types of learning require other methods and are not easy to measure. In a comparative study of the effectiveness of different games or different learning methods, more objective measures are needed. The objective of this research was not to compare the increasing complexity of different methods or to conduct an efficiency study on using games. To answer the research questions of this dissertation, the subjective measures are sufficient.

9.3.2 Critical remarks from a gamer's perspective

'Is this all? We have been using simulation games for many years; what is new about serious gaming?'

We can argue whether serious gaming is something new or whether we have been using it for years. Independent of that discussion, there is something new, and that is the use of technology and gaming concepts from the entertainment industry in games with a serious purpose. The entertainment video game industry develops games about large-scale systems with the use of relatively complicated models. These games are entertaining, challenging and attractive to players. The combination of using complicated models in a way which allows players to interact is useful if we want to develop games about large systems for learning and policy purposes.

The ideas from the entertainment industry are interesting, but there are no games with a realistic story of Maasvlakte 2. Therefore, we had to develop a serious game ourselves. Because we had not previously done this, the development process was a learning process in itself. We do not claim that the game in its present form represents the ultimate game design or the best way of using games for understanding complex systems. At the beginning of the development, we did not know if it was possible to develop a serious game with our limited resources. Therefore, SIMMV2 was developed as a prototype to show the added value of serious gaming for understanding infrastructure projects. The first positive experiences led to an improved prototype, SimPort-MV2. New experiences and developments will make it possible to improve serious games.

‘How can one validate a game about a situation which does not exist?’

SimPort-MV2 is a game about the construction and exploitation of Maasvlakte 2, which in reality has just begun. The outcomes of the game therefore cannot be validated based on the real-world system. In general, emergent properties are difficult to validate. In order to examine the validity of SimPort-MV2, we used face validation. Experts from the Port of Rotterdam were asked if the outcomes and the processes in the game were realistic. Although face validation has disadvantages, it offers some opportunity for reflection. Furthermore, the outcomes of the game itself are not really important for the learning outcome, although it is important to define the winner of the game. The most important part of the game is to analyse the processes and the discussions and to observe patterns of behaviour. The feedback from the simulation has to support the discussion about the consequences of decisions. That is also the reason why the use of realistic data instead of the real data and clients is not a problem for the validity.

9.3.3 Critical remarks from a policy perspective

‘So, based on the output of the game, is it possible to forecast future behaviour?’

Predicting the future cannot be done with simulations, nor with serious games. Games are always an abstract aspect of reality in which the most relevant factors are taken into account. As complex adaptive systems theory shows, small changes could have a great impact on the behaviour of the system. Therefore, less important factors which are excluded from the game can have great influence. It is not known what Maasvlakte 2 will look like in 30 years, but this will surely be different from any of the outcomes of the game.

The game does simulate possible future paths within the boundaries of the game. These insights into the diversity of these paths or similarities in the dilemmas could be input for the next round in the policy-making process. Therefore, the game itself is already an intervention in the future path.

‘How can we use gaming in a policy process when it takes a couple of years to develop a game?’

The mismatch between the date the game is needed and the date the game is finished is caused by two factors. The client asks for a game which they need directly, but developing a game can take months or even years. This was the case with the SimPort-MV2 game for the Port of Rotterdam. Due to many circumstances, the development took even longer than expected. The most important reason was the development team’s learning process in developing serious games. The Port of Rotterdam Authority took part in this learning process and was cooperative even when the first session was delayed.

Based on this development process, several lessons were learned for developing these games in the future. One suggestion is to start with a small system and extend the concept further in a subsequent version. This is only possible when a flexible technical environment is used. Second, there are many game engines available, which could reduce the programming time. However, these engines also have limitations.

Third, many infrastructures have similar characteristics and uncertainties in the future. Many game concepts could therefore be used for different infrastructures. By developing several general game concepts which are easy to adapt to different infrastructure sectors, it will be much easier to develop new games in the future. This implies learning from earlier design projects and re-using concepts, but with attention to the specific issues of different sectors.

‘Does being part of a game and trying to win give valid outcomes for the behaviour of the game?’

Due to the competition element, a team could try to find the boundaries of the game instead of reacting as a port manager. This has advantages; a team can experiment with extreme situations, for example, it can choose an extreme building strategy and experience what happens as the economic situation changes. On the other hand, this could give unreliable outcomes in the game. This game behaviour was experienced only twice. In one team (Strandhazen), the players asked about the points at which the performance was saved (after 10, 20 and 30 years), and in their decision-making they made use of this information. They only started building after 10 years. In the first period, therefore, the costs were not taken into account. The second example was a team (the ‘A-ploeg’) that decided to take the ‘carrying on, but not rushing it’ building strategy. The reason was that they thought the designers made the middle option the best option. Because this unrealistic game play was only observed twice out of 80 teams and had limited effects on the outcome, we can say that in general participants take their role seriously and play the game as realistically as possible.

9.4 Implications for gaming in practice

The research discusses and reflects on the concepts and relations of infrastructures, complex adaptive systems and serious gaming. This section describes how the results contribute to discussions in the field of policy in infrastructure sectors and in the gaming community.

9.4.1 Community of policy- and decision makers in infrastructures

First, we describe the three main contributions of this research for policy- and decision makers, especially in the field of infrastructures. This community could use serious gaming in the policy- or decision-making process.

‘Serious gaming for learning about policy-making in complex multi-actor systems’

The theoretical exploration of gaming and learning showed that gaming is used in all types of learning, but we focused especially on cognitive knowledge. In relation to complex adaptive systems, we derived that gaming could support increasing understanding, specifically knowledge, insights about the dynamic processes and social skills. More insights about the contribution of gaming were derived from the empirical study of the contribution of SimPort-MV2.

The surveys of the participants showed that they increased their knowledge, insights and social skills about the Maasvlakte 2 project in general. In the discussions during the debriefing, similar learning points were identified. From these results, we argue that serious gaming contributes to an increase in knowledge, insights and skills about the topic of the game SimPort-MV2. Based on our analysis, the generalization of this newly acquired knowledge to more general learning objectives was not evident.

In a group interview with employees of the Port of Rotterdam a week after playing the game SimPort-MV2, they also described the gaming session as a method for sharing perspectives and targets and a way to learn a similar language. This game can be used as an eye-opener to see the big picture or as a method for defining one's role in the project. Second, gaming can be used as a starting point for discussions about the role of different departments and functions in a project of this size and the dependencies between the roles and personalities.

In conclusion, this indicates that gaming for policy making is especially interesting when the game is closely related to the topic of the policy discussion. Furthermore, gaming can be used at the start of a large project to inform the participants about the whole picture, to discuss different objectives and roles and to increase knowledge and dependencies of a project. However, we should not expect that playing the game once contributes directly to the decision-making process. It is only a helpful intervention in the process, and the outcomes of the game support the discussion but do not directly influence the decision. The reality is more complex than the level of abstraction in the game.

'Serious gaming to derive new insights into the complexity of systems like port development'

A second outcome of this research is an illustration of the use of serious gaming to derive new insights into the dynamics of a complex adaptive system. From this perspective, gaming is not only used as a learning tool, but also as a simulator of part of the complex real world. The outcome of each session illustrates one possible future path within the boundaries of the game. Analysing multiple paths derived from multiple gaming sessions provides insights into patterns of system behaviour.

What does this mean for the Port of Rotterdam? Maasvlakte 2 is a highly complex system, and the behaviour of the future is uncertain. Each team that played the game SimPort-MV2 explored one path of the development and exploitation of Maasvlakte 2, related to different building and commercial strategies and in different economic environments. The results of more than 80 teams showed that the outcome of MV2 is sensitive to the building strategy and economy. A decline in economic growth leads to a decrease in demand, a worse negotiation position for the Port Authority and limited sales, which can be frustrating for commercial directors. Consequently, commercial directors contracted less interesting clients and became more flexible with respect to strict environmental requirements and objectives. These contracts are signed for a long period and still have effects after 30 years, even when the economy is growing again. The choice of building strategy also has significant effects on the outcome. This is not strictly related to the choice of the strategy, but also to the drive of the building director to build as quickly as possible, without relating the building of the Maasvlakte 2 area to the demand of clients.

Furthermore, the analysis of the outcome showed that it is possible to reach a break-even point within 30 years and to synchronize the building and exploitation processes, although the teams show that this is not easy to do and requires discipline in adapting the strategy according to the developments in the system.

The use of serious gaming as a simulation of a bounded subsystem of reality has proven to be possible. However, this does not mean that serious gaming is comparable to a decision support system. The limitations of gaming, related to the level of abstraction and therefore the exclusion of many inputs from the environment, leads to the added value of gaming for seeing patterns of behaviour and not for guiding decisions about the best solution.

'Contribution to combining theory of complex adaptive systems with the social sciences like policy and public administration'

Working in a field on the boundary of technical-physical systems and social networks requires a combined view of those perspectives. This research contributes to this combination by comparing concepts of Complex Adaptive Systems theory with the concepts used in policy, public administration and organization sciences. Although this could be done in more depth, we conclude that both CAS and the concepts mentioned above deal with systems with comparable characteristics, such as uncertainty, adaptation, emergence, and path dependencies. Furthermore, in combining these concepts and CAS, knowledge and insights can be shared.

Consequently, this also calls for tools and methods which incorporate aspects of technical and social systems. Serious gaming, as explained in this dissertation, is one example of a tool which combines the mentioned theories and tools and methods, such as group processes, role playing games and agent-based models. Therefore, serious gaming focuses on the boundaries between physical and social systems.

9.4.2 Community of gamers and game researchers

Second, this research contributes to the discussions in the gaming community. The three main contributions are discussed below.

‘New insights about the design of a serious game’

In a serious game two worlds have to be combined. The first is the world of simulation games, of which the objective is to simulate parts of reality in an interactive way, and the second is the world of entertainment computer games, where enjoyment, challenge, story and interfaces are most important.

This means that serious games have to fulfil two criteria, namely the validity of the simulation (based on the criteria of simulation games) and the playability of the game (based on the requirements of entertainment games). Serious games are more than just a computer game with an attractive interface. A serious game also contains a realistic simulation and a challenging game play, and is well embedded in a learning or policy-making context. In other words, beyond the engagement in the game, serious games also have to be meaningful. This could lead to dilemmas and trilemmas as described by Harteveld et al. (Harteveld, Guimaraes, Mayer, & Bidarra, 2010).

One of these dilemmas is related to the double function of SimPort-MV2. On the one hand, the game was used as an individual learning tool and on the other hand as a simulation of a socio-technical system. This has consequences for the game’s level of abstraction, such as the details of the simulation or decisions of players. For analysing the behaviour of the socio-technical system, a valid and detailed simulation is required. However, from the learning perspective, the objective is that players learn the cause-and-effect relations of their decisions. This becomes difficult if the simulation is so complicated that it is considered a black box.

Developing a game is relatively expensive, just like drafting a book or realizing an infrastructure, but once it is there, it is cheap to distribute or play it. There is also a risk that after a well-considered design process, the game may not work. To avoid this problem with SimPort-MV2, because of the lack of experience with developing serious games, it was decided to start with a prototype. After concluding that the concept worked, the game was developed further. For SimPort-MV2 this meant a re-development of the programming language and a re-design of the interfaces and the number of elements in the game. Even then, new elements or subsystems were added or replaced during the game to make the game available to a larger group of players.

In conclusion, the designers of serious games have to take into account the requirements of simulation games and entertainment games. Together with requirements related to the game’s purpose, designers have to contend with many dilemmas. Finally, to avoid developing an overly complex game, it is advisable to start with the development of a relatively simple prototype and extend this prototype as necessary.

‘Founding of games as complex adaptive systems and the meaning of using games for understanding complexity’

One of the values of gaming is that it simulates complex systems and that it can be used to understand complexity (among others Duke & Geurts, 2004). However, less research is done on why games simulate complex adaptive systems and what part of complexity can be understood with gaming. This research elaborated on these two aspects.

First, the analysis of games as a complex adaptive system showed that not all games can be considered complex. Puzzle games, for example, lack the properties assigned to a complex adaptive system. The outcome of our analysis was that in order to simulate a CAS, games have to be multi-player or have multiple agents, have flexible rules and relations and have an open game outcome. SimPort-MV2 showed that these requirements lead to a game which simulates a complex adaptive system.

Second, SimPort-MV2 illustrates that gaming can contribute to an increased understanding of complex adaptive systems. It is possible to explore the diversity and the adaptation of the players due to the changing environment and to extract some internal rules of the players. Furthermore, it is possible to show different paths of evolution of the system and dynamics. Finally, the observations at the system level show that gaming can be used to explore emergency, self-organization, path dependency, robustness and instability. When asked about the learning outcomes, the players agree that they increased their knowledge about Maasvlakte 2 but not necessarily about managing complex projects.

‘A large evaluation study of the effects of gaming’

One of the disadvantages of many evaluation studies is that the number of participants is rather small. There are many input variables which influence the (learning) outcome. Before a statistical analysis can be made of this variety of input and throughput variables with the outcome, many respondents are needed. Serious games are often played with a limited number of players, and comparisons between games have other limitations. Therefore, performing a reliable analysis between the related variables is difficult.

The game SimPort-MV2 has been played many times with different groups of players. This led to more than 400 participants filling in surveys and more than 80 game outcomes with different results. This gives the opportunity to perform several statistical analyses and to discover more quantitative evidence of why games work. With this number of respondents it was possible to analyse several relations in the theory-based evaluation framework. However, the high number of variables influencing the game outcome requires even more respondents to test all the relations in the framework.

9.5 'Game over' or 'Ready for the next level'?

In this research, the use of serious gaming for understanding complexity was explored from different perspectives. Attention was paid to the design of serious games, the analysis of the game output for understanding system behaviour and the increase of the individual understanding of complexity by the participants. Based on the results, we conclude that serious gaming is a valuable tool for policy makers and other stakeholders to experience complexity.

Does this mean the game is over and all questions are answered? No, these conclusions bring us just a step further in gaming research. We contribute to a description of what serious gaming is and what is meant by gaming for understanding complex systems. However, we are still engaged in a learning process. All new knowledge, insights and prototypes can be and are used for further research. The redevelopment of SIMMV2 into a more flexible design of SimPort-MV2 is an example of the learning process that has already occurred within this research. Therefore, we would like to end with some unexplored fields for further research into serious gaming, understanding complex systems and gaming as policy intervention.

'Developing research methods and tools for measuring learning and analysing system behaviour'

The demand for more methods or methodologies for game research is not new (Duke, 1998; Gosen & Washbush, 2004; Klabbers, 2006) but still relevant. There are many practical reasons that limit the resources for evaluating games in such a way that they are comparable. Games are developed for a specific purpose or group of players, and the number of respondents is in general limited (see, for example, the small number of respondents in the table with the overview of game evaluations in Ke (2009)). It is easy to simply state that more research is necessary. More interesting is the question of how more research is needed. Based on our experience while conducting this research, several follow-up questions arose.

One of these questions is how to measure individual learning effects. We are not referring to direct and knowledge-related learning, which can be measured with knowledge tests, but the measurement of increasing social skills and changes in behaviour over the short- and long terms. These long-term effects have two components. The first is the retention of the newly acquired knowledge, insights and skills after playing a game once. How does this change the behaviour of the player, and which situations evoke the knowledge, insights and skills of the gaming session? The second component of long-term effects is related to long-term playing. The game SimPort-MV2 is played once by each participant. The participants expect that they will have better results if they play the game again. The question of whether this statement is true was outside the scope of this research. However, it is an interesting question. Do the learning effects increase or intensify after playing a game multiple times? For what type of learning is this useful, and how does this change the design of the game? There are people who argue that playing entertainment video games for a long time, such as World of Warcraft, and reaching higher levels, is related to systems thinking, team functioning, etc. (Gee, 2003). What does this mean for serious games? And what does it mean for the design? Is it possible to play the same game more often, or is variance in levels or game play needed?

Another tool which is lacking or limited in game research is tracking systems to follow what the players do in the game or to extract relevant game decisions and output to an easy-to-analyse database. These tools are available but developed for single use and hardly tested. To increase the advantages of using serious games for policy design and recommendation, a tracking system is necessary for collecting data and analysing patterns of different sessions.

'Comparing different types of infrastructure sectors and problems with different types of games'

In this research, one type of infrastructure, namely port development, and one type of question, namely the consequences of strategic behaviour over the long term, are simulated in one type of game, which is a serious, multi-player strategic building game. This was successful. However, this does not answer the question of whether gaming also has added value for other types of infrastructures such as electricity or road systems, or for other types of questions such as capacity shortage or changes in the market system.

There are several examples of other games about infrastructures which are successfully used in research on liberalization, such as Infrastratego (Kuit, 2002; Ten Heuvelhof, De Jong, Kuit, & Stout, 2003), on project management, e.g. Ventum (Mastik & Scalzo, 2002) and Ventum Online (Delft University of Technology & Tygron Serious Games, 2007), on transactions in supply chains (Meijer, 2009) or behaviour in contracting in the game Road Roles (Altamirano & De Jong, 2009). Except for Ventum

Online, these games cannot be considered serious games from our point of view. Furthermore, these games are not designed and evaluated from a complex adaptive systems perspective, and therefore they are hardly comparable. Most of these games were already designed and used before the rise of serious gaming. Therefore, no attention was paid to a well-founded choice to use computer technology. That means more comparative research between serious gaming and infrastructures has not been performed and is still needed. Related questions are, for example, for which types of problems or infrastructures serious gaming has an added value.

We assumed that serious gaming, especially the involvement of a computer simulation and visualization, is useful for projects with a physical impact. The conclusions from SimPort-MV2 support the value of the use of computer technology to deal with a simulated physical reality. The design of the game can be improved, based on knowledge from the entertainment videogame industry and research into human-computer interaction. The added value of the effort to develop a serious game instead of a low-tech simulation game for other types of cases has not been researched. Other games developed for other problems could call for different designs; the added value of computer technology to interact with the physical environment may be lower in a negotiation game. However, there could be other reasons to develop a serious game, such as saving the decisions of players for post-processing, demand for a single-player game, or a multiplayer game where players are not at the same location. Many questions are unanswered about when to develop a serious game and what the added value would be in those situations.

‘Defining the minimal game design requirements for simulating complex adaptive systems’

This research unravelled characteristics of complex adaptive systems (CAS) and how these characteristics can be simulated in a serious game. Based on the characteristics of CAS, several design requirements for the game are derived, e.g. multiplayer or multi-agent, flexible rules and an open-ended game outcome. These requirements in combination with the requirements derived from serious gaming and the content of the topic led to a game which displayed the characteristics of CAS. However, the relation between the design requirements and the outcome is not evaluated in this dissertation. Therefore, we do not argue that this design is the only way to simulate a complex adaptive system. The question arises as to the requirements of a game design for simulating a complex adaptive system. In order to answer this question, game elements and game patterns have to be further analysed in the context of gaming and related to the characteristics of elements and dynamics in complex systems.

On the other hand, the question should be asked as to which part of understanding CAS gaming is useful. This research showed that analysing game output contributes to an understanding of the dynamics in the system, and to the way in which players are affected when they are part of the system. There are also other questions related to increasing the understanding of complex systems: for example, how to define the robustness or resilience of a system, the capacity of the system, or the more analytical question of what constitutes a system. Gaming is not a solution to all questions related to understanding complexity. Another field to explore is for which types of understanding (serious) gaming has advantages and for which situations other tools, such as purely computer-based simulations, interactive or participatory modelling or expert panels, are more effective.

'Role of gaming in the policy-making process'

Finally, there is a lack of knowledge about the effect of gaming and the increase of knowledge and insights about the real policy-making process. Although there are many assumptions that gaming has effects, there is less evidence showing whether or not gaming affects decision making and in what way this is accomplished. More specific questions are, for example: is the quality or the grounding of a decision greater? Is the decision making process improved? If gaming has a direct effect on the process and the decision, when is the impact the highest?

There are several reasons, as explained in Chapter 6, why SimPort-MV2 was not able to influence the decision-making process around the tendering of the construction and the negotiation with possible customers. In an interview with a couple of players from the Port of Rotterdam, the possible contribution to the policy-making process was discussed. According to these players, SimPort-MV2 could be used to test the relation between different processes and to observe different dilemmas. However, the reality is much more complex than testing strategies, and direct influence on the decisions is not possible. If an influence on the process could be observed, it was more in the direction of role division, cooperation and tuning between processes. Furthermore, several lessons could be gathered, such as the long-term consequences of the decisions to reduce CO_2 emissions in the Port of Rotterdam, and the wisdom of having modest plans and ambitions, because in reality circumstances will be different than expected. The game gives fewer opportunities to solve possible dilemmas.

Another observation related to the use of gaming in professional environments is the time required to play a game. Playing and reflecting upon SimPort-MV2 takes at least four hours. It is difficult to make time for this, especially when the value can only be expressed in soft elements. To improve the usability of gaming, play time should be shorter. This has also been observed in the entertainment game industry, where there is a trend to develop small and less time-consuming games rather than games that are played for many hours. Hunicke (Hunicke, LeBlanc, & Zubek, 2004) compared it with having a box of chocolates instead of a large chocolate cake. You may prefer a small, high-quality piece of chocolate; you do not necessarily want to eat a whole cake. By this metaphor she suggested that it may be better to develop some short, high-quality games as part of a larger gaming environment in which players can choose a game each time they play. Translating this to policy-making processes, this could mean that multiple objectives should be spread over several games which can be played at several different times. Additional research into the development of small games with a serious message and the use of these small games by professionals is needed.

These four possible directions for research illustrate that the game is not over yet. This dissertation contributes a starting point for new research in the field of infrastructures, serious gaming and complex adaptive systems. This level is therefore finished, and we can start on the next level.

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APPENDIX A. PRE QUESTIONNAIRE SIMPORT-MV2

Background information	
1. Your study number/student number/exam number	
2. Your (active) e-mail address	
3. Your institution	1. TU Delft: Technology, Policy and Management 2. TU Delft: Civil Engineering 3. Port of Rotterdam 4. UNESCO IHE 5. Other, namely
4. Subject code	
5. Your age	
6. Gender (m/f)	1. Male 2. Female
8. Is participation in the serious game required or elective?	1. Required 2. Elective

Game use	
9. How often in your private capacity (ie not part of education or work) do you play regular games, like board games and role plays?	1. Never 2. A couple of times per year 3. Monthly 4. Weekly 5. Daily 6. Don't know
10. How often in your private capacity (ie not part of education or work) do you play computer games (eg video games with game consoles, or Internet-based games)?	1. Never 2. A couple of times per year 3. Monthly 4. Weekly 5. Daily 6. Don't know
11. Why do you enjoy playing computer games?	
12. What computer game features interest you?	
13. How often in your study/education/work have you participated in a serious game (e.g. a management game, business game, policy game, crisis simulation, role play etc., with or without the use of a computer)?	1. Never 2. Once or twice 3. 3 or 4 times 4. 5 - 8 times 5. More than 8 times 6. Don't know

Below are a number of statements about the use of a computer, digital learning environments, serious games, and expectations of SimPort-MV2. Please indicate whether you agree or disagree with the statements by checking the appropriate box.

1. = Strongly disagree
2. = disagree
3. = neutral
4. = agree
5. = strongly agree

n.a. = not applicable

14. Computer use	Strongly disagree				Strongly agree	
1. In general, I enjoy trying out new uses and applications for computers.	1	2	3	4	5	n.a.
2. In general, I quickly become comfortable in using new computer applications.	1	2	3	4	5	n.a.
3. In general, I think the use of computer simulations to support decision making is worthwhile.	1	2	3	4	5	n.a.

	Strongly disagree				Strongly agree	
15. Digital learning environment (only student survey)						
1. I feel comfortable with digital learning environments (such as Blackboard, WebCT, etc.) in education.	1	2	3	4	5	n.a.
2. The use of e-learning digital learning environments in education is valuable.	1	2	3	4	5	n.a.
3. I enjoy using digital learning environments.	1	2	3	4	5	n.a.
4. In my opinion, digital learning environments enhance cooperation in a group.	1	2	3	4	5	n.a.
5. In my opinion, digital learning environments can help you work where and when you want.	1	2	3	4	5	n.a.

16. Projects (only student survey)	Strongly disagree				Strongly agree	
1. In general, it improves my learning to work together with other students in groups.	1	2	3	4	5	n.a.
2. In general, I enjoy working together with other students in groups.	1	2	3	4	5	n.a.
3. In general, I would rather have formal lectures than a project.	1	2	3	4	5	n.a.
4. In general, I would rather study textbooks than do a project.	1	2	3	4	5	n.a.
5. In general, I would rather work individually than in a group on a project.	1	2	3	4	5	n.a.

Strongly disagree					Strongly agree
17. Serious games					
1. In general, I think the use of serious games in education is valuable.	1	2	3	4	5	n.a.
2. In general, I think it's fun to take part in a serious game in education.	1	2	3	4	5	n.a.
3. I think that serious games in education add something to other forms of teaching (e.g. formal lectures and seminars).	1	2	3	4	5	n.a.
4. In my own field/area of specialization I am comfortable using computer simulations.	1	2	3	4	5	n.a.
5. Taking part in this serious game sounds like fun.	1	2	3	4	5	n.a.
6. The subject of the serious game appeals to me, content-wise.	1	2	3	4	5	n.a.

Strongly disagree						Strongly agree
18. By playing this serious game I expect to …						
1. gain better insight into the theory presented in formal lectures and books.	1	2	3	4	5	n.a.
2. learn to work together with other students in a team.	1	2	3	4	5	n.a.
3. learn to communicate.	1	2	3	4	5	n.a.
4. learn to discuss and reason.	1	2	3	4	5	n.a.
5. learn to negotiate.	1	2	3	4	5	n.a.
6. gain content-related (subject) knowledge.	1	2	3	4	5	n.a.
7. gain theoretical knowledge.	1	2	3	4	5	n.a.
8. learn to think beyond disciplinary boundaries.	1	2	3	4	5	n.a.
9. learn to see the connections across subject areas.	1	2	3	4	5	n.a.
11. become prepared for later professional practice (in an internship, traineeship, or work itself, etc.).	1	2	3	4	5	n.a.
12. improve relevant (professional) skills.	1	2	3	4	5	n.a.
13. gain a number of new insights about the real 2nd Maasvlakte.	1	2	3	4	5	n.a.
14. see some of the long-term effects/pitfalls of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
15. gain more insight into the technical complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
16. gain more insight into the strategic complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
17. gain more insight into the commercial and economic complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.

APPENDIX B. POST QUESTIONNAIRE SIMPORT-MV2

Background information	
1. Date of the SimPort-MV2 session in which you participated:	
2. Your student number	
3. Your (active) e-mail address (to combine pre and post game survey)	
4. How many hours did the session you participated in last (calculated from the start of the introduction by the game leaders through the end of the debriefing and discussion)?	… hours
5. What was the name of your team?	
6. What was your role at the start of SimPort-MV2?	□ General director □ Commercial director □ Building director □ Observer, other □ Something else, namely: ________________________
7. Did you change or switch roles/tasks during SimPort-MV2?	□ No, I stayed with my original role/task □ Yes, I took on another role/task from time to time □ Yes, I often took on another role/task □ Don't know/n.a.
8. Did you play your initial role, as indicated above, alone or together with one or more others?	□ Alone □ Together

Previous knowledge 2nd Maasvlakte (only professionals)	
9. In your daily work, to what extent are you actively involved in various strategic aspects of the (real!) 2nd Maasvlakte?	□ Not involved at all □ Involved to some extent □ Fairly involved □ Strongly involved □ Very strongly involved
10. In your daily work, to what extent are you actively involved in various building and equipment aspects of the 2nd Maasvlakte.	□ Not involved at all □ Involved to some extent □ Fairly involved □ Strongly involved □ Very strongly involved
11. In your daily work, to what extent are you actively involved in	□ Not involved at all

various commercial aspects of the 2nd Maasvlakte.	□ Involved to some extent □ Fairly involved □ Strongly involved □ Very strongly involved
12. How experienced and informed were you – before you took part in the serious game – about issues related to the 2nd Maasvlakte?	□ Not at all informed □ Somewhat informed □ Reasonably well informed □ Well informed □ Very well informed

Please indicate the extent to which you agree or disagree with the following statements concerning the design and execution of the serious game:

1 = strongly disagree
2 = disagree
3 = neither agree nor disagree
4 = agree
5 = strongly agree
n.a. = don't know/not applicable to me

Strongly disagree					Strongly agree	
13. Quality of the serious game						
1. The aim of SimPort-MV2 was clear.	1	2	3	4	5	n.a.
2. The instructions and explanations provided at the start of the serious game were clear.	1	2	3	4	5	n.a.
3. Lectures, seminars and serious game were well aligned with each other. (only students survey)	1	2	3	4	5	n.a.
4. The aim of the serious game was relevant for the Port of Rotterdam.	1	2	3	4	5	n.a.
5. The objectives of the serious game are relevant to my course of study	1	2	3	4	5	n.a.
6. The topic of the serious game is relevant to my course of study	1	2	3	4	5	n.a.
7. The serious game was built up in an interesting and stimulating way.	1	2	3	4	5	n.a.
8. The game materials – such as the role descriptions and the manual – were understandable and clearly written.	1	2	3	4	5	n.a.
9. The tasks in the serious game were understandable and clearly formulated.	1	2	3	4	5	n.a.
10. The game was well facilitated.	1	2	3	4	5	n.a.
11. The rules of the game were clear and straightforward.	1	2	3	4	5	n.a.
12. All of the materials and documents needed to play the serious game were available.	1	2	3	4	5	n.a.

13. Given the aims of the serious game, SimPort-MV2 was sufficiently detailed.	1	2	3	4	5	n.a.
14. Given the aims of the serious game, SimPort-MV2 was sufficiently realistic.	1	2	3	4	5	n.a.
15. The tasks in the serious game were too easy.	1	2	3	4	5	n.a.
16. The tasks in the serious game were too difficult.	1	2	3	4	5	n.a.
17. The underlying cause-effect relations became clear enough during the course of the game.	1	2	3	4	5	n.a.
18. Good feedback was given during and directly after the game.	1	2	3	4	5	n.a.
19. Fellow players made a good effort.	1	2	3	4	5	n.a.
20. As a team, we did enough internal reflection and adjustment.	1	2	3	4	5	n.a.
21. We had too little time to be able to play the serious game well.	1	2	3	4	5	n.a.
22. The game play was too slow.	1	2	3	4	5	n.a.
23. The discussions between the players during the game were good.	1	2	3	4	5	n.a.
24. As a team, we worked together well during the game.	1	2	3	4	5	n.a.
25. I really put myself into my role.	1	2	3	4	5	n.a.
26. In general, other players (team members) played their roles well.	1	2	3	4	5	n.a.

Please indicate the extent to which you agree/disagree with the statements below about serious games in education.

1 = Strongly disagree
2 = disagree
3 = not agree/ not disagree
4 = agree
5 = Strongly agree
n.a. = don't know / not applicable

Strongly disagree					Strongly agree	
14. The serious game in education (only students survey)						
1. I think that this serious game adds something to other forms of education (formal lectures, seminars).	1	2	3	4	5	n.a.
2. It improves my learning to work on this serious game	1	2	3	4	5	n.a.
3. I had fun working together with other students.	1	2	3	4	5	n.a.
4. I would very much like to play other serious games in education.	1	2	3	4	5	n.a.

Please indicate the extent to which you agree/disagree with the following statements about the possible effects and results of the serious game.

1 = strongly disagree
2 = disagree
3 = neither agree nor disagree
4 = agree
5 = strongly agree
n.a. = don't know/not applicable to me

15 Results/effects Strongly disagree					Strongly agree	
1. The use of SimPort-MV2 is worthwhile for the port authority.	1	2	3	4	5	n.a.
2. The use of SimPort-MV2 in education is valuable.	1	2	3	4	5	n.a.
3. I think that SimPort-MV2 can promote cooperation between different departments and individuals.	1	2	3	4	5	n.a.
4. I think that SimPort-MV2 can promote better communication between different departments and individuals.	1	2	3	4	5	n.a.
5. I found it educative to take part in SimPort-MV2 with others.	1	2	3	4	5	n.a.
6. I enjoyed taking part in SimPort-MV2 with others.	1	2	3	4	5	n.a.
7. I would like to play SimPort-MV2 again sometime.	1	2	3	4	5	n.a.
8. If we as a team were to play SimPort-MV2 again, our team performance would be significantly better.	1	2	3	4	5	n.a.
9. Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte.	1	2	3	4	5	n.a.
10. SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
11. SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
12. SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
13. SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
14. SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	1	2	3	4	5	n.a.
15. I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	1	2	3	4	5	n.a.
16. SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	1	2	3	4	5	n.a.

Please indicate the extent to which you agree/disagree with the statements below.

1 = strongly disagree
2 = disagree
3 = neither agree nor disagree
4 = agree
5 = strongly agree
n.a. = don't know/not applicable to me

Strongly disagree					Strongly agree	
16. By playing this serious game, …						
1. the theory from formal lectures and books became more understandable.	1	2	3	4	5	n.a.
2. I have learned to work better together with other students in a team.	1	2	3	4	5	n.a.
3. I have learned to communicate better.	1	2	3	4	5	n.a.
4. I have learned to discuss and reason better.	1	2	3	4	5	n.a.
5. I have learned to negotiate better.	1	2	3	4	5	n.a.
6. I have gained gain content-related (subject) knowledge.	1	2	3	4	5	n.a.
7. I have gained (theoretical) knowledge.	1	2	3	4	5	n.a.
8. I have learned to think beyond disciplinary boundaries.	1	2	3	4	5	n.a.
9. I have learned to see the relations between different subject areas.	1	2	3	4	5	n.a.
10. I have prepared myself for later professional practice (in an internship, traineeship, work, etc.).	1	2	3	4	5	n.a.
11. I have improved relevant (professional) skills.	1	2	3	4	5	n.a.

Please indicate the extent to which you agree/disagree with the following statements about the operation and use of the computers in SimPort-MV2:

1 = strongly disagree
2 = disagree
3 = neither agree nor disagree
4 = agree
5 = strongly agree
n.a. = don't know/not applicable to me

Strongly disagree					Strongly agree	
17. Computer use						
1. The computers in the game were easy to operate.	1	2	3	4	5	n.a.
2. I enjoyed using the computers in the game.	1	2	3	4	5	n.a.
3. The computer gave me enough control of the play during the game.	1	2	3	4	5	n.a.

4. I often needed help using the computers during the game.	1	2	3	4	5	n.a.
5. Style attributes, such as color, typeface and forms, used on the computer screens are attractive and suitably designed.	1	2	3	4	5	n.a.
6. The digital mapping materials in the game were understandable.	1	2	3	4	5	n.a.
7. Navigation through the user screens (interfaces) was logical and easy to use.	1	2	3	4	5	n.a.
8. The user screens (interfaces) in the game gave enough of a sense of the changes in the port area.	1	2	3	4	5	n.a.
9. I had a clear feeling of time IN the game.	1	2	3	4	5	n.a.
10. The user interfaces gave enough insight into the performance of the 2nd Maasvlakte.	1	2	3	4	5	n.a.
11. During the game there were few or no computer malfunctions.	1	2	3	4	5	n.a.
12. When there were computer malfunctions, these were quickly and satisfactorily remedied.	1	2	3	4	5	n.a.
13. You ought to be able to play SimPort-MV2 (also) from your desk at work.	1	2	3	4	5	n.a.
14. You ought to be able to play SimPort-MV2 alone (as well as in a group).	1	2	3	4	5	n.a.
15. SimPort-MV2 should be further expanded (e.g. with more functionality, more data, etc.).	1	2	3	4	5	n.a.
16. The Tutorial increased my understanding of SimPort-MV2.	1	2	3	4	5	n.a.
17. I could follow and understand the steps in the Tutorial.	1	2	3	4	5	n.a.
18. I think sound and video can improve the Tutorial.	1	2	3	4	5	n.a.

18. If some aspect of SimPort-MV2 especially appealed to you, what is it?
19. If some aspect of SimPort-MV2 needs improvement, what is it?

APPENDIX C. QUANTITATIVE RESULTS PROCESS VARIABLES

In this appendix, the outcomes of numerical analysis of the process variables are presented. This consists of the Factor analysis and the descriptive analysis of the indicators. For the data reduction, the principle factor analysis was used and when there were multiple factors, we use the rotation method Varimax.

C.1 Computer interaction

Descriptive analysis computer interaction

Table C-1. Computer interaction

	N	Mean	Std. Deviation
Enjoyment			
The computers in the game were easy to operate	415	3.9	.85
I enjoyed using the computers in the game	415	4.1	.70
The computer gave me enough control of the play during the game	414	3.7	.80
Interfaces			
Style attributes used on the computer screens are attractive and suitable designed	412	3.8	.72
The digital mapping materials in the game were understandable	415	3.8	.73
navigation through the user screens was logical and easy to use	413	3.7	.83
The user screens in the game gave enough of a sense of the changes in the port area	410	3.6	.80
I had a clear feeling of time IN the game	416	3.1	1.01
The user screens gave enough insight into the performance of the Maasvlakte 2	409	3.5	.78
Help			
I often needed help using the computers during the game	412	2.7	1.12

In general, the participants were positive about the computer interaction.

Factor analysis computer engagement

Table C-2. Factor analysis computer engagement

		I ENJCOMP
SAKC31	The computer gave me enough control of the play during the game	.752
SAKC30	I enjoyed using the computers in the game	.733
SAKC29	The computers in the game were easy to operate	.727
	Eigen value	1.633
	Explained variance	54%
	KMO Measure of sampling adequacy	0.704
	Cronbach´s Alpha	.778

This analysis gives one Factor: representing the enjoyment of using computer simulations (ENJCOMP)

Factor analysis quality computer interfaces

Table C-3. Factor analysis quality computer interfaces

		I QUAINT
SAKC36	The user screens in the game gave enough of a sense of the changes in the port area	.724
SAKC35	navigation through the user screens was logical and easy to use	.706
SAKC34	The digital mapping materials in the game were understandable	.607
SAKC38	The user screens gave enough insight into the performance of the 2nd Maasvlakte	.572
SAKC33	Style attributes used on the computer screens are attractive and suitable designed	.552
SAKC37	I had a clear feeling of time IN the game[1]	
	Eigen value	2.023
	Explained variance	40%
	KMO Measure of sampling adequacy	0.788
	Cronbach´s Alpha	.769

[1] this indicator was excluded from the analysis

This analysis gives one factor, which represents the quality of the interfaces (QUAINT)

C.2 Engagement

Descriptive analysis engagement

Table C-4. Engagement of playing SimPort-MV2

	N	Mean	Std. Deviation
The tasks in the simulation game were too easy.	412	2.6	.80
The tasks in the simulation game were too difficult.	412	2.7	.80
We had too little time to be able to play the simulation game well.	397	3.2	1.16
The game play was too slow.	396	2.1	.76
If we as a team were to play SimPort-MV2 again, our team performance would be significantly better.	415	4.4	.79
Fun factor			
I found it educative to take part in SimPort-MV2 with others.	414	4.0	.68
I enjoyed taking part in SimPort-MV2 with others	416	4.3	.65
I would like to play SimPort-MV2 again sometime	416	3.7	1.03
I had fun working together with other students	233	4.2	.59

Factor analysis engagement

Table C-5. Factor Analysis fun playing SimPort-MV2

		I FUNFACTOR
SAES5	I enjoyed taking part in SimPort-MV2 with others	.838
SALS2	I had fun working together with other students	.629
SAES11	I found it educative to take part in SimPort-MV2 with others.	.567
SAKC6	I would like to play SimPort-MV2 again sometime	.525
	Eigen value	1.695
	Explained variance	42%
	KMO Measure of sampling adequacy	.701
	Cronbach´s Alpha	.702

This analysis gives one Factor, representing the fun of the players playing the game SimPort-MV2 (FUNFACTOR)

C.3 Personal interaction

Descriptive analysis personal interaction

Table C-6. Personal interaction during the game session

	N	Mean	Std. Deviation
Fellow players made a good effort	394	4.3	.64
As a team, we did enough internal reflection and adjustment	396	3.8	.84
The discussions between the players during the game were good	396	3.7	.77
As a team, we worked together well during the game	396	3.8	.81
I really put myself into my role	395	3.8	.73
In general, other players (team members) played their roles well	397	3.9	.66

Factor Analysis personal interaction

Table C-7. Factor analysis personal interaction

		I PERSINT
PAKS21	As a team, we worked together well during the game	.786
PAKS39	As a team, we did enough internal reflection and adjustment	.706
PAKS23	In general, other players (team members) played their roles well	.713
PAKS20	The discussions between the players during the game were good	.641
PAKS22	I really put myself into my role	.557
PAKS16	Fellow players made a good effort	.530
	Eigen value	2.628
	Explained variance	44%
	KMO Measure of sampling adequacy	.783
	Cronbach´s Alpha	.818

This analysis gives one factor, which represents the personal interaction (PERSINT).

C.4 Correlations between process factors and the learning outcome

Table C-8. Correlations between general learning and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
It improves my learning to work on this simulation game (this role play).	Pearson Correlation	.231**	.203**	.499**	.244**
	Sig. (2-tailed)	.000	.002	.000	.000
	N	231	225	230	230
I would very much like to play other simulation games in education.	Pearson Correlation	.281**	.140*	.662**	.235**
	Sig. (2-tailed)	.000	.037	.000	.000
	N	231	224	230	230
The use of SimPort-MV2 in education is valuable.	Pearson Correlation	.194**	.204**	.541**	.264**
	Sig. (2-tailed)	.002	.001	.000	.000
	N	249	242	229	227
The use of SimPort-MV2 is worthwhile for the Port Authority	Pearson Correlation	.257**	.296**	.348**	.329**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	383	374	211	359

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

There are many significant correlations between the process factors and the general learning outcome. The correlations between learning and fun factor are high.

Table C-9. Correlations between declarative knowledge and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
Theory Based Notions					
I have gained (theoretical) knowledge.	Pearson Correlation	.126*	.266**	.231**	.235**
	Sig. (2-tailed)	.036	.000	.000	.000
	N	278	272	230	274
The theory from formal lectures and books became more understandable.	Pearson Correlation	.186**	.093	.228**	.160*
	Sig. (2-tailed)	.005	.172	.001	.017
	N	223	216	222	221
Domain specific subject knowledge					
I have gained gain content-related (subject) knowledge.	Pearson Correlation	.017	.168**	.266**	.170**
	Sig. (2-tailed)	.783	.005	.000	.005
	N	277	271	229	273
I've gained a number of new insights about the real 2nd Maasvlakte.	Pearson Correlation	.219**	.257**	.293**	.198**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	413	400	231	388
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	Pearson Correlation	.213**	.300**	.203**	.248**
	Sig. (2-tailed)	.000	.000	.002	.000
	N	410	397	229	384

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C-10. Correlations between procedural knowledge and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
Linear processes					
SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	Pearson Correlation	.116*	.254**	.249**	.266**
	Sig. (2-tailed)	.019	.000	.000	.000
	N	409	397	228	384
SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	Pearson Correlation	.173**	.248**	.211**	.245**
	Sig. (2-tailed)	.000	.000	.001	.000
	N	413	400	231	387
SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	Pearson Correlation	.164**	.254**	.229**	.203**
	Sig. (2-tailed)	.001	.000	.000	.000
	N	412	399	231	386
The underlying cause-effect relations became clear enough during the course of the game.	Pearson Correlation	.148**	.247**	.112	.249**
	Sig. (2-tailed)	.003	.000	.089	.000
	N	413	401	230	389
Complex processes					
SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	Pearson Correlation	.242**	.324**	.233**	.313**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	410	397	229	384
SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	Pearson Correlation	.199**	.280**	.268**	.216**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	392	379	230	386
I have learned to think beyond disciplinary boundaries.	Pearson Correlation	.098	.204**	.222**	.180**
	Sig. (2-tailed)	.104	.001	.001	.003
	N	276	270	228	272
I have learned to see the relations between different subject areas.	Pearson Correlation	.161**	.232**	.246**	.166**
	Sig. (2-tailed)	.007	.000	.000	.006
	N	278	272	230	273

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C-11. Correlations between strategic knowledge and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
Dealing with the physical system					
I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	Pearson Correlation	.229**	.227**	.243**	.240**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	390	378	230	386
I have prepared myself for later professional practice (in an internship, traineeship, work, etc.).	Pearson Correlation	.240**	.201**	.306**	.168*
	Sig. (2-tailed)	.000	.003	.000	.012
	N	227	220	226	225
Dealing with the social system					
I think that SimPort-MV2 can promote cooperation between different departments and individuals.	Pearson Correlation	.206**	.231**	.432**	.210**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	406	394	225	381
I think that SimPort-MV2 can promote better communication between different departments and individuals.	Pearson Correlation	.218**	.266**	.408**	.232**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	404	391	225	378
I learned to communicate	Pearson Correlation	.157**	.195**	.309**	.107*
	Sig. (2-tailed)	.003	.000	.000	.049
	N	345	333	230	339
I learned to discuss and reason.	Pearson Correlation	.111*	.170**	.181**	.080
	Sig. (2-tailed)	.040	.002	.006	.142
	N	344	332	229	338
I have learned to work better together with other students in a team.	Pearson Correlation	.159**	.192**	.281**	.134*
	Sig. (2-tailed)	.008	.001	.000	.027
	N	277	271	229	273
I have learned to negotiate better.	Pearson Correlation	.103	.203**	.192**	.121*
	Sig. (2-tailed)	.089	.001	.004	.046
	N	275	269	228	271
I have improved relevant (professional) skills.	Pearson Correlation	.186**	.182**	.266**	.189**
	Sig. (2-tailed)	.002	.003	.000	.002
	N	276	270	229	272

**. Correlation is significant at the 0.01 level (2-tailed). *. significant at the 0.05 level (2-tailed).

C.5 Factor analysis learning outcome

Table C-12. Factor analysis general learning outcome

		I GENLRN
SAKC3	The use of SimPort-MV2 in education is valuable.	.842
SAES4	It improves my learning to work on this serious game.	.653
SAKC7	I would very much like to play other serious games in education.	.577
PALE30	The use of SimPort-MV2 is worthwhile for the Port Authority	.493
	Eigen value	1.712
	Explained variance	43%
	KMO Measure of sampling adequacy	0.727
	Cronbach´s Alpha	0.721

This analysis gives one Factor, which represent general learning (GENLRN).

Table C-13. Correlations between process factors and general learning

		GENLRN
ENJCOMP	Pearson Correlation	.322**
	Sig. (2-tailed)	.000
	N	209
QUAINT	Pearson Correlation	.240**
	Sig. (2-tailed)	.001
	N	205
FunFactor	Pearson Correlation	.702**
	Sig. (2-tailed)	.000
	N	209
PERSINT	Pearson Correlation	.393**
	Sig. (2-tailed)	.000
	N	208

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX D. QUANTITATIVE RESULTS INPUT VARIABLES

In this appendix, the outcomes of numerical analysis of the input variables are presented. This consists of the factor analysis and the descriptive analysis of the indicators. For the data reduction, the principle factor analysis was used and when there were multiple factors, we use the rotation method Varimax.

D.1 Player characteristics

Descriptive analysis computer experience

Table D-1. Computer experience

	N	Mean	Std. Deviation
The use of digital learning environments (like Blackboard, Web CT, etc.) in education is valuable.	207	4.4	.70
I feel comfortable with digital learning environments in education.	207	4.4	.67
I enjoy using digital learning environments.	207	3.7	.79
In general, I enjoy trying out new uses and applications for computers	360	3.8	.98
In general, I quickly become comfortable in using new computer applications	359	3.9	.85
I think the use of computer simulations to support decision making is worthwhile	329	4.0	.71

Factor analysis computer experience

Table D-2. Factor analysis value of computer experiences

		I VALUEDL	II VALUENC
SVCG5	The use of digital learning environments (like Blackboard, Web CT, etc.) in education is valuable.	.892	
SVCG4	I feel comfortable with digital learning environments in education.	.657	
SVCG6	I enjoy using digital learning environments.	.555	
PACG3	In general, I enjoy trying out new uses and applications for computers		.806
PACG11	In general, I quickly become comfortable in using new computer applications		.637
	Eigen value	1.584	1.170
	Explained variance	32%	23%
	KMO Measure of sampling adequacy		.652
	Cronbach´s Alpha	.749	.754

This analysis gives two Factors, one representing the value of Digital learning environments (VALUEDL), and representing the value of learning new computer programs (VALUENC).

Frequencies game experience

Table D-3. Game experience of all participants

	Never	Couple of times per year	Monthly	Weekly	Daily
Playing games private (n=294)	17%	43%	26%	12%	2%
Playing computer games private (n=295)	18%	32%	18%	21%	11%
	Never	1-2 times	3-4 times	5-8 times	More than 8
Participation in simulation games for education or work (n=400)	18%	47%	29%	4%	4%

Descriptives serious game expectations

Table D-4. Expectations of serious games all participants

	N	Mean	Std. Deviation
In general, I think the use of serious games in higher education is valuable.	285	3.8	.66
In general, I think it's fun to take part in a serious game in education.	290	3.9	.70
I think that serious games in higher education add something to other forms of teaching.	290	4.0	.68
Taking part in this serious game sounds like fun.	295	3.8	.69
The subject of the serious game appeals to me, content-wise.	290	3.7	.81

Factor analysis serious game expectations

Table D-5. Factor analysis expectations serious gaming

		I EXPSERGAM
SVES5	In general, I think it's fun to take part in a serious game in education.	.747
SVES4	In general, I think the use of serious games in higher education is valuable.	.724
SVES6	I think that serious games in higher education add something to other forms of teaching.	.710
SVLE1	Taking part in this simulation game sounds like fun.	.690
SVLE2	The subject of the simulation game appeals to me, content-wise.	.489
	Eigen value	2.303
	Explained variance	46%
	KMO Measure of sampling adequacy	0.774
	Cronbach´s Alpha	.798

This analysis gives one factor, representing the expectations of serious games (EXPSERGAM).

Descriptives learning expectations

Table D-6. Expectations of learning outcomes

I expect to…	N	Mean	Std. Deviation
gain more insight into the strategic complexity of the 2^{nd} Maasvlakte.	289	4.0	.62
gain more insight into the commercial and economic complexity of the 2^{nd} Maasvlakte.	288	3.9	.64
see some of the long-term effects/pitfalls of the 2^{nd} Maasvlakte.	289	3.9	.70
gain a number of new insights about the real 2^{nd} Maasvlakte.	288	3.8	.75
learn to negotiate.	289	3.8	.78
gain more insight into the technical complexity of the 2^{nd} Maasvlakte.	289	3.7	.78
learn to think beyond disciplinary boundaries.	285	3.7	.79
learn to see the connections across subject areas.	288	3.7	.80
learn to work together with other students in a team.	290	3.7	.80
learn to discuss and reason.	287	3.6	.82
learn to communicate.	291	3.6	.80
gain better insight into the theory presented in formal lectures and books.	229	3.6	.81
gain content-related (subject) knowledge.	291	3.5	.88
improve relevant (professional) skills.	287	3.5	.79
become prepared for later professional practice (in an internship, traineeship, or work itself, etc.).	228	3.4	.90
gain theoretical knowledge.	290	3.2	.92

Factor analysis learning expectations

Table D-7. Factor analysis learning expectations

		I SUBMV2	II SOCSKILLS	III THRKNOW	IV PROFSKILLS
SVLE26	see some of the long-term effects/pitfalls of the 2nd Maasvlakte.	.829			
SVLE28	gain more insight into the strategic complexity of the 2nd Maasvlakte.	.815			
SVLE29	gain more insight into the commercial and economic complexity of the 2nd Maasvlakte.	.752			
SVLE27	gain more insight into the technical complexity of the 2nd Maasvlakte.	.725			
SVLE25	gain a number of new insights about the real 2nd Maasvlakte.	.715			
SVLE6	learn to communicate.		.792		
SVLE7	learn to discuss and reason.		.772		
SVLE8	learn to negotiate.		.735		
SVLE5	learn to work together with other students in a team.		.709		
SVLE11	learn to think beyond disciplinary boundaries.		.363		
SVLE10	gain theoretical knowledge.			.774	
SVLE9	gain content-related (subject) knowledge.			.752	
SVLE4	gain better insight into the theory presented in formal lectures and books.			.559	
SVLE12	learn to see the connections across subject areas.			.432	
SVLE15	improve relevant (professional) skills.				.701
SVLE14	become prepared for later professional practice.				.681
	Eigen value	3.141	2.685	1.983	1.175
	Explained variance	20%	17%	12%	7%
	KMO Measure of sampling adequacy				.824
	Cronbach´s Alpha	.873	.830	.759	.739

This analysis gives four factors of learning expectations. Factor 1 is about the subject Maasvlakte 2 (SUBMV2), Factor 2 is about social skills (SOCSKILLS), Factor 3 is about theoretical knowledge (THRKNOW), and Factor 4 is about professional skills (PROFSKILLS).

Descriptive preferred learning style

Table D-8. Preferred learning styles students participants

	N	Mean	Std. Deviation
In general, it improves my learning to work together with other students in groups.	232	4.0	.75
In general, I enjoy working together with other students in groups.	233	3.9	.79
In general, I would rather have formal lectures than a project.	231	2.7	.86
In general, I would rather study textbooks than do a project.	232	2.2	.93
In general, I would rather work individually than in a group on a project.	233	2.7	.92

Factor Analysis preferred learning style

Table D-9. Factor analysis learning preferences

		I LRNPREF
SVLS5INV	I would rather work in a group than individually on a project	.778
SVLS2	In general, I enjoy working together with other students in groups.	.740
SVLS1	In general, it improves my learning to work together with other students in groups.	.582
SVLS3INV	I would rather have a project than formal lectures	.560
SVLS4INV	I would rather do a project than study textbooks	.555
	Eigen value	2.113
	Explained variance	42%
	KMO Measure of sampling adequacy	.758
	Cronbach´s Alpha	.776

This analysis gives one factor, representing the learning preferences (LRNPREF).

D.2 Factor analysis game characteristics

Descriptives game characteristics

Table D-10. Quality of the game SimPort-MV2 and SIMMV2 together

	N	Mean	Std. Deviation
The aim of SimPort-MV2 was clear	417	4.0	.72
The aim of the simulation game was relevant for the Port of Rotterdam	396	4.0	.72
The objectives of the simulation game are relevant to my course of study	313	3.7	.88
The topic of the simulation game is relevant to my course of study	253	3.8	.91
The simulation game was built up in an interesting and stimulating way	417	4.2	.61
The game materials - such as the role description and the manuals - were understandable and clearly written	411	3.8	.75
The tasks in the simulation game were understandable and clearly formulated	413	3.7	.76
The rules of the game were clear and straightforward	411	3.6	.86
All the materials and documents needed to play the simulation game were available	415	4.1	.76

Factor analysis game characteristics

Table D-11. Factor analysis game characteristics

		I QUAGAME	II RELGAME
PAKS35	The game materials were understandable and clearly written	.701	
PAKS9	The rules of the game were clear and straightforward	.676	
PAKS7	The tasks in the serious game were understandable and clearly formulated	.644	
PAKS1	The aim of SimPort-MV2 was clear	.463	
PAKS10	All the materials and documents needed to play the serious game were available	.433	
SAKS3	The objectives of the serious game are relevant to my course of study		.833
SAKS4	The topic of the serious game is relevant to my course of study		.708
PAKS5	The serious game was built up in an interesting and stimulating way		.415
	Eigen value	1.918	1.416
	Explained variance	24%	18%
	KMO Measure of sampling adequacy		.729
	Cronbach´s Alpha	.735	.700

This analysis gives two factors. Factor 1 represents the quality of the game (QUAGAME) and factor 2 represents the relevance of the game (RELGAME).

D.3 Facilitation and embedding

Descriptives facilitation game session

Table D-12. Quality of the facilitation of the game

	N	Mean	Std. Deviation
The instructions and explanations provided at the start of the simulation game were clear.	411	3.7	.85
The game was well facilitated	413	4.1	.71
Good feedback was given during and directly after the game	396	3.9	.70

D.4 Correlations between input variables

Correlations between input variables

Table D-13. Correlations between the input variables

		VALUEDL	VALUENC	EXPSERGAM	LRNPREF	SUBMV2
VALUEDL	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	231				
VALUENC	Pearson Correlation	.280**	1			
	Sig. (2-tailed)	.000				
	N	231	411			
EXPSERGAM	Pearson Correlation	.368**	.162**	1		
	Sig. (2-tailed)	.000	.007			
	N	218	276	276		
LRNPREF	Pearson Correlation	.308**	.039	.295**	1	
	Sig. (2-tailed)	.000	.556	.000		
	N	227	230	216	230	
SUBMV2	Pearson Correlation	.323**	.196**	.322**	.213**	1
	Sig. (2-tailed)	.000	.001	.000	.001	
	N	224	286	267	223	286
THRKNOW	Pearson Correlation	.150*	.185**	.275**	.054	.181**
	Sig. (2-tailed)	.024	.005	.000	.420	.007
	N	224	227	213	223	223
PROFSKILLS	Pearson Correlation	.192**	.150*	.337**	.044	.254**
	Sig. (2-tailed)	.004	.025	.000	.511	.000
	N	221	224	211	221	220
SOCSKILLS	Pearson Correlation	.317**	.084	.357**	.229**	.159**
	Sig. (2-tailed)	.000	.160	.000	.001	.008
	N	220	282	264	219	277
QUAGAME	Pearson Correlation	.122	.156**	.048	.066	.182**
	Sig. (2-tailed)	.086	.004	.475	.353	.006
	N	200	348	222	199	229
RELGAME	Pearson Correlation	.203**	.074	.335**	.129	.206**
	Sig. (2-tailed)	.004	.281	.000	.068	.003
	N	202	217	206	201	210
Age	Pearson Correlation	-.153*	-.044	.105	-.050	.016
	Sig. (2-tailed)	.024	.394	.093	.465	.794
	N	218	379	259	217	272

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation of input factors (continuous)

		THRKNOW	PROFSKILLS	SOCSKILLS	QUAGAME
THRKNOW	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	227			
PROFSKILLS	Pearson Correlation	.404**	1		
	Sig. (2-tailed)	.000			
	N	220	224		
SOCSKILLS	Pearson Correlation	.358**	.357**	1	
	Sig. (2-tailed)	.000	.000		
	N	222	217	282	
QUAGAME	Pearson Correlation	-.011	.176*	.009	1
	Sig. (2-tailed)	.877	.014	.899	
	N	198	196	225	404
RELGAME	Pearson Correlation	.139*	.319**	.088	.202**
	Sig. (2-tailed)	.049	.000	.206	.001
	N	200	199	207	247
Age	Pearson Correlation	-.043	-.058	.062	-.043
	Sig. (2-tailed)	.530	.403	.313	.438
	N	215	212	267	333

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation of input factors (continuous)

		RELGAME	Age
RELGAME	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	251	
Age	Pearson Correlation	-.226**	1
	Sig. (2-tailed)	.001	
	N	216	388

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

D.5 Correlations between input factors and process factors

Correlations between player characteristics and process factors

Table D-14. Correlations between player factors and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
VALUEDL	Pearson Correlation	.175*	.135	.210**	.097
	Sig. (2-tailed)	.013	.059	.003	.168
	N	203	197	202	203
VALUENC	Pearson Correlation	.238**	.061	.201**	.106*
	Sig. (2-tailed)	.000	.263	.003	.047
	N	357	343	216	352
EXPSERGAM	Pearson Correlation	.087	.041	.344**	.069
	Sig. (2-tailed)	.190	.544	.000	.302
	N	231	225	205	227
LRNPREF	Pearson Correlation	.133	.053	.375**	.157*
	Sig. (2-tailed)	.059	.461	.000	.026
	N	202	195	201	201
SUBMV2	Pearson Correlation	.182**	.096	.176*	.140*
	Sig. (2-tailed)	.005	.147	.011	.032
	N	237	230	209	233
THRKNOW	Pearson Correlation	.139*	.137	.031	.038
	Sig. (2-tailed)	.049	.055	.660	.593
	N	201	195	200	200
PROFSKILLS	Pearson Correlation	.144*	.166*	.152*	.106
	Sig. (2-tailed)	.043	.021	.033	.138
	N	199	192	198	198
SOCSKILLS	Pearson Correlation	.045	.043	.173*	.012
	Sig. (2-tailed)	.495	.521	.013	.851
	N	233	227	205	229
Age	Pearson Correlation	-.152**	-.046	-.033	-.100
	Sig. (2-tailed)	.005	.403	.627	.066
	N	342	329	216	336
Playing computer games private	Pearson Correlation	.093	-.013	.235**	.231**
	Sig. (2-tailed)	.150	.841	.001	.000
	N	241	234	214	237

*. Correlation is significant at the 0.05 level (2-tailed).

		ENJCOMP	QUAINT	FunFactor	PERSINT
VALUEDL	Pearson Correlation	.175*	.135	.210**	.097
	Sig. (2-tailed)	.013	.059	.003	.168
	N	203	197	202	203
VALUENC	Pearson Correlation	.238**	.061	.201**	.106*
	Sig. (2-tailed)	.000	.263	.003	.047
	N	357	343	216	352
EXPSERGAM	Pearson Correlation	.087	.041	.344**	.069
	Sig. (2-tailed)	.190	.544	.000	.302
	N	231	225	205	227
LRNPREF	Pearson Correlation	.133	.053	.375**	.157*
	Sig. (2-tailed)	.059	.461	.000	.026
	N	202	195	201	201
SUBMV2	Pearson Correlation	.182**	.096	.176*	.140*
	Sig. (2-tailed)	.005	.147	.011	.032
	N	237	230	209	233
THRKNOW	Pearson Correlation	.139*	.137	.031	.038
	Sig. (2-tailed)	.049	.055	.660	.593
	N	201	195	200	200
PROFSKILLS	Pearson Correlation	.144*	.166*	.152*	.106
	Sig. (2-tailed)	.043	.021	.033	.138
	N	199	192	198	198
SOCSKILLS	Pearson Correlation	.045	.043	.173*	.012
	Sig. (2-tailed)	.495	.521	.013	.851
	N	233	227	205	229
Age	Pearson Correlation	-.152**	-.046	-.033	-.100
	Sig. (2-tailed)	.005	.403	.627	.066
	N	342	329	216	336
Playing computer games private	Pearson Correlation	.093	-.013	.235**	.231**
	Sig. (2-tailed)	.150	.841	.001	.000
	N	241	234	214	237

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between game characteristics and process factors

Table D-15. Correlations between game quality and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
QUAGAME	Pearson Correlation	.362**	.428**	.356**	.364**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	401	389	226	378
RELGAME	Pearson Correlation	.271**	.262**	.418**	.287**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	249	243	228	228

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between facilitation indicators and process factors

Table D-16. Correlations between facilitation and embedding and process factors

		ENJCOMP	QUAINT	FunFactor	PERSINT
The instructions and explanations provided at the start of the simulation game were clear.	Pearson Correlation	.181**	.218**	.158*	.189**
	Sig. (2-tailed)	.000	.000	.017	.000
	N	408	395	228	384
The game was well facilitated	Pearson Correlation	.321**	.311**	.199**	.340**
	Sig. (2-tailed)	.000	.000	.002	.000
	N	410	397	229	386
Good feedback was given during and directly after the game	Pearson Correlation	.227**	.196**	.258**	.357**
	Sig. (2-tailed)	.000	.000	.000	.000
	N	393	381	231	388
Lectures, seminars and simulation game were well aligned with each other.	Pearson Correlation	.124	.125	.113	.118
	Sig. (2-tailed)	.056	.056	.095	.081
	N	241	234	221	221

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

D.6 Correlation between input factors and learning outcome

Correlations between player characteristics and general learning

Table D-17. Correlations between player factors and general learning

		VALUEDL	VALUENC	EXPSERGAM	LRNPREF	Age
It improves my learning to work on this simulation game (this role play).	Pearson Correlation	.198**	.103	.299**	.297**	-.055
	Sig. (2-tailed)	.004	.129	.000	.000	.422
	N	204	218	206	203	217
I would very much like to play other simulation games in education.	Pearson Correlation	.240**	.168*	.456**	.301**	-.026
	Sig. (2-tailed)	.001	.013	.000	.000	.706
	N	204	218	206	203	217
The use of SimPort-MV2 in education is valuable.	Pearson Correlation	.194**	.077	.329**	.109	-.098
	Sig. (2-tailed)	.006	.259	.000	.124	.150
	N	201	216	205	200	216
The use of SimPort-MV2 is worthwhile for the Port Authority	Pearson Correlation	.255**	.183**	.239**	.171*	-.007
	Sig. (2-tailed)	.000	.001	.000	.021	.903
	N	185	331	212	183	317

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-18. Correlations between learning expectations and general learning outcome

		SUBMV2	SOCSKILLS	THRKNOW	PROFSKILLS
It improves my learning to work on this simulation game (this role play).	Pearson Correlation	.213**	.224**	.213**	.268**
	Sig. (2-tailed)	.002	.001	.002	.000
	N	211	207	202	200
I would very much like to play other simulation games in education.	Pearson Correlation	.092	.248**	.093	.218**
	Sig. (2-tailed)	.184	.000	.189	.002
	N	211	208	202	200
The use of SimPort-MV2 in education is valuable.	Pearson Correlation	.122	.229**	.156*	.307**
	Sig. (2-tailed)	.079	.001	.028	.000
	N	209	205	199	197
The use of SimPort-MV2 is worthwhile for the Port Authority	Pearson Correlation	.231**	.169*	.079	.216**
	Sig. (2-tailed)	.001	.013	.290	.004
	N	218	215	183	180

**. Correlation is significant at the 0.01 level (2-tailed).*. significant at the 0.05 level (2-tailed).

Correlations between player characteristics and declarative knowledge

Table D-19. Correlation between player factors and declarative knowledge

		VALUEDL	VALUENC	EXPSERGAM	LRNPREF	Age
I have gained (theoretical) knowledge.	Pearson Corr	.061	-.090	.152*	.174*	-.004
	Sig. (2-tailed)	.391	.165	.022	.013	.953
	N	203	242	228	202	242
the theory from formal lectures and books became more understandable.	Pearson Corr	.082	.068	.195**	-.013	.193**
	Sig. (2-tailed)	.252	.325	.006	.860	.005
	N	195	209	197	194	210
I have gained gain content-related (subject) knowledge.	Pearson Corr	-.036	-.017	.143*	.095	.118
	Sig. (2-tailed)	.610	.788	.031	.178	.068
	N	202	241	227	201	241
I've gained a number of new insights about the real 2nd Maasvlakte.	Pearson Corr	.193**	.179**	.177**	.121	-.249**
	Sig. (2-tailed)	.006	.001	.007	.085	.000
	N	204	357	230	203	342
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	Pearson Corr	.120	.124*	.106	.148*	-.048
	Sig. (2-tailed)	.088	.019	.109	.036	.381
	N	202	354	228	201	339

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table D-20. Correlations between learning expectations and declarative knowledge

		SUBMV2	SOC SKILLS	THRKNOW	PROFSKILLS
I have gained (theoretical) knowledge.	Pearson Correlation	.212**	.157*	.184**	.078
	Sig. (2-tailed)	.001	.017	.009	.275
	N	235	232	202	199
the theory from formal lectures and books became more understandable.	Pearson Correlation	.055	.260**	.228**	.278**
	Sig. (2-tailed)	.432	.000	.001	.000
	N	204	200	196	192
I have gained content-related (subject) knowledge.	Pearson Correlation	.123	.163*	.237**	.225**
	Sig. (2-tailed)	.060	.013	.001	.001
	N	234	231	201	198
I've gained a number of new insights about the real 2nd Maasvlakte.	Pearson Correlation	.365**	.158*	.162*	.141*
	Sig. (2-tailed)	.000	.016	.022	.047
	N	237	233	202	200
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	Pearson Correlation	.105	.197**	.196**	.164*
	Sig. (2-tailed)	.109	.003	.005	.021
	N	235	231	200	198

**. Correlation is significant at the 0.01 level (2-tailed). *. significant at the 0.05 level (2-tailed).

Correlations between player characteristics and procedural knowledge

Table D-21. Correlation between player factors and procedural knowledge

		VALUEDL	VALUENC	EXPSERGAM	LRNPREF	Age
SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	Pearson Correlation	.114	.136*	.190**	.125	.010
	Sig. (2-tailed)	.108	.010	.004	.078	.857
	N	201	353	228	200	338
SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	Pearson Correlation	.006	.110*	.079	.057	-.073
	Sig. (2-tailed)	.935	.037	.229	.416	.177
	N	204	357	231	203	342
SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	Pearson Correlation	.014	.123*	.160*	.155*	-.027
	Sig. (2-tailed)	.842	.020	.015	.027	.624
	N	204	356	231	203	341
The underlying cause-effect relations became clear enough during the course of the game.	Pearson Correlation	.008	.033	-.026	.022	.020
	Sig. (2-tailed)	.907	.537	.697	.757	.718
	N	205	358	232	203	342
SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	Pearson Correlation	.136	.071	.119	.166*	-.125*
	Sig. (2-tailed)	.053	.180	.071	.018	.021
	N	202	354	229	201	340
SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	Pearson Correlation	.158*	.136*	.251**	.053	.107*
	Sig. (2-tailed)	.025	.011	.000	.456	.048
	N	203	355	229	202	340
I have learned to think beyond disciplinary boundaries.	Pearson Correlation	.015	.082	.221**	.091	-.047
	Sig. (2-tailed)	.832	.203	.001	.201	.471
	N	201	240	226	200	240
I have learned to see the relations between different subject areas.	Pearson Correlation	.047	.178**	.193**	.100	.078
	Sig. (2-tailed)	.508	.005	.003	.156	.225
	N	203	242	228	202	242

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table D-22. Correlations between learning expectations and procedural knowledge

		SUBMV2	SOCSKILLS	THRKNOW	PROFSKILLS
SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	Pearson Correlation	.092	.206**	.294**	.184**
	Sig. (2-tailed)	.161	.002	.000	.010
	N	234	231	200	197
SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	Pearson Correlation	.179**	.047	.116	.141*
	Sig. (2-tailed)	.006	.470	.102	.046
	N	238	234	202	200
SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	Pearson Correlation	.198**	.049	.101	.245**
	Sig. (2-tailed)	.002	.453	.154	.000
	N	238	234	202	200
The underlying cause-effect relations became clear enough during the course of the game.	Pearson Correlation	-.106	.039	.033	.062
	Sig. (2-tailed)	.101	.549	.642	.387
	N	238	234	202	200
SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	Pearson Correlation	.135*	.122	.101	.154*
	Sig. (2-tailed)	.039	.063	.156	.030
	N	236	233	200	198
SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	Pearson Correlation	.179**	.122	.103	.243**
	Sig. (2-tailed)	.006	.063	.147	.001
	N	236	232	201	199
I have learned to think beyond disciplinary boundaries.	Pearson Correlation	.177**	.283**	.135	.278**
	Sig. (2-tailed)	.007	.000	.057	.000
	N	233	230	200	198
I have learned to see the relations between different subject areas.	Pearson Correlation	.216**	.255**	.227**	.197**
	Sig. (2-tailed)	.001	.000	.001	.005
	N	235	231	201	199

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations between player characteristics and strategic knowledge

Table D-23. Correlation between player factors and strategic knowledge

		VALUEDL	VALUENC	EXPSERGAM	LRNPREF	Age
I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	Pearson Corr	.116	.155**	.182**	.101	-.019
	Sig. (2-tailed)	.098	.004	.006	.151	.730
	N	204	353	229	202	338
I have prepared myself for later professional practice (in an internship, traineeship, work, etc.).	Pearson Corr	.084	.101	.202**	.183**	.018
	Sig. (2-tailed)	.237	.142	.004	.010	.796
	N	199	213	201	198	213
I think that SimPort-MV2 can promote cooperation between different departments and individuals.	Pearson Corr	.139*	.148**	.276**	.136	.034
	Sig. (2-tailed)	.049	.005	.000	.055	.533
	N	201	352	228	199	335
I think that SimPort-MV2 can promote better comm. between different departments and individuals.	Pearson Corr	.126	.129*	.162*	.114	.041
	Sig. (2-tailed)	.076	.015	.015	.111	.452
	N	199	350	227	198	333
I learned to communicate	Pearson Corr	.039	.154**	.245**	.091	-.245**
	Sig. (2-tailed)	.583	.007	.000	.197	.000
	N	203	309	229	202	307
I learned to discuss and reason.	Pearson Corr	-.001	.094	.170*	.107	-.217**
	Sig. (2-tailed)	.985	.099	.010	.131	.000
	N	202	308	228	201	306
I have learned to work better together with other students in a team.	Pearson Corr	-.028	.121	.243**	-.026	.003
	Sig. (2-tailed)	.697	.061	.000	.712	.957
	N	202	241	227	201	241
I have learned to negotiate better.	Pearson Corr	.000	.113	.155*	.078	.180**
	Sig. (2-tailed)	.998	.083	.020	.270	.005
	N	201	239	225	200	239
I have improved relevant (professional) skills.	Pearson Corr	.034	.086	.165*	.097	.035
	Sig. (2-tailed)	.628	.183	.013	.172	.594
	N	202	240	226	201	240

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D-24. Correlations between learning expectations and strategic knowledge

		SUBMV2	SOC SKILLS	THRKNOW	PROFSKILLS
I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2^{nd} Maasvlakte.	Pearson Correlation	.134*	.156*	.198**	.128
	Sig. (2-tailed)	.040	.017	.005	.071
	N	235	231	201	199
I have prepared myself for later professional practice (in an internship, traineeship, work, etc.).	Pearson Correlation	.197**	.232**	.152*	.339**
	Sig. (2-tailed)	.004	.001	.032	.000
	N	206	204	198	196
I think that SimPort-MV2 can promote cooperation between different departments and individuals.	Pearson Correlation	.248**	.155*	.057	.194**
	Sig. (2-tailed)	.000	.018	.426	.006
	N	234	231	198	196
I think that SimPort-MV2 can promote better communication between different departments and individuals.	Pearson Correlation	.101	.138*	.135	.075
	Sig. (2-tailed)	.125	.036	.058	.299
	N	233	230	197	195
I learned to communicate	Pearson Correlation	.014	.392**	.310**	.292**
	Sig. (2-tailed)	.835	.000	.000	.000
	N	236	233	202	199
I learned to discuss and reason.	Pearson Correlation	.011	.410**	.347**	.211**
	Sig. (2-tailed)	.869	.000	.000	.003
	N	235	232	201	198
I have learned to work better together with other students in a team.	Pearson Correlation	.041	.383**	.332**	.335**
	Sig. (2-tailed)	.536	.000	.000	.000
	N	234	231	201	198
I have learned to negotiate better.	Pearson Correlation	-.018	.310**	.160*	.272**
	Sig. (2-tailed)	.782	.000	.024	.000
	N	232	229	200	198
I have improved relevant (professional) skills.	Pearson Correlation	.185**	.250**	.092	.338**
	Sig. (2-tailed)	.005	.000	.194	.000
	N	233	230	201	198

*. Correlation is significant at the 0.05 level (2-tailed).**. significant at the 0.01 level (2-tailed).

Correlations between game characteristics and general learning

Table D-25. Correlation between game quality and general learning outcome

		QUAGAME	RELGAME
It improves my learning to work on this simulation game (this role play).	Pearson Correlation	.208**	.365**
	Sig. (2-tailed)	.002	.000
	N	228	230
I would very much like to play other simulation games in education.	Pearson Correlation	.242**	.344**
	Sig. (2-tailed)	.000	.000
	N	228	230
The use of SimPort-MV2 in education is valuable.	Pearson Correlation	.184**	.507**
	Sig. (2-tailed)	.004	.000
	N	245	247
The use of SimPort-MV2 is worthwhile for the Port Authority	Pearson Correlation	.261**	.352**
	Sig. (2-tailed)	.000	.000
	N	375	231

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between game characteristics and declarative knowledge

Table D-26. Correlations between quality of the game and declarative knowledge

		QUAGAME	RELGAME
I have gained (theoretical) knowledge.	Pearson Correlation	.167**	.262**
	Sig. (2-tailed)	.006	.000
	N	268	229
the theory from formal lectures and books became more understandable.	Pearson Correlation	.114	.266**
	Sig. (2-tailed)	.091	.000
	N	219	221
I have gained gain content-related (subject) knowledge.	Pearson Correlation	.108	.220**
	Sig. (2-tailed)	.077	.001
	N	267	228
Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte.	Pearson Correlation	.209**	.326**
	Sig. (2-tailed)	.000	.000
	N	402	250
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2nd Maasvlakte.	Pearson Correlation	.253**	.216**
	Sig. (2-tailed)	.000	.001
	N	399	248

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between game characteristics and procedural knowledge

Table D-27. Correlations between quality of the game and procedural knowledge

		QUAGAME	RELGAME
SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	Pearson Correlation	.178**	.210**
	Sig. (2-tailed)	.000	.001
	N	398	247
SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	Pearson Correlation	.219**	.186**
	Sig. (2-tailed)	.000	.003
	N	402	250
SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	Pearson Correlation	.242**	.186**
	Sig. (2-tailed)	.000	.003
	N	401	250
The underlying cause-effect relations became clear enough during the course of the game.	Pearson Correlation	.223**	.192**
	Sig. (2-tailed)	.000	.002
	N	403	250
SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	Pearson Correlation	.216**	.227**
	Sig. (2-tailed)	.000	.000
	N	400	248
SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	Pearson Correlation	.207**	.240**
	Sig. (2-tailed)	.000	.000
	N	381	229
I have learned to think beyond disciplinary boundaries.	Pearson Correlation	.213**	.220**
	Sig. (2-tailed)	.000	.001
	N	267	227
I have learned to see the relations between different subject areas.	Pearson Correlation	.257**	.174**
	Sig. (2-tailed)	.000	.008
	N	268	229

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between game characteristics and strategic knowledge

Table D-28. Correlation between game quality and strategic knowledge

		QUAGAME	RELGAME
I expect that the insights/results of the sessions with SimPort-MV2 can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	Pearson Correlation	.174**	.163*
	Sig. (2-tailed)	.001	.013
	N	379	229
I have prepared myself for later professional practice.	Pearson Correlation	.189**	.301**
	Sig. (2-tailed)	.005	.000
	N	223	226
I think that SimPort-MV2 can promote cooperation between different departments and individuals.	Pearson Correlation	.283**	.363**
	Sig. (2-tailed)	.000	.000
	N	395	244
I think that SimPort-MV2 can promote better communication between different departments and individuals.	Pearson Correlation	.308**	.259**
	Sig. (2-tailed)	.000	.000
	N	393	243
I learned to communicate	Pearson Correlation	.077	.177**
	Sig. (2-tailed)	.160	.007
	N	335	229
I learned to discuss and reason.	Pearson Correlation	.018	.023
	Sig. (2-tailed)	.746	.729
	N	334	228
I have learned to work better together with other students in a team.	Pearson Correlation	.163**	.218**
	Sig. (2-tailed)	.008	.001
	N	267	229
I have learned to negotiate better.	Pearson Correlation	.168**	.068
	Sig. (2-tailed)	.006	.305
	N	265	227
I have improved relevant (professional) skills.	Pearson Correlation	.226**	.296**
	Sig. (2-tailed)	.000	.000
	N	266	228

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations between facilitation and embedding and general learning

Table D-29. Correlation between facilitation and general learning outcome

		The instructions and explanations of the simulation game were clear.	The game was well facilitated	Good feedback was given during and directly after the game	Lectures and game were well aligned with each other.
It improves my learning to work on this simulation game (this role play).	Pearson Correlation	.149*	.064	.360**	.119
	Sig. (2-tailed)	.024	.334	.000	.076
	N	230	231	233	223
I would very much like to play other simulation games in education.	Pearson Correlation	.155*	.077	.198**	.085
	Sig. (2-tailed)	.019	.246	.002	.206
	N	230	231	233	223
The use of SimPort-MV2 in education is valuable.	Pearson Correlation	.177**	.220**	.236**	.107
	Sig. (2-tailed)	.005	.000	.000	.097
	N	247	248	230	239
The use of SimPort-MV2 is worthwhile for the Port Authority	Pearson Correlation	.189**	.276**	.305**	.118
	Sig. (2-tailed)	.000	.000	.000	.078
	N	381	381	364	224

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations between facilitation and embedding and declarative knowledge

Table D-30. Correlation between facilitation and declarative knowledge

		The instructions and explanations provided at the start of the simulation game were clear.	The game was well facilitated	Good feedback was given during and directly after the game	Lectures, seminars and simulation game were well aligned with each other.
I have gained (theoretical) knowledge.	Pearson Correlation	.038	.085	.192**	.082
	Sig. (2-tailed)	.534	.159	.001	.221
	N	276	277	280	223
the theory from formal lectures and books became more understandable.	Pearson Correlation	.155*	.145*	.135*	.312**
	Sig. (2-tailed)	.021	.030	.043	.000
	N	222	222	224	219
I have gained gain content-related (subject) knowledge.	Pearson Correlation	.009	.074	.100	.116
	Sig. (2-tailed)	.879	.223	.097	.084
	N	275	276	279	222
Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2^{nd} Maasvlakte.	Pearson Correlation	.154**	.128**	.276**	.095
	Sig. (2-tailed)	.002	.010	.000	.139
	N	409	411	394	242
SimPort-MV2 has shown what some of the long-term effects/pitfalls could be of the 2^{nd} Maasvlakte.	Pearson Correlation	.120*	.169**	.248**	.136*
	Sig. (2-tailed)	.015	.001	.000	.035
	N	406	408	391	240

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations between facilitation and embedding and procedural knowledge

Table D-31. Correlation between facilitation and procedural knowledge

		The instructions and explanations provided at the start of the simulation game were clear.	The game was well facilitated	Good feedback was given during and directly after the game	Lectures, seminars and simulation game were well aligned with each other.
SimPort-MV2 provided insight into the technical complexity of the 2nd Maasvlakte.	Pearson Corr	.091	.136**	.198**	.096
	Sig. (2-tailed)	.067	.006	.000	.139
	N	406	407	390	240
SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte.	Pearson Corr	.171**	.179**	.237**	.012
	Sig. (2-tailed)	.001	.000	.000	.851
	N	409	411	394	242
SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte.	Pearson Corr	.161**	.184**	.226**	.125
	Sig. (2-tailed)	.001	.000	.000	.053
	N	408	410	393	242
The underlying cause-effect relations became clear enough during the course of the game.	Pearson Corr	.150**	.204**	.324**	.021
	Sig. (2-tailed)	.002	.000	.000	.741
	N	410	412	395	242
SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term.	Pearson Corr	.126*	.194**	.256**	.054
	Sig. (2-tailed)	.011	.000	.000	.406
	N	406	408	391	240
SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync.	Pearson Corr	.122*	.113*	.195**	.172*
	Sig. (2-tailed)	.016	.025	.000	.010
	N	388	391	393	222
I have learned to think beyond disciplinary boundaries.	Pearson Corr	.104	.070	.133*	.001
	Sig. (2-tailed)	.087	.245	.027	.984
	N	274	276	278	221
I have learned to see the relations between different subject areas.	Pearson Corr	.127*	.085	.126*	.114
	Sig. (2-tailed)	.035	.157	.035	.091
	N	275	277	280	222

**. Correlation is significant at the 0.01 level (2-tailed). *. significant at the 0.05 level (2-tailed).

Correlations between facilitation and embedding and strategic knowledge

Table D-32. Correlation between facilitation and strategic knowledge

		The instructions provided at the start of the simulation game were clear.	The game was well facilitated	Good feedback was given during and directly after the game	Lectures, and simulation game were well aligned with each other.
The insights/results can contribute to a good realization and exploitation of the actual 2nd Maasvlakte.	Pearson Corr	.127*	.091	.225**	.190**
	Sig. (2-tailed)	.013	.072	.000	.004
	N	386	389	391	222
I have prepared myself for later professional practice.	Pearson Corr	.178**	.078	.108	.016
	Sig. (2-tailed)	.007	.243	.105	.809
	N	227	226	228	219
I think that SimPort-MV2 can promote cooperation between different departments and individuals.	Pearson Corr	.265**	.267**	.202**	.050
	Sig. (2-tailed)	.000	.000	.000	.448
	N	402	404	387	236
I think that SimPort-MV2 can promote better communication between different departments and individuals.	Pearson Corr	.241**	.243**	.184**	.069
	Sig. (2-tailed)	.000	.000	.000	.291
	N	400	402	385	235
I learned to communicate	Pearson Corr	-.061	.012	.016	.108
	Sig. (2-tailed)	.257	.824	.769	.108
	N	343	344	346	223
I learned to discuss and reason.	Pearson Corr	-.102	-.055	-.005	-.009
	Sig. (2-tailed)	.058	.309	.928	.889
	N	342	343	345	222
I have learned to work better together with other students in a team.	Pearson Corr	.061	.044	.114	.087
	Sig. (2-tailed)	.312	.466	.057	.197
	N	275	276	279	222
I have learned to negotiate better.	Pearson Corr	.067	.019	.085	.186**
	Sig. (2-tailed)	.269	.750	.161	.005
	N	273	274	277	221
I have improved relevant (professional) skills.	Pearson Corr	.188**	.099	.181**	.126
	Sig. (2-tailed)	.002	.101	.002	.060
	N	274	275	278	222

*. Corr is significant at the 0.05 level (2-tailed). **. Corr is significant at the 0.01 level (2-tailed).

SUMMARY

Experiencing Complexity

A gaming approach for understanding infrastructure systems

Introduction: understanding complex infrastructure systems

Our current society is highly dependent, both socially and economically, on well-functioning infrastructure systems. At the same time, these infrastructures are increasingly difficult to manage, due to their large number of interdependencies. Furthermore, the development of new infrastructures faces problems of limited time, budget constraints and social resistance. In addition to the complexity of the physical system, infrastructure systems both affect and are influenced by a social environment containing a large variety of actors. Consequently, policy makers and designers of infrastructure systems face several challenges in planning and designing interventions to infrastructure systems. The direct and indirect, short- and long-term consequences of these interventions are uncertain.

In this dissertation it is argued that infrastructures can be considered as complex adaptive systems and that this complexity is one of the causes of the difficulties for policy makers and designers. The adaptive and emergent properties of the system can lead to unexpected or unintended effects. In order to improve policy making, a better understanding of the complexity of the system is necessary. Descriptive analyses can be used to recognize or explain complex systems properties. However, these analyses do not provide insights into the behaviour and consequences of interventions. For the analysis of future behaviour of the system, computer simulations are often used. These are useful, but they have the disadvantage that they do not take into account the social characteristics of actors, or they do so in only a limited way. It is important that simulations include these characteristics, since the social as well as the technical characteristics of the system influence the system's behaviour. Another disadvantage is that these simulations are black boxes for policy makers, who thus have difficulties in understanding the dynamics of the system.

In this research, serious gaming is introduced as a method for simulating complex adaptive systems. It provides a supporting tool for policy makers by increasing their understanding of infrastructure systems. Serious games are simulation games that use

the existing game concepts and technology of the entertainment video game industry. Such games compensate the limitations of pure simulations by introducing real players who simulate the social system. In this way, the real stakeholders or at least the stakeholders' roles become part of the simulated system. Secondly, gaming has the added value of giving players the experience of dealing with complex systems.

Although simulation games have been used for a long time, the influence of entertainment video games brings these games to another level. By using the technology and game concepts of video games, simulation games can make use of more complicated models and improve the visualization of the dynamics in the physical system. These games are called serious games. The starting hypothesis is: *Serious gaming is a useful tool for simulating complex socio-technical infrastructure systems and supporting policy makers and designers in understanding the complexity of the planning and design of these systems.*

Research question and methodology

The main research question of this dissertation is:

> To what extent can serious gaming simulate complex infrastructure systems, and how can serious gaming be used in understanding complex infrastructure systems?

To answer this question, the relations between the design of infrastructures, complex adaptive systems and serious games are explored from a theoretical perspective (Figure S-1). This leads to two different uses of serious gaming for policy makers: 1) gaming as a simulation of a socio-technical complex adaptive system and 2) gaming as an intervention tool for players to increase their understanding of complex adaptive systems.

In the empirical part of this dissertation, these uses are applied in a real-world setting. Based on the design science approach, a game about the land reclamation project Maasvlakte 2 in the Port of Rotterdam is discussed and evaluated. Maasvlakte 2 is described as a complex adaptive system which is affected by the decisions of the Port of Rotterdam Authority. The consequences of different strategic choices surrounding the construction and exploitation of the area are unknown and uncertain. Playing a serious game is expected to increase the insights about the financial and physical consequences

The developed game SimPort-MV2 has been played by more than 80 teams and with more than 400 participants. The decisions of the players in the game, the outcomes of the sessions and the observations that followed were used to explore patterns of behaviour within the system. Secondly, surveys were used to evaluate the players' gaming expectations and experiences. For the analysis of the individual learning experience, we used a theory-based evaluation model developed by Kriz and Hense (Kriz & Hense, 2006) and adapted this model for serious gaming.

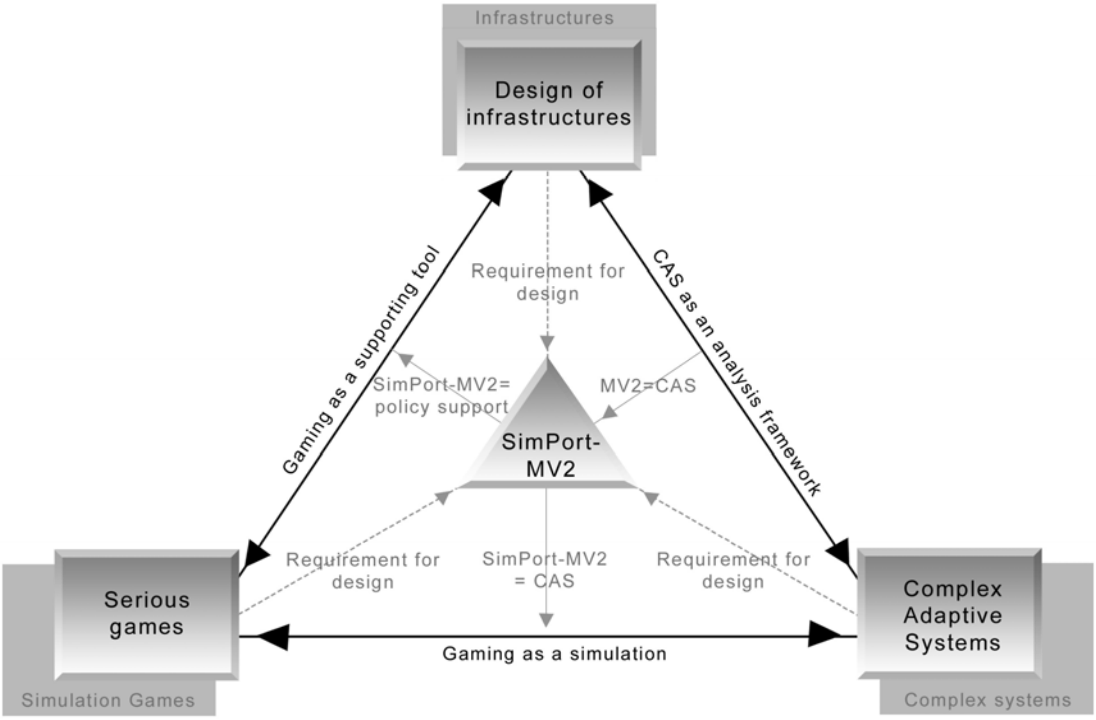


Figure S-1. Relations between infrastructures, complex systems and serious games and the game SimPort-MV2

Complex adaptive systems for understanding infrastructures

We consider infrastructures as systems that have both social and physical components and observe that there are conflicting values between actors and uncertainties in the behaviour of the system. For the analysis and explanation of the behaviour of these infrastructure systems, the theory of Complex Adaptive Systems is used (Holland, 1995, 1997; Kauffman, 1995). Based on the ratio between the number of elements and their relationships, Complex Adaptive Systems are classified as systems that fall between chaotic and periodic systems and in which the behaviour is non-linear but also not random. This classification follows from simple representations of systems in Cellular Automata simulations. In real-world systems it is difficult to define the number of elements and relationships and calculate the class. Therefore, other, observable, indicators are needed to identify a system as being complex and to analyse the complexity of the system.

These indicators are represented in a three-layered framework, consisting of an agent, network, and system level. At each level several properties are defined, which characterize complex adaptive systems. At the agent level these properties are agent diversity, protocol similarity and adaptivity. The network level focuses on the interactions between agents. The central properties at this level are network evolution and network dynamics. Finally, at the system level, we observe the dynamics based on the interaction of agents which can lead to emergence. Properties of the system level are self-organization, path-dependency, system instability and system robustness. This framework can be used for the analysis of the complexity of infrastructures (see Figure S-2).

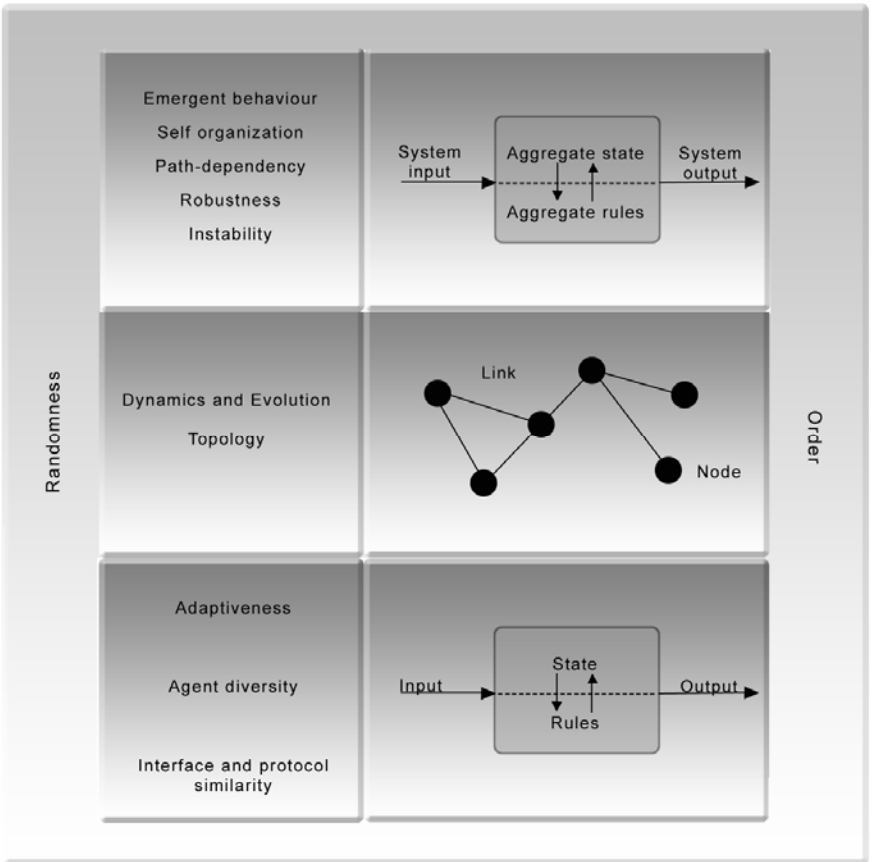


Figure S-2. Conceptual framework of Complex Adaptive Systems

Based on the properties of complex adaptive systems, we can argue that infrastructures have similar characteristics and that they can therefore be considered as complex adaptive systems.

Serious gaming for simulating and learning about complex adaptive systems

Although the framework is useful for analysing the dynamics, it does not provide insights into the future behaviour of the system or the consequences of intervening in the system. Policy makers use (large-scale) simulations to increase their insights about possible future developments, but these simulations have the disadvantage that the cause and effect relationships do not become clear and that the social networks are not taken into account. Serious gaming compensates these disadvantages and is thus proposed as a way to increase insights about the complexity of infrastructure systems.

In simulation games, these large-scale computer simulations are hardly used; the physical environment is often represented with blocks or papers. If computers are used, they function as calculators for financial effects or as referees. However, the entertainment video game industry illustrates that it is possible to simulate large complex systems, like cities or civilizations, in a way which is understandable for the players and where players influence the dynamics of the system by taking actions. This smart combination of simulation games with components of entertainment games offers opportunities for the role of gaming in the policy making of complex adaptive systems. The physical environment and the complex properties as self-organization and emergence can be taken into account in a more realistic way. Also, by saving the decisions of the players and outcomes of the system, patterns of behaviour can be analysed.

If we want to simulate socio-technical complex adaptive systems in games, these games must show complex adaptive systems properties as described in the framework. This means that such a game needs to have: 1) an open outcome with a large solution space, 2) dynamic rules open to changes and evolving interactions during game play and 3) multiple players or multiple adaptive agents. In this way, a game environment is created in which complexity can emerge.

The existence of games which simulate complex adaptive systems says nothing in itself about whether this leads to a better understanding of the complexity of systems. To answer the question about the value of gaming, a distinction is made between using gaming to learn about system behaviour and using gaming as a learning instrument for players to experience complexity.

In the first place, gaming can be used as a simulator of complex systems. Each gaming session explores one possible path through the solution space. By analysing the dynamics and outcomes of multiple gaming sessions, policy makers can learn about the behaviour of the system, the variables for which the system is robust or instable, and which bottlenecks can be observed towards the desired end state. In addition, the behaviour of the players, their strategies, decisions and reactions in the system can be observed and analysed.

In the second place, players of the game go through a learning experience. They act and react in a complex environment and experience the dynamics of the system. By participating in this learning experience they increase their cognitive knowledge, which is described as increasing subject-related content and theory-related notions, understanding linear and complex processes within complex systems, and practicing management skills.

Research results and findings

This broad explorative study into serious gaming as a way to better understand complex infrastructure systems has provided three types of results: the experiences of developing a serious game, simulating a complex adaptive system in serious games, and the learning experiences of the individual players.

1. Developing a serious game

The development of a serious game requires a balancing choice between fulfilling the requirements related to the validity of the simulation, the simulation of complex adaptive systems, learning aspects and gaming characteristics.

This led to the development of a multi-player game, SimPort-MV2, with the objective of making appropriate planning and implementation decisions, both individually and collectively, that will lead to a satisfactory design and exploitation of the Second Maasvlakte (1,000 ha) over a 30-year period. In the game, a team of 3 to 6 persons has to decide on a building and commercial strategy and design an allocation plan. Then the time starts running and they have to build the area and contract clients according to their strategies. At the end, the teams are compared on their design, the financial situation and the client satisfaction.

The game was developed according to the previously mentioned requirements. It was decided that a hybrid version of a computer game with social game elements would be used. This set-up has the advantage that the participants are free to choose and change their communication methods. Using the visualization technology from the entertainment game industry leads to an increasing understanding of the consequences of decisions of participants on the physical system. Based on the validation, we conclude that game play shows complex system behaviour and that it fulfils the gaming requirements, like challenge, rules, winning, etc.

However, choices in the conceptualization of the system and design of the game set limits to the validity of the game output. In the development of a game which simulates a complex adaptive system, there is always the possibility that apparent insignificant factors will be sensitive to the dynamics of the system. On the one hand, one would like to include as many variables as possible, but on the other hand, boundaries have to be set in order to develop a playable game which contributes to a better understanding of the system. Therefore, SimPort-MV2 was developed with a high level of abstraction and does not provide the optimal solution.

2. Serious gaming as simulation of complex adaptive systems

Playing the game with different participants directly means a variety of agents. In the gaming sessions, we observed that the players developed a similar language and communication protocol to coordinate the project in the game. Secondly, we observed that the participants adapted continuously to new situations and new events. Third, several signs of network dynamics and evolution were found. The port area has been developed, new contracts have been signed, and the structure of the team was adapted to the development. Finally, the game output showed a great variety of port areas together with different financial situations as a consequence of the decisions of the players. Based on the analysis of the decisions and outcomes of the gaming sessions, we can conclude that SimPort-MV2 simulates a Complex Adaptive System.

The Complex Adaptive Systems framework is used to explain the simulated behaviour over the years. The teams showed self-organizing properties, for example as observed in the structure of their processes. The construction and exploitation of the area illustrate the characteristics and consequences of path-dependencies. Based on the outcomes of the game, we conclude that the planning as proposed by the Port of Rotterdam is feasible under normal circumstances. However, the game output also shows that the direct income and profit of MV2 are highly uncertain and will depend on the number of contracted clients. The financial outcome after 30 years is sensitive to the chosen building strategy and economic climate, especially if the economy declines in the building and exploitation period. The outcome is robust for the commercial strategy and allocation plan, because these are more flexible. Furthermore, it is a challenge to follow a synchronized construction and exploitation process. Miscommunication between the building directors and commercial directors can lead to conflicting situations and delays in one of the processes.

These results of SimPort-MV2 shows that gaming can be used to simulate different paths into the future and to analyse the emergent behaviour and other properties at the system level, show the network dynamics and increase the insights into the behaviour of adaptive agents.

3. Serious gaming as a learning intervention

The game SimPort-MV2 appears to be a successful intervention if we look at the enthusiasm of the players and the positive atmosphere during the sessions. However, this does not necessarily say anything about actual learning effects.

The learning results show that SimPort-MV2 is supportive in understanding the complexity of the Maasvlakte 2 system. More specifically, the participants increased their knowledge about Maasvlakte 2, gained more insights into the commercial and strategic complexity, the picture of Maasvlakte in the future and why and how the commercial and building processes have to be integrated. Finally, the participants agree that the game can promote cooperation and communication between different departments of the Port of Rotterdam. Lower learning results were found with regard to the general notions and skills about complex adaptive systems and about the technical complexity.

With the exception of the level of increased knowledge about MV2, the professional participants scored equal to or higher than the student participants on the learning indicators related to Maasvlakte 2. This illustrates that serious gaming is not only a valid intervention in formal education, but that gaming in a professional setting also leads to increased insights into the dynamics of the system. The professionals also agree that these gaming methods can be used as an exploration of alternatives and as a discussion-supporting tool in policy- and decision-making processes.

Correlation analyses show that the learning outcome is mainly influenced by the engagement of the players during game play. Other relevant factors are the expectations of the value of serious gaming, the relevance of the subject of the game for the player, the facilitation of the game and the quality of the game. Engagement is influenced by, among others, the personal interaction between the players, the learning preferences of the players and the quality of the interfaces. Therefore, these factors indirectly influence the learning outcome. Furthermore, the quality of the game and facilitation are important, which means that playing just a game does not necessary lead to the expected effects. Furthermore, gaming is not the preferred learning intervention for all students or professionals.

Future research

This research contributes to an explanation of the use of serious gaming for understanding infrastructures. However, the limitation of using one game to test the relationships between gaming and understanding the complexity of infrastructure is not enough to provide general conclusions. This research game is not over, but we are now ready for the next level. This next research level could focus on any of several topics.

The first direction of new research should be to develop research methods and tools for measuring learning effects and analysing behaviour. If we want to evaluate the impact of games on the long term and compare different types of games with each other or with other interventions, new methods and tools have to be designed in which reliable data can be collected.

The second direction is related to the first about the role of gaming in the policy-making process. Games can improve the knowledge of and insights into a system. However, the question remains as to whether this will influence policy- and decision-making processes. To measure these effects, we need other ways of doing research than those presented here.

Third, we need more research to the effect of serious gaming related to other infrastructure sectors, like electricity or transport, and to questions such as capacity shortage and changing market systems. Do these sectors and questions demand other tools for understanding, and what is the role of dynamic simulations and visualizations?

Fourth but not last, additional research could be done to improve the design of games which attempt to simulate complex adaptive systems. This research gave some relevant variables, but these could be more precisely researched so as to improve the development process and outcomes.

SAMENVATTING

Complexiteit Ervaren

Een spelaanpak voor het begrijpen van infrastructuursystemen

Introductie: Het begrijpen van complexe infrastructuur systemen

Onze huidige sociale en economische samenleving is zeer afhankelijk van goed functionerende infrastructuursystemen. Tegelijkertijd zijn deze infrastructuren door het groot aantal afhankelijkheden in toenemende mate moeilijk te managen. Verder worden de ontwikkelingen van nieuwe infrastructuren gekenmerkt door problemen zoals een beperkt budget en sociale weerstand. Naast de complexiteit van het fysieke systeem worden infrastructuursystemen beïnvloed door en beïnvloeden ze de sociale omgeving, die bestaat uit een grote variëteit aan actoren. Dientengevolge, hebben beleidsmakers en ontwerpers van infrastructuursystemen verschillende uitdagingen tijdens het plannen en ontwerpen van infrastructuurinterventies. De directe en indirecte en de korte en lange termijn consequenties van deze interventies zijn onzeker.

Wij beargumenteren dat infrastructuren beschouwd kunnen worden als complex adaptieve systemen en dat deze complexiteit een van de redenen is voor de problemen van beleidsmakers en ontwikkelaars. De adaptieve en emergente kenmerken van het systeem kunnen leiden tot onverwachte en onbedoelde effecten. Om beleidsvorming te verbeteren is een beter begrip van de complexiteit van het systeem noodzakelijk. Beschrijvende analyses kunnen worden gebruikt voor het herkennen en uitleggen van complexe systeemkenmerken. Maar deze analyses geven geen inzicht in gedrag en consequenties van interventies. Voor de analyse van het gedrag van het systeem in de toekomst worden vaak computersimulaties ingezet. Deze zijn nuttig, maar ze hebben het nadeel dat sociale karakteristieken van actoren niet of beperkt in beschouwing worden genomen. Dit is wel van belang wanneer zowel de sociale als technische karakteristieken van het systeem van invloed zijn op het gedrag. Een ander nadeel is dat deze simulaties een black box zijn voor beleidsmakers en dat zij problemen hebben met het begrijpen van de dynamiek in het systeem.

In dit onderzoek is serious gaming geïntroduceerd als een simulatie van complex adaptieve systemen en als een ondersteunende tool voor beleidsmakers om het begrijpen van infrastructuursystemen te vergroten. Serious games zijn spelsimulaties die gebruik maken van spelconcepten en de technologie van de entertainment videogame industrie. Deze spellen kunnen omgaan met de beperkingen van pure simulaties door het simuleren van het sociale systeem met echte spelers. Op deze manier worden de echte belanghebbenden of hun rollen onderdeel van het gesimuleerde systeem. Ten tweede gaan spellen om met de beperkingen van computersimulaties door spelers te laten ervaren hoe het is om te gaan met complexiteit.

Ondanks dat spelsimulaties al een lange tijd gebruikt worden, brengt de invloed van de entertainment videogames deze spelsimulatie op een ander niveau. Door het gebruik van de technologie en spelconcepten van videogames, kunnen spelsimulaties gebruik maken van gecompliceerdere modellen en de visualisatie van de dynamiek in het fysieke systeem verbeteren. Deze spellen worden *serious games* genoemd. De starthypothese is dan ook: *Serious gaming is een bruikbare tool voor het simuleren van complexe sociaaltechnische infrastructuursystemen en ondersteunen beleidsmakers en ontwerpers in het begrijpen van de complexiteit in het plannen en ontwerpen van deze systemen.*

Onderzoeksvraag en methode

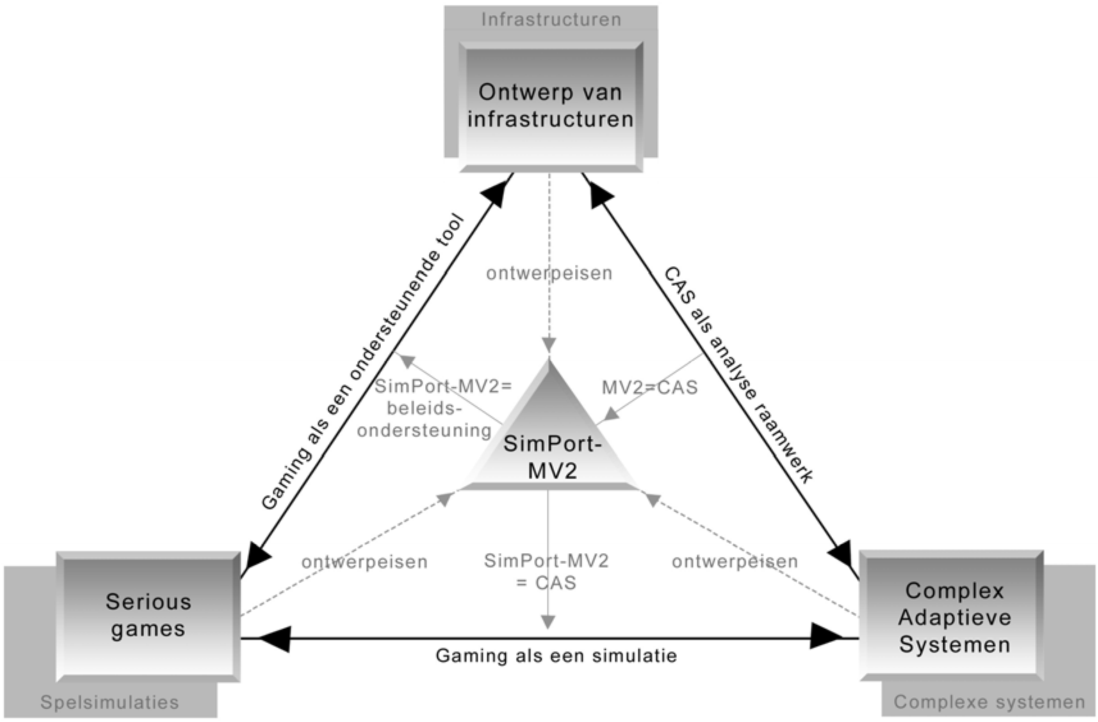
De hoofdvraag van dit onderzoek is:

> In welke mate kunnen serious games complexe infrastructuren simuleren en hoe kunnen serious games worden gebruikt voor het begrijpen van complexe infrastructuur systemen?

Om deze vraag te beantwoorden worden de relaties tussen het ontwerpen van infrastructuren, complex adaptieve systemen en serious games verkend vanuit een theoretisch perspectief (zie Figuur S-1). Dit leidt tot twee verschillende toepassingen van serious games voor beleidsmakers: 1. gaming als een simulatie van een sociaaltechnisch complex adaptief systeem en 2. gaming als een interventietool voor spelers om hun inzicht in complex adaptieve systemen te vergroten.

In het empirische deel worden deze toepassingen toegepaste in een case. Er is een spel ontwikkeld en geëvalueerd over het landaanwinningproject Maasvlakte 2 in de haven van Rotterdam. Maasvlakte 2 is beschreven als complex adaptief systeem, welke beïnvloed wordt door de beslissingen van het Havenbedrijf Rotterdam N.V. De consequenties van verschillende strategische beslissingen rond de aanleg en exploitatie van het gebied zijn onbekend en onzeker. Het spelen van een serious game zou moeten bijdragen aan het vergroten van de inzichten van de financiële en fysieke consequenties en de aantrekkelijkheid van het gebied voor potentiële klanten door invloed van beslissingen van het Havenbedrijf.

Het ontwikkelde spel SimPort-MV2 is met meer dan 80 teams en meer dan 400 spelers gespeeld. De beslissingen van de spelers in het spel, de uitkomsten van de sessies en de observaties zijn gebruikt voor het verkennen van patronen in het systeemgedrag. Ten tweede zijn enquêtes gebruikt voor de evaluatie van de spelverwachtingen en –ervaringen vanuit het perspectief van de spelers. Voor de analyse van de individuele leerervaringen is gebruik gemaakt van het theoriegebaseerde evaluatiemodel van Kriz en Hense (Kriz & Hense, 2006), die aangepast is voor serious gaming.

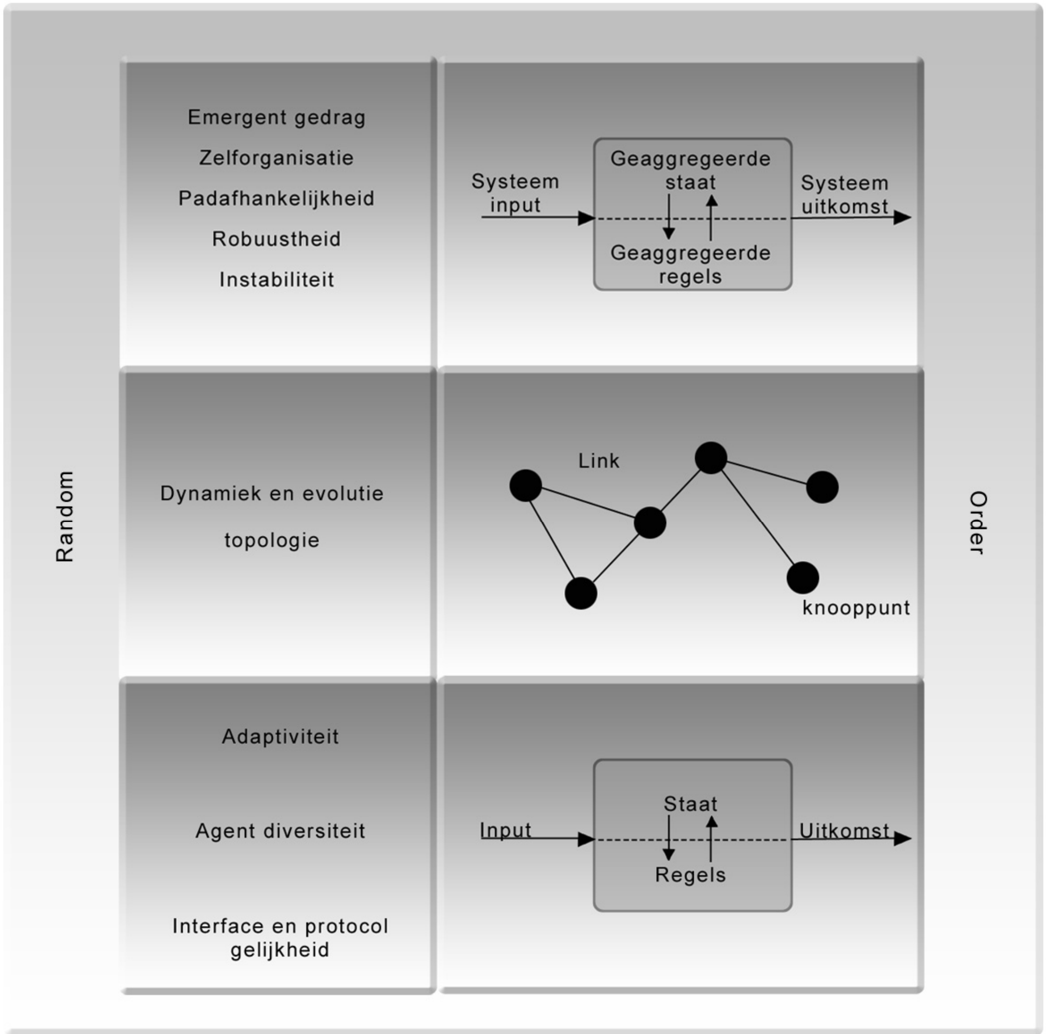


Figuur S 1. Relaties tussen infrastructuren, complexe systemen and serious games en het spel SimPort-MV2

Complexe adaptieve systemen voor het begrijpen van infrastructuren

We beschouwen infrastructuren als systemen met sociale en fysieke componenten en observeren dat er conflicterende waarde zijn tussen actoren en onzekerheden in het gedrag van het systeem. Voor de analyse en uitleg van het gedrag van deze infrastructuursystemen is de theorie van Complexe Adaptieve Systemen gebruikt (Holland, 1995, 1997; Kauffman, 1995). Complexe Adaptieve Systemen worden op basis van de verhoudingen van het aantal elementen en relaties geclassificeerd als systemen tussen chaotisch en periodiek, waarbij het gedrag niet-lineair is maar ook niet random. Deze classificatie volgt uit simpele representaties van system in Cellular Automata simulaties. In de werkelijkheid is het moeilijk om het aantal elementen en relaties te definiëren en daarmee de klasse te berekenen. Daarom zijn andere, observeerbare indicatoren nodig om het systeem als complex te identificeren en de complexiteit van het systeem te analyseren.

Deze indicatoren worden gerepresenteerd in een drielagen raamwerk, bestaande uit een agent-, netwerk- en systeemlaag. Op iedere laag zijn een aantal kenmerken gedefinieerd die complex adaptieve systemen karakteriseren.



Figuur S 2. Conceptueel raamwerk Complex Adaptieve Systemen

Op de agentlaag zijn deze kenmerken agentdiversiteit, protocolgelijkheid, en aanpasbaarheid. De netwerklaag focust op de interacties tussen agenten (en actoren). De centrale kenmerken zijn netwerkevolutie en netwerkdynamiek. Tenslotte observeren we op de systeemlaag de dynamiek gebaseerd op de inter-acterende agenten. Deze dynamiek kan emergent zijn. Kenmerken op het systeemniveau zijn zelforganisatie, padafhankelijkheid, systeeminstabiliteit en systeemrobuustheid. Dit raamwerk kan worden gebruikt voor de analyse van de complexiteit van infrastructuren (zie Figuur S-2).

Op basis van de kenmerken van complex adaptieve systemen kunnen we beredeneren dat infrastructuren vergelijkbare karakteristieken hebben en daarom als complex adaptieve systemen beschouwd kunnen worden.

Serious gaming voor het simuleren van en leren over complexe adaptieve systemen

Ondanks dat het raamwerk te gebruiken is voor het analyseren van de dynamiek, geeft dit raamwerk geen inzicht in het toekomstig gedrag van het systeem en de consequenties van het ingrijpen in het systeem. Beleidsmakers gebruiken (grootschalige) simulaties voor het vergroten van het inzicht in mogelijke toekomstige ontwikkelingen, maar deze hebben als nadeel dat de relaties tussen oorzaak en gevolg niet duidelijk worden en dat het sociale netwerk niet meegenomen wordt. Daarom is serious gaming voorgesteld als een manier om het inzicht in de complexiteit van infrastructuren vergroten.

Tot op heden werden grootschalig computersimulaties in spelsimulaties nauwelijks gebruikt. De fysieke omgeving wordt vaak gerepresenteerd in pionnen, blokken en papier. Als computers worden gebruikt, functioneren deze als rekenmachine voor het bereken van financiële effecten of als scheidsrechter. De entertainment videogame industrie laat zien dat het mogelijk is om grote complexe systemen te simuleren, zoals steden en beschavingen, op een manier zodat het te begrijpen is voor spelers en waar spelers de dynamiek van het systeem kunnen beïnvloeden door het doen van acties. De intelligente combinatie van spelsimulaties met componenten van de entertainmentspellen geven mogelijkheden voor het gebruik van spellen voor beleidsvorming in complex adaptieve systemen. De fysieke omgeving en de complexe kenmerken zoals zelforganisatie en emergentie kunnen in een meer realistische manier meegenomen worden. En door het opslaan van de beslissingen van de spelers en uitkomsten van het systeem kan het gedrag geanalyseerd worden.

Als we sociaaltechnische complexe adaptieve systemen in spellen willen simuleren, moeten deze spellen complex adaptieve systeemkenmerken als beschreven in het raamwerk kunnen laten zien. Dit betekent dat deze spellen de volgende drie kenmerken moeten hebben: 1. een open uitkomst met een grote oplossingsruimte, 2. flexibele regels die te veranderen zijn en ontwikkelende interacties tijdens het spelen en 3. een multiplayer spel of een spel met meerdere adaptieve agenten. Op deze manier wordt er een spelomgeving gecreëerd waar complexiteit zou kunnen ontstaan.

Het hebben van een spel, dat een complex adaptief systeem simuleert, zegt nog niets over het beter begrijpen van de complexiteit van het systeem. Om de vraag te beantwoorden wat de waarde is van spellen is een onderscheid gemaakt in het gebruik van gaming om te leren over het systeemgedrag en het gebruik van gaming als tool om de spelers de complexiteit te laten ervaren.

In de eerste plaats kan gaming gebruikt worden als simulator van een complex systeem. Iedere gaming sessie verkent een mogelijk pad door de oplossingsruimte. Door het analyseren van de dynamiek en uitkomsten van meerdere spelsessies kunnen beleidsmakers leren over het gedrag van het systeem, voor welke variabele het systeem robuust en instabiel is, en welke knelpunten kunnen worden geobserveerd richting de gewenste eindsituatie. Ook het gedrag van spelers, hun strategieën, beslissingen en reacties in het systeem kunnen worden geobserveerd en geanalyseerd.

In de tweede plaats krijgen de spelers van het spel een leerervaring. Ze acteren en reageren in een complexe omgeving en ervaren de dynamiek van het systeem. Door het participeren in deze leerervaring kunnen ze hun cognitieve kennis vergroten. Deze kennis is beschreven als toename van onderwerp gerelateerd inhoud en theoretische noties, begrijpen van lineaire en complexe processen in het complexe systeem en het oefenen van managementvaardigheden.

Onderzoeksresultaten en bevindingen

De brede verkennende studie naar serious gaming voor het begrijpen van complexe infrastructuursystemen geven drie type resultaten. Ten eerste de ervaring van het ontwikkelen van een serious game. Ten tweede het simuleren van een complex adaptief systeem in een serious game. En ten derde de leerervaringen van de individuele spelers.

1. Ontwikkelen van een serious game

De ontwikkeling van een serious game vraagt een gebalanceerde keuze tussen het voldoen van de eisen met betrekking tot de validiteit van de simulatie, de simulatie van een complex adaptief systeem, leeraspecten en spelkarakteristieken.

Dit leidde tot een multiplayer spel, SimPort-MV2, met als doel geschikte planning en implementatiebeslissingen te nemen, individueel en gezamenlijk, dat zal leiden tot een tevreden ontwerp en exploitatie van de Tweede Maasvlakte (1000 ha) over een periode van 30 jaar. Een team van 3 tot 6 personen moeten beslissen over bouw en commerciële strategieën en een vlekkenplan ontwikkelen. Daarna start de tijd en moeten ze het gebied aanleggen en klanten contracteren op basis van hun gekozen strategieën. Aan het eind kunnen de teams hun ontwerp, de financiële situatie en klanttevredenheid vergelijken.

Het spel is ontwikkeld volgens de bovengenoemde eisen. Er is gekozen voor een hybride versie van een computerspel met sociale spelelementen. Deze opzet heeft het voordeel dat de deelnemers vrij zijn om hun wijze van communiceren in te richten en aan te passen. Het gebruik van de visualisatie uit de entertainment industrie leidt tot een verhoogd begrip van de consequenties van de beslissingen van de spelers op het fysieke systeem. Op basis van de validatie concluderen we dat het spel complex systeem gedrag laat zien en dat het voldoet aan de spelkarakteristieken, zoals uitdaging, regels, winnen etc.

Maar de keuzes in de conceptualisatie van het systeem en ontwerp van het spel geeft beperkingen aan de validiteit van de speluitkomsten. In de ontwikkeling van het spel, die een complex adaptief systeem moet simuleren, is er altijd een mogelijkheid dat ogenschijnlijk niet significante factoren gevoelig zijn voor de dynamiek van het systeem. Aan de ene kant, wil je zoveel mogelijk variabelen meenemen, maar aan de andere kant moeten grenzen gesteld worden om een speelbaar spel te ontwikkelen welke bijdraagt aan een beter begrip van het systeem. Daarom is SimPort-MV2 ontwikkeld op een hoog abstractieniveau geeft het spel geen optimale oplossing.

2. Serious gaming als simulatie van complex adaptieve systemen

Het spelen van een spel met verschillende deelnemers betekent direct en variëteit aan agenten. In de spelsessies observeren we dat spelers een gemeenschappelijke taal en communicatie protocol ontwikkelen om het project te coördineren in het spel. Ten tweede observeren we dat de spelers zich continu aanpassen aan nieuwe situaties en gebeurtenissen. Ten derde zijn er verschillende aanwijzingen van netwerkdynamiek en evolutie gevonden. Het havengebied is ontwikkeld, nieuwe contracten zijn gesloten en de teamstructuur werd aangepast aan de ontwikkeling. Tenslotte laat de speluitkomst een grote variëteit aan havengebieden met verschillende financiële situaties zien als gevolg van de beslissingen van de spelers. Op basis van de analyse van de beslissingen en uitkomsten van de spelsessies kunnen we concluderen dat SimPort-MV2 een complex adaptief systeem simuleert.

Het Complex Adaptieve Systemen raamwerk is gebruikt om het gesimuleerde gedrag over de jaren te verklaren. De teams vertonen zelforganiserend vermogen, bijvoorbeeld te zien in de structuur van de processen. De constructie van het gebied en exploitatie van het gebied illustreren de karakteristieken en consequenties van padafhankelijkheden. Gebaseerd op de uitkomsten van het spel concluderen we dat de planning zoals voorgesteld door het Havenbedrijf Rotterdam mogelijk is onder normale omstandigheden. Echter, de speluitkomsten laten ook zien dat de directe inkomsten en winst van Maasvlakte 2 erg onzeker zijn en afhangen van de hoeveelheid gecontracteerde klanten. De financiële uitkomsten na 30 jaar is gevoelig voor de gekozen bouwstrategie en economisch klimaat, in het bijzonder wanneer de economie verslechterd in de bouw- en exploitatieperiode. De uitkomsten zijn robuust voor de commerciële strategie en vlekkenplan, omdat deze flexibelere zijn. Daarnaast is het een uitdaging om de constructie en exploitatie gesynchroniseerd te laten lopen.

Miscommunicatie tussen bouwdirecteuren en commerciële directeuren leiden tot conflictsituaties en vertragingen in het proces.

Deze resultaten van SimPort-MV2 laten zien dat gaming gebruikt kan worden voor het simuleren van verschillende paden in de toekomst en om het emergente gedrag en andere kenmerken op de systeemlaag te analyseren, om netwerkdynamiek te laten zijn en om de inzicht in het gedrag van adaptieve agenten te verhogen.

3. Serious gaming as leerinterventie

Het spel SimPort-MV2 lijkt een succesvolle interventie als we kijken naar het enthousiasme van de spelers en de positieve atmosfeer tijdens de sessies. Echter dit zegt niets over de leereffecten.

De leerresultaten laten zien dat SimPort-MV2 bijdraagt aan het begrijpen van de complexiteit van het Maasvlakte 2 systeem. Meer specifiek, de deelnemers vergroten hun kennis over Maasvlakte 2, kregen meer inzicht in de commerciële en strategische complexiteit, toekomstbeeld van de Maasvlakte 2 en het belang van het integreren van de commerciële aanpak en bouwprocessen. Tenslotte waren de deelnemers het eens dat het spel samenwerking en communicatie tussen verschillende afdelingen van het Havenbedrijf konden promoten. Mindere leerresultaten werden gevonden bij de algemene noties en vaardigheden van complex adaptieve systemen en over de technische complexiteit.

Uitgezonderd de toegenomen kennis over Maasvlakte 2, scoorden de professionals gelijk of hoger op de leerindicatoren gerelateerd aan Maasvlakte 2 dan de studentdeelnemers. Dit illustreert dat serious gaming is niet alleen een waardevolle interventie in het formele onderwijs, maar dat gaming in een professionele setting ook leidt tot meer inzichten in de dynamiek van het systeem. De professionals waren het ook eens dat deze gaming methodes bruikbaar kunnen zijn als een verkenning van alternatieven en als een discussie ondersteunende tool in het beleids- en besluitvormingsproces.

Correlaties laten zien dat de leeruitkomsten voornamelijk beïnvloed worden door betrokkenheid van de spelers tijdens het spel. Andere relevante factoren zijn de verwachtingen over de waarde van serious gaming, de relevantie van het onderwerp van het spel voor de speler. De betrokkenheid wordt onder andere beïnvloed door de persoonlijke interactie tussen de spelers, de leervoorkeuren van de spelers en de kwaliteit van de interfaces. Deze factoren beïnvloeden dus indirect de leeruitkomsten. De facilitatie en kwaliteit van het spel zijn belangrijk. Dit betekent dat alleen het spelen van een spel niet noodzakelijk tot de gewenste effecten leidt. Verder blijkt dat gaming als leerinterventie niet voor alle studenten en professionals de voorkeur heeft.

Toekomstig onderzoek

Dit onderzoek draagt bij aan de verkenning van het gebruik van serious gaming voor het begrijpen van infrastructuren. Echter de beperking van één spel voor het testen van deze relatie is niet voldoende om tot algemene conclusies te komen. Het spel is nog niet over, maar we zijn klaar voor het volgende level. In het volgende level kan het onderzoek zich focussen op verschillende onderwerpen.

De eerste mogelijke onderzoekskant is de ontwikkeling van onderzoeksmethoden en -tools voor het meten van leereffecten en het analyseren van het systeemgedrag. Wanneer we de impact van games op lange termijn of verschillende type games met elkaar of andere interventies willen evalueren, moeten er nieuwe methodes en tool ontwikkeld worden zodat betrouwbare data verzameld kan worden.

Een tweede onderzoeksrichting is gerelateerd aan de eerste, maar vooral gericht op gaming in beleidsprocessen. Games kunnen de kennis en inzichten in het systeem vergroten, maar dan is het nog steeds de vraag of dit het beleids- en besluitvormingsproces beïnvloedt. Om deze effecten te meten hebben we andere onderzoeksmethodes nodig dan hier gepresenteerd.

Ten derde hebben we meer onderzoek nodig naar het effect van serious gaming in andere infrastructuursectoren, zoals elektriciteit en transport, en andere type problemen, zoals capaciteitstekorten of over veranderde markten. Vragen deze sectoren en problemen andere tools voor het verbeteren van het inzicht en wat is de rol van dynamische simulaties en visualisatie?

In de vierde plaats kan additioneel onderzoek worden gedaan naar het verbeteren van het ontwerpen van spellen om complex adaptieve systemen te simuleren. Dit onderzoek geeft enige relevante variabelen maar deze kunnen nauwkeurige worden onderzocht en het ontwikkelproces en uitkomsten verbeteren.

CURRICULUM VITAE

Geertje Bekebrede was born on 2 June 1979 in Koog aan de Zaan (The Netherlands). She completed secondary school (VWO) at the St.-Michaëlcollege in Zaandam. She subsequently studied System Engineering, Policy Analysis and Management at Delft University of Technology. As part of her study she did a three-month internship in Bangladesh about the role of the public in solving the problem of arsenic contaminated drinking water. She did her master thesis at WL/Delft Hydraulics, which is now part of Deltares, in Delft. She participated in a project about the drought in The Netherlands. Her master thesis focused on increasing the participation of involved actors by tools which inform actors about the urgency of the problem. During her study, she was student assistant at the Policy Analysis section in the field of System Dynamics.

After graduation in 2002, she started as a teacher at the Policy Analysis Section, Faculty Technology, Policy and Management, Delft University of Technology. In this period she continued her work in the field of System Dynamics and policy analysis in multi-actor systems. Between 2004 and 2010 Geertje was a PhD student at the Policy, Organization, Law and Gaming Section at the same Faculty. The topic of her thesis was understanding the complexity of infrastructure systems with serious gaming. Besides her involvement in the design and evaluation of the SimPort-MV2 game for the Port of Rotterdam, she was involved in several other game design and research projects.

Currently, she is an Assistant Professor at the Policy, Organisation, Law and Gaming Section, Faculty Technology, Policy and Management. Furthermore, she is the chair of the board of the Dutch Simulation and Gaming Association SAGANET.

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