User simulation of space utilisation : system for office building usage simulation

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User Simulation of Space Utilisation

System for Office Building Usage Simulation

PROEFSCHRIFT

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Preface

This thesis is the result of five years of researching, developing and testing a system called USSU, short for User Simulation of Space Utilisation. The aim of this research project was to develop a system that can be applied for analysing and evaluating the space utilisation of a building for any given organisation. This project focussed on the simulation of human activity behaviour in office buildings, as the lives of many people are affected by the design of office buildings. Research is still poor on the complexity of normal day-to-day, human activity and movement behaviour in buildings. Knowledge of real, dynamic behaviour of occupants of office buildings is limited. A system for (office) building simulation that produces data about activities of members of an organisation can improve the relevance and performance of building simulation tools. If reliable human movement models can be created, then these models can not only be used to analyse existing situations, but also to simulate new building designs taking the digital design as input. This is also relevant for architects to evaluate the performance of a building design.

This research project was started in June 2003 and was completed in October 2008. It was embedded in the Design and Decision Support Systems (DDSS) programme implemented by the chair of Urban Planning and the chair of Design Systems of the faculty of Architecture, Building, and Planning of the Eindhoven University of

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C1 **Introduction**

1.1   Introduction

Activity and location schedules are input for building simulations (e.g. building performance simulation or evacuation simulation). These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Therefore a more advanced scheduling method is needed that adequately represents real-life complexity of human activity and location schedules. In the research project User Simulation of Space Utilisation (USSU), a system has been developed that produces detailed data about activities of members of an organisation for accurate building performance evaluation. This first chapter provides an introductory discussion of the undertaken research reported in this thesis. It treats the motivation,

research objectives and questions of the project. Next, the research method and relevance are discussed. Finally the structure of the thesis is explained.

1.2   Motivation

In the building industry and in building related research, people are motivated by the possibilities of analysing the performance of a building design before it is constructed (e.g. with regard to the indoor comfort level or overall code compliance). Building simulation is a commonly used method for predicting the behaviour of buildings. It is the most widely used approach to assess the performance of a building before its construction (Tianzhen et al., 2000). Simulation is adopted for its possibility to reproduce (certain) physical behaviour of a building. Increasing computer power, better algorithms and better calibrated models make it possible to simulate physical processes at a more detailed building level in shorter periods of time (Hensen, 2004).

In research and practice, different definitions are used for the simulation of the behaviour of buildings, such as building simulation, building performance analysis and building performance simulation. It is sometimes unclear what is exactly meant with these definitions as they are used in various contexts. To prevent any confusion the term building simulation will be applied throughout this thesis. This refers to the simulation of any given physical process that occurs within (or in close proximity) of a building, with a focus on processes related to human (activity) behaviour. Building simulation includes topics from research areas as building performance simulation and evacuation simulation (see chapter two).

Building simulation is relevant for engineers, in domains like building physics or structural engineering, as well as for designers, like architects. By simulation a designer can find out what the consequences of his design decisions are on the performance of the building. According to Raymond and Cunliffe (1997): "*What kind of office we need depends on what we do*". Furthermore, a designer also has the possibility to analyse and compare different design alternatives. In this way, simulation can make the design process more efficient (de Wilde, 2004), which leads to more optimal, cost effective designs.

Therefore it is not surprising that building simulation is now an integral part of the building process. Many simulation tools are available and their usage is considered commonplace by engineers (Soebarto and Williamson, 2002; Augenbroe, 2001). There are however some drawbacks to the current available simulation tools and their usage. One drawback is that there are no applications of building simulation which involve the usage of the building by its occupants. The available building simulation tools do not deal with the activities users perform at a certain time (Zimmermann, 2003) and with the resulting movement through space and utilisation of space. At best these tools rely on assumptions referring to human behaviour, for example in the case of thermal load calculations (Nicol, 2001). In building physics, behaviour research is mainly focussed on control-oriented user behaviour, i.e. the interaction between the occupants of a building and its controls, like windows, lights and heating systems (Hunt, 1978; Fritsch et al, 1990; Zimmermann, 2006; Mahdavi, et al., 2008). To extend the knowledge about user control behaviour, with as final goal to incorporate this knowledge in building information

systems, Japee and Schiler (1995) propose a post occupancy analysis for extracting patterns of user control behaviour. Nicol (2001) suggests the usage of stochastic models of occupant behaviour as starting point for developing sound building control systems.

1.3   Research objective and questions

The main goal of this research project was:

To develop a system that can be applied for analysing and evaluating the space utilisation of a building for any given organisation.

This project focussed on the simulation of human activity behaviour in office buildings. The lives of many people are affected by the design of office buildings. According to van Meel (2000):
"The office building (…) is perhaps the most important building type of the 20th century. (…) Offices are all around us. They dominate the contemporary city and accommodate more than half the working population in the Western world. Because of their significance, offices have recently received much attention in both research and practice."

From the point of view of building simulation, an office building is also one of the key buildings types. Research in the area of building simulation is not limited to office buildings, other buildings types like hospitals (Meldhado et al., 2005) or elements of the built environment like infrastructure (Boer and Veldhuijzen van Zanten, 2005; Sun and de Vries, 2006) are also investigated. However, many research projects are focussed on offices; the same applies for the development and application of building simulation tools in practice. This all together makes office buildings an interesting and relevant building type for a system that evaluates space utilisation in relation to human activity behaviour. Buildings like an enterprise building or a university staff building are instances of the office building type; the latter is applied in this thesis to illustrate the theory behind this research project and to validate the developed system.

In order to realise this objective, research focussed on the following research questions:
1. Human activity behaviour in office buildings is complex. It comprises different types of activities and various factors influencing these activities.

   ➔   Which types of activities should be taken into account and what are the relevant attributes?

2. Related to the previous question is the matter of how to combine the different types of activities into one approach for modelling the activity behaviour found in organisations.

   ➔   What is the modelling approach to simulate human activity behaviour in (office) buildings?

3. Finally the accuracy of a system for predicting the space utilisation of an organisation warrants investigation.

➜ Is it possible to develop a system that takes into account the various aspects perceived as essential in the modelling approach and that provides realistic human activity behaviour output?

1.4   Research approach

To understand the complexity of the behaviour of people in the built environment, with a special focus on office buildings, research initially focussed on reviewing literature from divergent research fields, ranging from ergonomics to environmental psychology and space syntax. In relation to the second research question different approaches for modelling human behaviour with regard to the simulation of realistic user behaviour of the utilisation of buildings were examined. Human behaviour research in context of building simulation has common ground to topics in the research area of pedestrian behaviour simulation as well as to topics in the research areas of activity based modelling and workflow modelling. Based on the literature review a modelling approach was formulated to simulate human activity behaviour in office buildings (see Figure 1.1). This approach also details the way in which the building space is modelled.
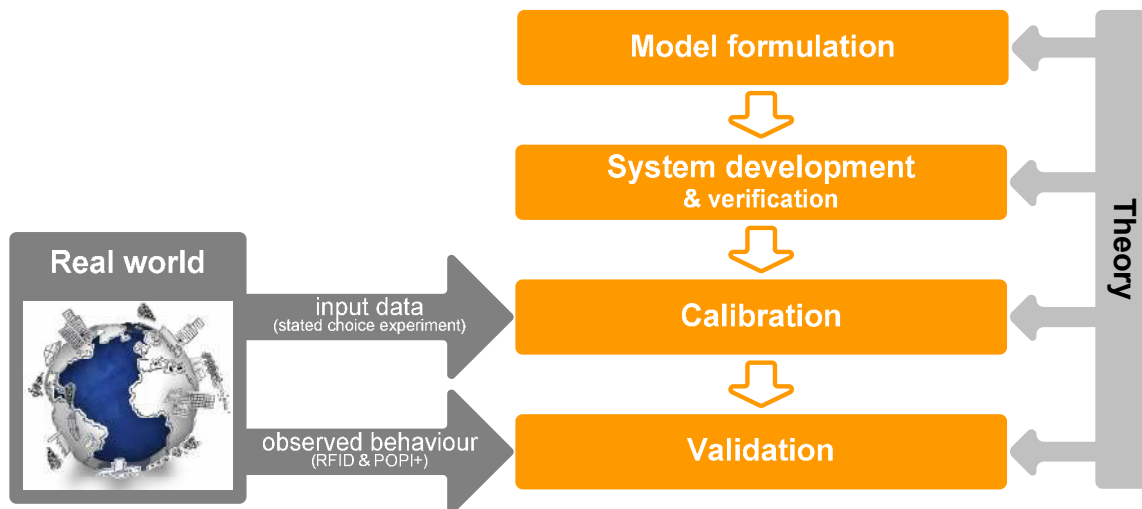
Figure 1.1: Research approach.

Next, based on the modelling approach the USSU system was developed (see Figure 1.1). An extensive process of software design, including Unified Modelling Language (UML) use cases and class diagrams (Fowler and Scott, 2000), resulted in a detailed system design detailing the various sub-systems. To determine the accuracy of this system in predicting the space utilisation of an organisation, a prototype was implemented with the detailed system design as guideline. Verification formed an integral part of the implementation of the prototype; verification was applied to check whether or not the various sub-systems and algorithms were correctly implemented. The prototype formed the basis for validating the USSU system.

Before the USSU system could be validated, a comprehensive data collection was required in order to calibrate the USSU prototype (see Figure 1.1). The prototype relies on detailed input information about the (workflow of the) organisation and the spatial conditions in which its members perform their activities. This meant that data had to be collected about the organisation and building which were chosen for the validation of the developed system.

Next, to validate the predictions of the prototype data was collected about real human activity behaviour in an office building (see Figure 1.1). For the validation of USSU two approaches were followed, namely comparison with activity diaries and tracking movement in space. To assess the validity of the system, the predicted space utilisation was compared with the observed space utilisation on a set of performance indicators, so-called criterion variables. These criterion variables (e.g. the usage of facilities or movement behaviour of employees) specify the aspects on which the comparison of the observed and predicted activity schedules was performed. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees.

1.5   Research relevance and contributions

A system for building simulation that produces schedules containing data about activities of members of an organisation can improve the relevance and performance of building simulation tools. Scheduling can be defined as the organisation of activities that consume time and other resources, like labour, money, etc. The methods that are found in literature supporting scheduling processes apply a network representation (Eiselt and Sandblom, 2004). Usually in such a network the nodes represent the activities and the arcs the relations or dependencies. In a PERT (Program Evaluation and Review Technique) network uncertainty about the duration of an activity is added. Another extension is the incorporation of (limited) resources to execute the activities. The most important outcome of such network analyses is the well known critical path. Furthermore, linear programming techniques can be applied to search for optimal resource consumption. Another approach to scheduling is the application of Genetic Algorithms to generate schedules and select those with the highest fitness given the set of resources (Beddoe and Petrovic, 2004; Ingolfsson et al., 2000).

In this research project, however, scheduling has not an analyses or optimisation objective, but it is the process of generating schedules. More specifically schedules that provide a realistic representation of human activities that are executed in building spaces. These activity schedules are a source of dynamic input data for building usage simulation tools. However, reliable data on human movement in buildings is scarce. Existing human movement models are typically developed for (semi) public spaces, which lack applicability for indoor spaces. Data on human movement is valuable input for several research areas. For instance, the relevance and performance of building simulation tools like indoor climate simulations or working conditions assessments will substantially improve when realistic input data is applied. The USSU system serves as a pre-processor for simulation systems that need real-life data about the location of people at a specific time. It allows building simulation systems to be executed with much more

reliable data, reflecting the actual use of a building. If reliable human movement models can be created, then these models can not only be used to analyse existing situations, but also to simulate new building designs taking the digital design as input. This is also relevant for architects to evaluate the performance of a building design.

The main scientific contribution of this research project is the development of a system that can be used for analysing and evaluating the space utilisation of a building for a certain organisation. Most existing approaches to model activity schedules assume an individual-based decision making process. These models do not take into account the interaction between individuals. A special feature of the USSU system is the incorporation of interaction between activities (e.g. meetings). Another, innovative feature of the USSU system is its modular design which makes it easy to extend, maintain and modify. The modular design also supports comprehensive testability: the effects of additions and/or replacements of modules can be analysed in detail.

The usage of state-of-the-art RFID technology for the validation of a simulation model like USSU is another contribution of this research project. Currently, RFID technology is used by some Dutch organisations for access control and as a means of working hours registration, but up to now never on the detailed level as was used in the validation of USSU. RFID technology allows for a non-obtrusive way of collecting data about human movement. People only have to carry a small device (so-called RFID tag), for example in their wallet, and the RFID system automatically registers their movements. RFID makes it possible to track the movements of all participants across the floor and thereby to collect data about the real movement behaviour of the participants.

1.6   Thesis outline

This thesis is organised into three parts, namely theory, prototype and validation. Part one concerns theory in relation to this research and consists of four chapters. The second part of this thesis comprises two chapters and discusses the design and implementation of a prototype that was based on the modelling approach as discussed in part one. The final part treats the validation of the developed prototype and the conclusions that can be drawn from this research project. It contains five chapters.

1.6.1   Part 1: Theory

Chapter two provides an introduction to building simulation. It gives a description of the current application of building simulation and related drawbacks. Chapter three provides an in-depth description of human (activity) behaviour in office buildings. Attention will be paid to several factors influencing human behaviour and to a taxonomy of activities. It will also identify processes which are to be modelled in this research project to (realistically) simulate the space utilisation of office buildings for any given organisation. Chapter four discusses different approaches for modelling the human (activity) behaviour. It gives an overview of each of these approaches as well as a description of their relevance for modelling human behaviour in relation to office buildings. Chapter five describes the formulated approach for modelling human activity behaviour in office buildings.

1.6.2 Part 2: Prototype

Based on the modelling approach a detailed system design of USSU was created. This will be discussed in chapter six. Attention will be paid to the structure of sub-systems comprising the system. Next, chapter seven discusses the implementation of a prototype based on the system design. It will explain how the prototype was implemented and in which way the prototype can be applied to predict the space utilisation of an organisation housed in an office building.

1.6.3 Part 3: Validation

Chapter eight focuses on the validation method. It describes the test case chosen for the validation of USSU, how the validation is performed and how the goodness-of-fit is determined. Chapter nine details the calibration of the USSU prototype in relation to the chosen test case; it treats the comprehensive data collection which was performed in order to calibrate the prototype. Next, chapter ten discusses how the real human activity behaviour was observed. This chapter unfolds the two experiments which were performed for assessing the predictive quality of the USSU system in context of a real building, organisation and actual human behaviour. Then, chapter eleven presents the results of the validation. Finally, chapter twelve completes this thesis; it draws conclusions and highlights recommendations for possible future research.

PART 1 THEORY

C2 Building simulation

"The problem with user preferences and activities is the large range of possible actions and reactions due to the differences between the persons involved. Therefore, engineers tend to eliminate the influence of users as far as possible to optimize building performance. This leads to assumptions about average user preferences and behaviors. Especially in the case of control systems the current reality is fully automated systems without interaction based on average users " (Zimmermann, 2006).

2.1 Introduction

During the last three decades many different building simulation tools have been developed, for instance in the field of building performance simulation; see Hong et al. (2000) for an overview of the current diverse range of available simulation performance tools. However, building simulation is also applied to other fields, for example to model evacuation dynamics (see section 2.3) and for code compliance checking (see section

2.4). The current available simulation programs share a number of shortcomings, which influence their application in the construction industry (see section 2.5). They are mainly applied to code compliance checking and in little extent to design optimisation. More related to this research project, building simulation programs do not deal with activities performed by building occupants and with the resulting utilisation of space and movement through space. At best these tools rely on assumptions referring to human behaviour. The last section of this chapter reflects on the current application of building simulation programs, theirs shortcomings and relevant research trends.

2.2   Building performance simulation

"Building performance simulation (BPS) is a powerful tool which emulates the dynamic interaction of heat, light, mass (air and moisture) and sound within the building to predicts its energy and environmental performance as it is exposed to climate, occupants, conditioning systems, and noise sources" (Crawley, 2003).

In the early 1960s the roots of building performance simulation were founded on research being performed on energy transfer in buildings and on methods to predict the consumption of energy in the built environment. Since then the field continually has been maturing and expanding. The reasons for the growing interest in and application of building performance simulation were (and still are) manifold and not in the last place due to (external) factors like the oil crisis of the 1970s. The dependence of the (western) world on oil was made dramatically clear by the oil embargo of 1973. One third to even almost half of our primary energy supply is consumed in buildings (Schmidt, 2005; Sahlin et al., 2004). By designing energy efficient buildings, for instance by using energy saving building components (de Wilde, 2004), substantial energy savings are possible. The question was (and is): how to increase the energy efficiency of buildings? To do so new algorithms were developed to calculate heating and cooling loads and for the simulation of energy transfer in buildings.

Although people more and more lost interest in achieving energy efficient buildings after the 1970s, the introduction of desktop computers made it possible to simulate physical processes at a more detailed building level in shorter periods of time (Hensen, 2004). At the same time building simulation became available for a wider audience than before. Programs that originally were developed and maintained on mainframe systems could now be executed on personal computers. However, the majority of the building simulation programs were not widely applied in practice, mainly because these programs were (too) complex in use; most of these programs were designed to be used by researchers (see section 2.5).

As a result of the growing global concern for environmental issues during the 1990s, the field of building performance simulation regained interest. People started to worry about the enormous usage of fossil fuels by industry and housing. Designers started to strive for buildings which combine a good thermal comfort with low energy consumption and with minimal impact on the environment. The debate for sustainable, 'green' buildings caused buildings to become ever more complex. This was also influenced by the growing possibilities of the CAD (Computer Aided Design) software, which made more extreme architecture possible, like free form design. Predicting the energy and

environmental performance of buildings became more of a challenge with increasing building complexity. According to Tianzhen et al. (2000):
"The demand of 'green' buildings has made the application of building simulation a must, rather than a need".

The renewed concern about environmental issues and the growing emphasis on human comfort aroused interest in the performance based design approach. Instead of specifying the minimum criteria (e.g. budget constraints, functional requirements, safety regulations or energy codes) for a building, performance goals are developed in the early phases of the design project. These goals are the guidelines for the design process and are to be observed by all partners involved in the project, so that in the end a building performs as desired. According to Deru and Torcellini (2004):
"You get what you ask for. When there is a clear vision of the desired outcome, which is broken down into objectives and goals, there is a greater chance for producing a high-performance building".

Hien et al. (2005) suggest that building performance simulation can play an important role in reaching these goals and in measuring the success of a project.

There are several popular applications of building performance simulation, such as:

- (dynamic) Thermal load calculation.

  The calculation of peak building heating and cooling loads. These loads can among other things be used for selecting the right heating, ventilation and air conditioning systems (Crawley et al., 2001; Corgnati et al., 2008).

- Computational fluid dynamics (CFD).

  Originally used by the aerospace industry to predict airflows across an airplane wing, it is also applied in the building industry for predicting airflows in building spaces and for analysing wind flows around buildings (Zhai, 2006; Djunaedy et al., 2005; Bartak et al., 2002; Liu et al., 2004) .

- Interior lighting and acoustics simulation

  The interior lighting and acoustic conditions of buildings are influenced by many factors, e.g. room/window configuration, building orientation and internal finishes. This makes predicting the interior lighting levels (e.g. daylight level) and acoustics (e.g. reverberation time) rather difficult (Daniel et al., 2004; Citherlet and Hand, 2002; Kima and Kimb, 2007). So, not surprisingly, there is a variety of building performance simulation programs intended for simulating the indoor lighting and acoustic conditions, for instance Radiance for analysing and visualising the lighting conditions of a design (Ward, 1994).

In the research field of building performance simulation different research trends are observable. For example:

- Development of advanced behavioural models.

  In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Research is now mainly focussed on improving the prediction of the interaction between occupants and environmental controls (e.g. the operation of

lighting, window, heating/cooling and shading systems). See section 2.5 for a more in-depth discussion of this research trend.

- Making building performance simulation available and applicable in all phases of the design process, not only in the later design phases.

  Currently, building performance simulation is mainly applied in the later design phases. However, it are the early design phases where the impact of design decisions on the course of the design process, as well as on the performance of the building (design) is biggest. Building performance simulation programs should play an important role in the early design process. Struck et al. (2007) discuss research to improve the usefulness of building simulation programs in the early design phases.

- Improving the interoperability between the available simulation tools.

  A design project is normally a complex, multidisciplinary process. Each involved discipline uses its own set of applications (e.g. CAD software or building simulation tools). Generally, each application has its own model and format to store data. Consequently, the interoperability between applications is still quite limited. The development of a neutral data model for describing and exchanging building data could seriously improve the interoperability. An example of a neutral data model is IFC (Industry Foundation Classes) which receives much attention throughout the field of building research (O'Grady and Keane, 2005).

- Using the opportunities supplied by internet for building performance simulation.

  The internet offers a lot of opportunities to develop services like information exchange, distributed simulation and web hosted simulation (instead of traditional desktop simulation).

2.3   Evacuation simulation

"Evacuation is the process in which the people present in a building notice a fire and whereupon they experience several mental processes and carry out several actions before and/or during the movement to a safe place in or outside the building" (Kobes et al., 2007).

Evacuation simulation is applied to analyse human behaviour in the built environment under emergency situations, like fire accidents. Research in the field of evacuation simulation, including human behaviour in (fire) emergency situations and fire (protection) engineering, focuses on buildings of all types and sizes, ranging from residential buildings (Brennan and Thomas, 2001; Yung et al., 2001) to football stadiums (Klüpfel, and Meyer-König, 2005; Moldovan et al., 2007). This research area also deals with evacuation processes of infrastructures (Boer et al., 2005) and transportation systems, like airplanes (Galea et al., 2003), trains (Oswald et al., 2007) or ships (Klüpfel et al., 2000).

Research on evacuation behaviour started in the beginning of the 20th century (Bryan, 1999). The 1970s and 1980s were the most productive decades for research on human behaviour in fire situations, at least in the USA. Research is still abundant in the area of evacuation simulation. On the one hand ongoing research is influenced by the quest to understand human behaviour during large disasters like the 2001 world trade centre

evacuation (Averill et al., 2007; Galea et al., 2007) or the fire accident at a dance party in Gothenburg in 1998 (Bengtson et al., 2001). By analysing these tragic incidents researchers aim to improve their understanding of human behaviour in emergency situations for better (fire) safety designs. On the other hand research is brought on by the recent interest in performance based codes. Nowadays most (inter)national building regulations and codes, for instance the Dutch Building Regulation (Bouwbesluit, 2006), specify that a building design should allow all occupants to safely evacuate a building or to reach a safe place inside the building, with none or only small injuries (O'Connor, 2005). Performance based codes caused an increased interest in, and application of, computer based evacuation models. According to (Bryan, 2002):

"The worldwide movement toward performance codes has created a demand for computer evacuation models that will provide an estimate of the evacuation time for a building".
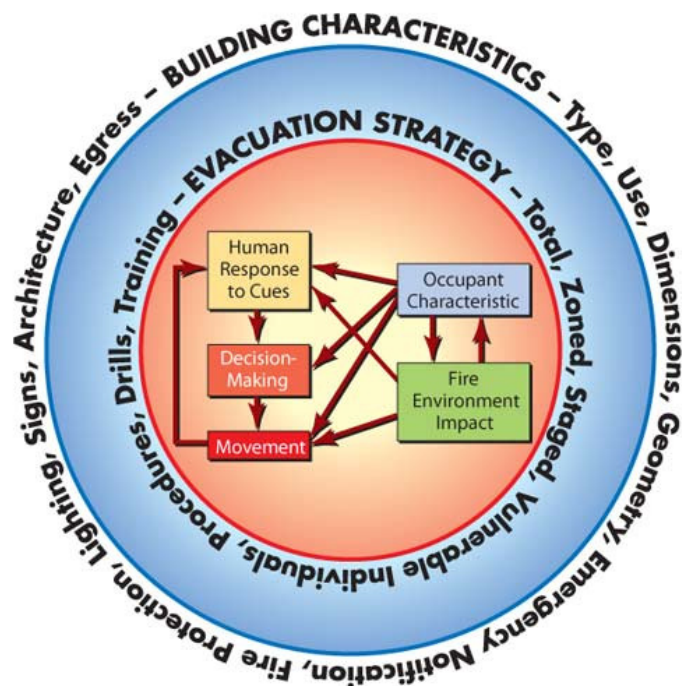
Figure 2.1: Context for human behaviour (O'Connor, 2005).

Like most other applications of building simulation, the application of evacuation simulation is anything but simple. Human behaviour in fires is complex and still not completely understood (Chu et al., 2007). According to Proulx (2001):

"The occupant behaviour varies according to three major elements; a) the occupant characteristics, b) the building characteristics and c) the fire characteristics. These three elements interplay in the whole development and outcome of the event".

O'Connor (2005) uses the same three elements to categorise all factors related to human evacuation behaviour, but he adds a fourth element, namely the evacuation strategies and procedures (see Table 2.1). The building characteristics and evacuation strategy form the basis for analysing human behaviour in fire (see Figure 2.1). These two factors are normally easily identified and understood. Accurately predicting the responses and behaviour of people in emergency situations is what makes evacuation

simulation complex and difficult. The evacuation process is governed by the interrelationship of three human processes, namely human response to clues, decision making and occupant movement. The evacuation process can be divided into two main phases, namely the pre-movement phase and the movement phase. The pre-movement phase is influenced by clue validation and overlapping decision making processes. The pre-movement phase starts when the first fire related clues have originated and lasts until people take the decision to move (BSI, 1997). The duration of the pre-movement phase is called the pre-movement time, which is composed of:

- Recognition time

  The time it takes to become aware of a dangerous situation by external stimuli (i.e. clues).

- Response time

  The time it takes to validate fire related clues and make decisions with regard to these clues.

Building characteristics	Evacuation strategy/procedures
Building type and use	Total, zoned, or staged evacuation
Physical dimensions	All or few occupants trained or drilled in procedures
Geometry of enclosures	Provisions for those with special needs - infirm, disabled, incarcerated
Number and arrangement of means of egress	Frequency of training or drills
Architectural characteristics/complexity	Who is trained or drilled
Lighting and signage	Defend-in-place
Emergency information systems	Relocation
Fire protection systems	

Occupant characteristics	Fire environment
Population and density	Smoke and toxic gases
Individuals alone or in groups	Temperature
Familiarity with building	Visibility
Distribution and activities	Transport, exposure, duration

Table 2.1: Factors and considerations in human behaviour analysis (O'Connor, 2005).

In the last decades research predominantly focussed on the movement phase. The overall goal was to realistically model the movement of people towards exits in emergency situations, based on methods like way finding or route choice behaviour. It was assumed that people immediately started moving to a safe place when they detected a fire or heard a fire alarm. Meaning that if it was possible to determine the movement time (i.e. the time it takes for people to leave the building after deciding to move) one would know the total evacuation time. In other words, the pre-movement time was thought to be zero. However, research revealed that this assumption was erroneous (Fahy and Proulx, 2001). In most cases, it takes considerable time before people make the decision to leave their workplace and start moving to the nearest safe place. People either do not hear the fire alarm, tend to ignore fire alarms and/or wait for other people to respond first before they respond themselves (Proulx, 2000). Nowadays

the common perception is that the movement time is only a part of the total evacuation time (see Figure 2.2). Several research projects focussed on the pre-movement phase (Brennan, 1997; MacLennan et al., 2003; Olsson and Regan, 2001).
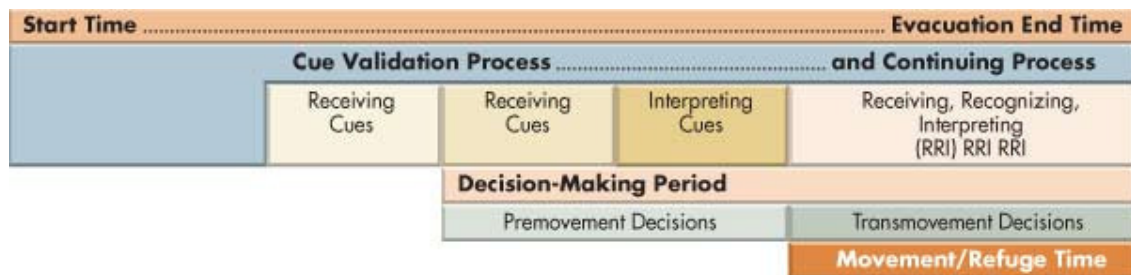
Figure 2.2: Composition of the evacuation time (SFPE, 2003).

Although human behaviour in fires is still not completely understood, evacuation simulation is not only a research topic, but it is also subject to application developments, like buildingExodus (Gwynne et al., 2001) or PedGo (Klüpfel at al., 2003).

2.4   Other applications of building simulation

One area, in which building simulation is applied, is structural engineering. In this area researchers are among other things interested in the performance of a building as a result of wind loads on its facades. This applies to:

- Collapse prevention.

  To confirm that a building can withstand wind forces, for instance caused by hurricanes, as described in building regulations (Wen, 2001).

- The day-to-day usage of a building.

  The movements of a building, caused by for instance wind, should not exceed certain values as the comfort of humans is concerned (Chan and Chui, 2006).

An example of the application of building simulation programs for code compliance checking is the analysis of the behaviour of a building with respect to earthquakes (Ellingwood, 2001; Çokcan et al., 2007). More related to the normal usage of a building is the application of building simulation for code compliance checking in relation to working conditions regulations (Working Conditions Act, 1999) in terms of:

- Safety: no acute dangers.
- Health: no long term physical health risks.
- Wellbeing: no psychological problems.

Much research has been performed to automate the process for building code compliance checking and to make it more accessible for the general public (van Leeuwen, 2004, Han et al., 1997, Yang and Li, 2001).

2.5   Shortcomings of building simulation

Building simulation is now an integral part of the design process. There are many simulation tools available and their usage is considered common practice by engineers (Soebarto and Williamson, 2002; Augenbroe, 2001; Hong et al., 2000). However, there are a number of shortcomings with respect to the current available simulation programs and their application.

The main shortcoming of building simulation with regard to this research project is that there are no building simulation programs which take into account the actual usage of a building by its occupants. According to Robinson (2006):

"By far the most complex processes taking place within buildings are those that results from human behaviour - we are intrinsically unpredictable animals. Moreover, these interactions have important implications for a building's energy balance, affecting both the indoor microclimate and the demands for applied energy. (…) Both the presence of people and these interactions are handled in entirely deterministic ways (if at all) in current simulation programs; typically based on some predefined schedule".

The available building simulation programs do not deal with activities performed by building occupants and with the resulting utilisation of space and movement through space (Zimmermann, 2003). At best these programs rely on assumptions referring to the human behaviour. The most advanced form of input in building simulation programs with regard to occupant presence are so-called diversity profiles (Abushakra et al., 2001). These profiles represent the combined behaviour of all occupants of a building. A diversity profile describes the presence of occupants and (for instance) the corresponding lighting loads (see Figure 2.3). Diversity profiles are assumed to be fixed for all (working) days. In other words, there is no variation in for instance presence between the simulated days. However, different diversity profiles can be applied for weekdays and weekends. Diversity profiles have several drawbacks. They are derived without taking the weather patterns into account. As a result the profiles can only be used in situations where the occupancy and (manual) control behaviour do not depend on the outdoor climate (e.g. in case of large, core office zones) (Bourgeois, 2005). Furthermore, temporal variations (e.g. differences between workdays and seasonal habits) are not taken into account (Page, 2007).
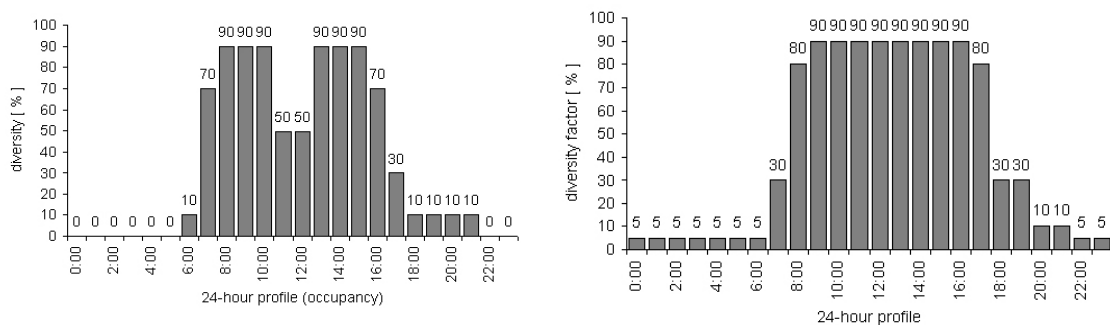
Figure 2.3: Diversity profiles, occupancy (left) and lighting (right) (Bourgeois, 2005).

In the field of building performance simulation, behaviour research is mainly focussed on control-oriented user behaviour, i.e. the interaction between the occupants of a building and environmental controls, like windows, lights and heating systems (Hunt, 1978;

Fritsch et al, 1990; Nicol, 2001; Zimmermann, 2006; Mahdavi, et al., 2008). If the occupancy of people is modelled, than this is mostly based on stochastic processes, such as Markov chains (Page, 2007; Yamaguchi et al, 2003) or Poisson distributions (Wang et al, 2005). According to the latter, the movement/activity behaviour of office building occupants is a random process. Although people may work according to a schedule, the resulting occupancy is random. To predict the occupancy and vacancy intervals of occupants Wang developed a truly stochastic model based on a Poisson process model. Although the vacant intervals were exponentially distributed, the occupied intervals were not. In other words, Wang was not able to reproduce the full complexity of real human presence in the built environment. Reinhart (2004) describes the development of the Lightswitch-2002 simulation algorithm. It is a sophisticated model for predicting the interaction of occupants with lighting and blinding systems. The occupancy levels are based on an adapted version of Newsham's stochastic model (Newsham, 1995). While this introduces some variability into the presence of occupants in comparison to the diversity profiles, the major part of the Lightswitch-2002 profiles are still fixed and these profiles are also repeated for all weekdays. Finally, the Lightswitch-2002 algorithm does not consider the impact of manual lighting and blind control on among other things the heating and cooling requirements. While manual lighting control will reduce the electric lighting energy demand, the overall energy performance is difficult to predict. SHOCC (Bourgeois, 2005) provides a platform for the integration of advanced behavioural models for a whole building energy simulation. SHOCC makes it possible to interface behavioural models (e.g. Lightswitch-2002) with a building energy simulation program, like ESP-r. SHOCC is a self-contained module that is responsible for controlling all occupant related events. Specifying and controlling data related to building occupants in ESP-r is a tedious, manual process. By using SHOCC all occupant data is processed and stored centrally. While it provides enhanced functionality, the sub-hourly occupancy is still based on the Lightswitch-2002 algorithm, with the above mentioned shortcomings. As SHOCC is still in development, it should be possible to add more advanced behaviour models if and when they become available.

Another shortcoming of building simulation tools is that most programs were originally not intended to be used by building designers. They were designed to be used by research scientists. Usage of these tools generally requires a steep learning curve and as a consequence these tools are mainly used by domain experts (Papamichael et al., 1997). In the literature there is disagreement upon if simulation tools should become more available and useful for the non-specialist, for example an architect (designer friendly tools approach) or if analysis should be delegated to domain experts (design integrated tools approach) (Augenbroe, 2001). In the first case a designer him/herself can perform simulation tasks, in the second case the analysis has to be somehow exported to domain experts.

Finally, building simulation tools are mainly used in the later design phases for code compliance checking, usage of simulation tools for design optimisation is limited (Hensen, 2004). According to (Hopfe and Hensen, 2006):
"Simulation tools are neither used to support the generation of design alternatives nor to make informed choices between different design options, and they are neither used for building and/or system optimization".

Hopfe et al. (2007) discusses an ongoing research project to enhance the usability of building performance simulation in the later design phases by providing the possibility of design optimisation.

2.6   Conclusions

Building simulation is considered to be common practice in the building industry. It has undergone a substantial growth both in the academic world and the building industry since its emergence three decades ago. Research in this field of building simulation is also abundant, for instance with regard to modelling the behaviour of humans in egress situations. Moreover, much research effort has been made to resolve the shortcomings of the current available building simulation programs, except for incorporating realistic activity behaviour of building occupants. Research is still poor on the complexity of normal day-to-day, human activity and movement behaviour in buildings. Knowledge of real, dynamic behaviour of occupants of office buildings is limited. A system for (office) building simulation that produces data about the activity behaviour of the members of an organisation can improve the relevance and performance of building simulation tools. This is relevant for engineering domains, like building physics, as well as for architects to analyse and evaluate the performance of a building design.

Chapter three will give a detailed description of the complexity of human activity behaviour in (office) buildings. It will among other things discuss the factors influencing human (activity) behaviour in office buildings and will identify processes which are to be modelled in this research project to realistically simulate the space utilisation of office buildings for any given organisation.

C3 Human behaviour in office buildings

"Activities are at the centre of any decision-making about the workplace. Before anyone can decide what workplace an organisation needs (…) they need to think through what should really go on in the new place" (Raymond and Cunliffe, 1997).

3.1   Introduction

Human activity behaviour in office buildings is very complex. The activity agenda of an employee is an aggregate system of different types of activities, which occur at various locations and which durations vary considerably (e.g. from 1 minute to several hours). An employee not only performs a rather large number of activities during a working day; his activities will also differ from day-to-day in terms of the order of activities and their timing (i.e. duration and start/end time). Some activities will be performed repeatedly during a day (e.g. *get a drink*), others will be performed only once in a couple of days, weeks or even months (e.g. *have an external presentation*). As a result an employee's

agenda will be different for each working day. In addition, an agenda will also differ from employee to employee. This is influenced by the role and (hierarchical) place in the organisation of employees, and their personal context.

This chapter starts by discussing the factors that influence human activity behaviour in office buildings. Each of the influencing factors will be discussed in detail, with a focus on the influence of the physical setting. Next, a description of the composition of activity behaviour is given. This description is based on a taxonomy of activity behaviour using three classifications of activities, namely planned/unplanned, solo/group and social/physiological/job related. This will be illustrated by a matrix showing the classification of several activities occurring in office based organisations. Then, the attributes of activities will be highlighted which are relevant for modelling human activity behaviour in office buildings. Finally, processes are identified which are to be modelled to realistically simulate the space utilisation for any given organisation. This chapter ends with conclusions regarding the human (activity) behaviour in office buildings.

3.2 Factors influencing human behaviour in (office) buildings

Many factors influence the behaviour of people in office buildings. The organisation which is housed in the building is such a factor. An organisation typically consists of many individuals, who each have a different role and position in the organisation. The behaviour of individuals is strongly dependent on the combination of role and place in the organisation (van der Aalst and van Hee, 2002). However, an individual's behaviour is also influenced by other factors, like physical setting and personal context (see Table 3.1).

Factor	Influence on
Organisation (role + place)	Job related activities (e.g. contact client, write report)
Physical setting	Human performance Job satisfaction Communication (social interaction)
Personal context	Non job related activities (e.g. have lunch and get a drink) Physical needs (i.e. space, light, temperature and sound) Psychological needs (e.g. interaction, privacy and personalisation)

Table 3.1: Classification of factors influencing human behaviour in (office) buildings.

In the following sections the factors influencing human (activity) behaviour in office buildings are discussed.

3.2.1 Organisation

An organisation consists of a number of roles (e.g. secretary or manager) and a number of organisational units (e.g. the sales or complaints department). In the field of sociology a role refers to the expected behaviour of an individual in a given social situation. A role should not be confused with another sociological concept, namely status. While a role defines what an individual does, status refers to someone's position and related

prestige. A definition more related to human activity behaviour simulation can be found in the field of workflow management. In workflow terminology a role is described as a group of resources that have a set of specific tasks. In business processes, supported by workflow management, production is carried out by resources. A resource is considered to be a unit of production. Basically, resources can either be classified based on their functional requirements or capabilities (role) or on their place in an organisation (organisational unit).

Example

Examples of roles are: secretary or salesperson. Each of these roles is responsible for different activities in an organisation. In most cases a secretary is not allowed to conduct activities such as *contact client* or *conduct market research*. A salesperson (normally) does not perform activities like *take minutes* at a (board) meeting.

To make sure that activities (or tasks in workflow terminology) are performed by qualified and authorised employees each activity is delegated to a certain role. In this way, a role is linked with a set of activities (i.e. tasks) and an activity can be performed by a limited number of resources (van der Aalst and van Hee, 2002). In most cases an employee has one role. However, in certain cases an employee can have two or more roles, for example an employee who is both a professor and head of an organisational unit.

Another way to look at organisations is from the viewpoint of organisational units. An organisational unit represents a similar group of people, like a department, research group or committee. It is a method for assigning resources to a certain place in an organisation. In this way, activities are performed in the right place in the organisation. An employee belongs to one or more organisational units.

3.2.2 Physical setting

The physical environment in which an organisation is housed influences the way employees perform their activities. Vice versa, human behaviour also has an effect on the physical environment. The relationship between physical setting and human (activity) behaviour is discussed in this section.

3.2.2.1 Influence on human performance

The Hawthorne studies of the 1920s can be regarded as one of the first important research projects on the relationship between physical environment and organisational behaviour and resulting performance (Sundstrom, 1986). It is one of the best known and most influential projects concerning the physical work setting. Several experiments were performed to study the effects of illumination on the output of employees assembling telephone equipment at the Hawthorne plant owned by General Electric Company. The main objective of this project was to investigate the relationship between the physical environment and productivity. However, results showed there was no evidence of a clear relationship between illumination and productivity. Apparently, productivity was influenced by other factors besides illumination such as the (motivating) effect of knowing that you are observed, the so-called Hawthorne effect.

Prior to the Hawthorne studies, researchers in the field of psychology considered people to be analogous to machines. The performance of people, like machines, was assumed to be limited by many factors; one of the factors was the physical environment. In their view the physical environment had a negative influence on the performance of all people without making a distinction between people. The effect was the same for all people. In addition, the physical environment was not considered to be influenced by human behaviour. After the Hawthorne studies, research related to the performance of employees and their environment widened. Researchers were interested in understanding the system of factors that influenced people in their working environment. A worker was no longer considered a piece of machinery, but was active and communicative. Factors that were investigated were among other things health, safety, physiological effects, and interpersonal communication and relationships. However, the physical environment was considered to be a minor factor.

The emergence of environmental psychology in the 1960s triggered a renewed interest into how people are affected by their physical environment, in terms of human behaviour, performance and health. In the field of environmental psychology, people and their environments are regarded as interdependent elements of a system which act on each other. Similar to what Winston Churchill said in a speech to the House of Commons in 1943:
"We give shape to our buildings and they, in turn, shape us" (Bonnes and Secchiaroli, 1995).

Much effort was put into understanding how people behave in a certain physical setting (Proshansky et al., 1970). According to environmental psychologists of the 1906s, there was a straightforward relationship between the physical setting and human behaviour, the so-called man-environment relations. In other words, if the physical setting is known then human behaviour related to this environment can easily be deduced. However, it soon became clear that human activity behaviour of employees varies even if their situation remains the same. Furthermore, similar activity behaviour can be observed in different physical settings.
"People did not seem to act invariantly the same in the same setting; they could adapt the same behaviour to different environments, and they could change behaviour in the same environment" (Gelernter, 1995).

3.2.2.2 Influence on job satisfaction

The physical setting not only influences the performance of an employee (and the organisation on the whole), it also has an influence on his job satisfaction. For an employee, job satisfaction describes the attitude to his job. In other words, it deals with how content employees are with their work and how their needs are satisfied. Job satisfaction is influenced by many factors, like:

- Job: level of pay, variety of tasks, responsibilities and promotional opportunities.
- Organisation: culture and management style.
- Physical environment: quality of the working conditions.

According to several theories (Maslow, 1943; Herzberg, 1972) the physical setting is one of the least important factors in the job satisfaction as an individual is concerned.

Only when the physical setting is perceived as inadequate or uncomfortable, it has some influence on job satisfaction. According to Sundstrom (1986):

"At the very least, inadequate or uncomfortable work places are associated with dissatisfaction with the environment. (…) It may gain importance to the individual's satisfaction as it leaves basic needs unfulfilled".

In these cases the physical setting works as 'dissatisfier'. This is confirmed by several surveys dealing with job satisfaction of office workers (Renwick and Lawler, 1978; Langdon, 1966). Although in all of these studies the physical setting (or working conditions) was linked with job satisfaction, it was predominantly perceived as one of the least important factors influencing job satisfaction. However, a more recent study (ASID, 1999) indicated otherwise:

"The physical workplace design ranked as one of the top three factors in contributing to job satisfaction; only daily activities and compensation ranked higher".

3.2.2.3 Influence on communication (social interaction)

There is a strong relationship between the physical environment and interpersonal communication. The proximity of workplaces influences informal communication between employees. Employees converse mainly with their closest neighbours, which sometimes results in friendships (Sundstrom, 1986; Davis, 1984). Their research showed that both conversation between two employees and their chance of becoming friends will decrease with increasing distance between their workplaces. In the case of job related (formal) communication there is no consistent relationship with interpersonal distance. Formal meetings take place regardless of the distance between workplaces.

The relationship between the physical enclosure of workspaces and both formal and informal communication is less clear. One of the premises behind the concept of open office landscape (so-called Burolandschaft) was that the open arrangement of workplaces would increase the communication between employees. It was assumed that visual accessibility would promote communication. However, according to Sundstrom (1986) studies performed on this relationship yielded mixed results. Only some studies found an improvement in communication when employees moved from a private office to a workplace in an open office space, others found no improvement. There is one exception: in the case of confidential communication there is a strong link with the physical enclosure of workspaces. Employees in open office space found it more difficult to communicate with each other on private topics. Apparently, a lack of enclosure limits the ability to hold confidential conversations.

3.2.2.4 Adaptation

The influence of the physical environment on human behaviour is dynamic as it changes with time. Modifications in the physical setting lead to changes in job performance and satisfaction. There are several processes which link environmental conditions with individual performance. These processes mostly involve short term influences. They are discussed below.

Arousal (or excitation).

Arousal relates to the general state of psychological and physiological alertness (or excitation) of an individual. The level of arousal has an influence on the performance of people, as shown in Figure 3.1. This figure also shows that the effect of change in arousal on someone's performance can either be positive or negative. If a change in arousal brings an employee into the optimal range of arousal, performance will increase, otherwise performance will decline. The optimal level of arousal for the performance of a task depends on its characteristics, mainly on the complexity. For complex tasks (e.g. writing a thesis) the optimal range of arousal is lower than for simpler tasks (e.g. reading a thesis). In other words, an excited employee can probably handle simple tasks well, but will have difficulties performing complex tasks. One of the factors influencing the level of the arousal is the physical environment. Environmental stimuli such as heat, noise or bright light can create arousal.
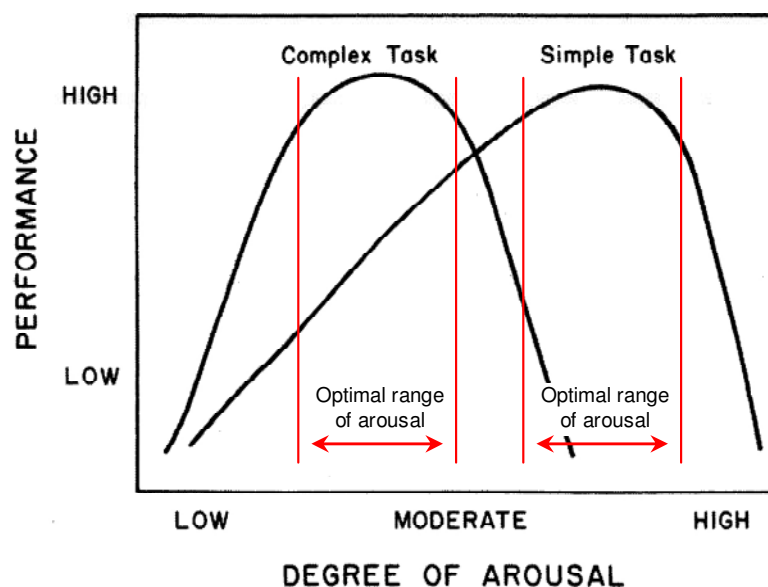
Figure 3.1: The complexity of a task and the relationship between arousal and performance (Sundstrom, 1986).

Distraction (or overload).

It is assumed that a person has a finite span of attention which he allocates to tasks according to their priority. Something distracting a person while he is performing a task, will cause a temporary lapse in his performance. It will take some time before he can fully focus on his task again. The manner in which an individual is influenced by distractions depends on his personal characteristics (e.g. some people are more easily distracted than others) and on job characteristics (e.g. complexity). If an employee struggles with performing a task, a distraction can more easily cause a lapse in performance, then when he performs a task with ease. In the latter case a distraction can even improve his performance when this distraction increases his level of arousal. The physical environment can be regarded as source of distraction. Conditions in the environment (e.g. loud noise or glaring light) can distract an individual's attention from the task he is performing.

Predicting the long term environmental effects of changes in the physical setting is difficult. To which extent these changes lead to changes in human behaviour in the long term is not well understood. One thing is clear, people will eventually adapt to the new conditions in their environment. There are several ways in which an individual can change his behaviour to adjust to the environment:

- Perceptual adaptation.

  This relates to changes into how an individual perceives his environment due to physiological and/or psychological processes, like defensive reappraisal or adaptation level theory (Wohlwill, 1975). In short: the longer an individual is exposed to an extreme environment, the less extreme he will perceive it.

- Behavioural adaptation.

  Habitual changes to accommodate the physical setting. Employees can change their physical setting to satisfy their needs (e.g. changing the orientation of a workplace to prevent arousal by bright sunlight or using headphones to prevent distraction by noise).

Predicting the long term effects of changes in the physical setting becomes even more complicated by considering the fact that an individual perceives his environment as a whole. Meaning that he values the environment as one system and not based on independent environmental factors.

3.2.3   Personal context

"The problem with user preferences and activities is the large range of possible actions and reactions due to the differences between the persons involved" (Zimmermann, G., 2006).

Not all differences in human activity behaviour can be explained by organisation (i.e. role and place) and physical setting. Factors related to the personal context of an employee will also influence his (activity) behaviour. The personal context refers to the needs of an individual, for instance related to the activities he conducts on a working day. The needs related to activities are to a considerable extent determined by an individual's characteristics and in lesser extent by the nature of activities. The personal context especially has a great impact on those activities which are not strongly related to someone's role or place in the organisation; activities like *have lunch* or *sport* (see section 3.3).

Each individual is unique, not only because of differences in gender and age, but also because of differences in personal history and (cultural) background. This means that the personal context varies per individual and as result his needs will also vary. While some context related factors are more or less fixed in time (e.g. gender and background), other factors are more temporal and will change with time. This means that personal context varies with time. It is influenced by events in his personal life, for instance by family related events. In addition, how an individual reacts to a situation in which his needs are not satisfied also differs per person.

Literature differentiates two types of activity related needs, namely physical and psychological (Raymond and Cunliffe, 1997). The following two sections will describe these two types.

3.2.3.1 Physical needs

The following physical needs can be differentiated:

- Space

  This is one of the most basic needs of an activity. An employee needs a certain amount of room to perform his activities and to move between activities.

- Light

  To be able to perform activities an employee also needs a certain amount of light. In most cases this is a combination of daylight and artificial lighting. The required amount of light varies per activity.

- Indoor climatic conditions

  The indoor climatic conditions have a big impact on the human comfort and on the capacity to perform activities. Workplaces need to be ventilated and the air temperature needs to be in a certain range for human comfort (e.g. 20 -21 °C)

- Sound

  Sound can be both wanted (i.e. music) and unwanted (i.e. noise). Research on sound as a factor of the ambient environment mainly focussed on noise (Leather et al., 2003; Sundstrom et al., 1994).

What is desired and required in relation to physical needs varies per person. For example: what for one individual can be a source of pleasure (e.g. music) is for another a source of distraction or even irritation (noise). Almost the same is true for the right air temperature; each employee will have a different range of temperatures that he perceives as comfortable.

3.2.3.2 Psychological needs

This section discusses the most important psychological needs related to activities, namely interaction, privacy and personalisation.

Interaction

Interaction between employees is important. From a business point of view interaction between employees is important as many activities rely on interaction to bring them to a successful end. However, interaction is also important with respect to informal, social contact between employees. It provides the possibility to communicate with colleagues and it transforms a set of individuals into a closely-related group of employees. This facilitates the creation of a pleasant, productive working environment, or according to Raymond and Cunliffe (1997):

"The coming together of team members is critical to the underpinning of corporate culture and loyalties in a world in which everything is changing".

Interaction between people can take many forms, like communication via telephone, written communication (e.g. e-mail) or face-to-face discussions, meetings or presentations.

Privacy

Closely related to interaction is privacy (or confidentiality). For an individual interaction can both be a source of stimulation and distraction. That is why he will usually try to regulate the amount of interaction, for instance by means of personalisation (see below). Regulation of interaction refers to controlling the flow of information from an employee to his colleagues and to controlling incoming stimulation. Two main types of privacy can be distinguished, namely:

▪ Speech/conversational privacy

This relates to the extent in which an employee is able to have (confidential) conversations without being overheard by others.

▪ Visual privacy

This refers to the extent in which the workplace of an employee is visual accessible from other workplaces, corridors etc. An individual will try to block unwanted observation of documents, behaviour or information visible on his computer screen.

Personalisation

Personalisation refers to the decoration, modification or rearrangement of a workplace by an employee to (better) reflect his identity (Tian and Belk, 2005). According to several studies (Wells and Thelen, 2002; Wells, et al., 2007) 70-90% of all employees personalise their workplace.

3.3   Taxonomy of activities

So far the composition of human behaviour in (office) buildings in terms of types of activities has not been discussed yet. To gain an insight into human activity behaviour occurring in office buildings, this section will describe three different ways to differentiate activities. This taxonomy will be illustrated with a matrix using example activities.

3.3.1   Social, physiological or job related activities

Many types of activities occur in office based organisations. The first classification of activities is based on the nature of the activity itself, namely if the activity is social, physiological or job related.

Job related activities depend on the workflow of an organisation. Each organisation has its own specific workflow (see section 6.3). For each employee these job related activities are to a considerable extent determined by the combination of role and place in the organisation. Job related activities can directly follow from this combination (e.g. *get PhD coaching*) as well as indirectly, like *walking to printer*. The latter activities are a side effect of the former activities.

While a large part of the activities are job related, others are the result of human nature. The latter activities strongly depend on the psychological or social needs and desires of an employee. These activities are respectively called physiological and social activities.

People engage in social activities dependent on their desires: to fulfil some wish or need. Examples of this kind of activities are: *have a break* and *chat with a colleague*. The physiological activities depend, as the name suggests, on the physiological characteristics and habits of the individual. Examples of these activities are *going to the toilet* and *smoke*. Both categories of activities occur frequently during a working day.

3.3.1.1 Solo or group activities

The second classification differentiates activities based on whether they require interaction or not. A working day of a typical employee consists for a large part of activities which do not require interaction between people. These so-called solo activities can largely be performed independent from other employees as these activities do not require any support or interaction with others. Interaction in relation to solo activities is limited to:

- Moments of shared activity
  This relates to short events which happen while a solo activity is conducted, such as discussing with co-authors when *writing a publication* or dealing with incoming telephones while *doing administrative work*.
- Accidental interaction
  This refers to (accidental) encounters between people, for instance when people meet up while walking between activity locations.

In contrast to solo activities, group activities involve several employees with a shared common goal. These activities typically are meetings and presentations of various types and require the presence of different numbers of people, like coaching meetings (e.g. 2 to 3 people), project meetings or presentations (e.g. 3 to 10 people) or company meetings (e.g. dozens of people). The composition of groups of people associated with these activities is not fixed; it will change over time.

3.3.2 Planned or unplanned activities

Finally, activities can be classified based on whether they are planned or not. Certain activities performed by employees during a working day are planned. These activities were entered in their agenda prior to the start of the working day in question. Most job related activities are planned in advance. For example an important meeting will be planned weeks or even months prior to its occurrence. However in some cases also social and psychological activities are planned in advance (e.g. *have a lunch*). Other activities are not planned in advance. These activities either happen due to unforeseen events (e.g. unexpected guests, accidental meetings and incoming mail) or are a result of personal wishes and/or needs, like *get a drink* or *going to the toilet*. These unplanned activities form an integral part of a working day in terms of time spent on these activities and resulting walking distance and time.

3.3.3 Taxonomy matrix

To illustrate the above given classifications of office-based activities, Table 3.2 gives a visual representation of this taxonomy, using an arbitrary list of activities. This matrix

shows that there are many possible combinations of classifications of activities. This taxonomy forms the basis for the classification of activities in so-called skeleton and intermediate activities as applied in this research project (see section 5.2).

	Social	Physiological	Job elated	Solo	Group	Planned	Unplanned
Do research			X	X			X
Get a drink	[1]	X		X			X
Have a meeting			X		X	X	
Have lunch	[1]	X			X	[2]	X
Give student coaching			X		X	X	
Following a course			X		X	X	
Going to the toilet		X		X			X
Have a break	X			X			X
Give lecture			X		X	X	
Smoke		X		X			X

Table 3.2: Classification of activities.
[1] Some physiological activities have a social side effect.
[2] In some cases this is a planned activity.

3.4 Activity attributes

Activities differ from each other in attributes like frequency, duration and importance. In this section the activity attributes relevant for modelling human activity behaviour in office buildings are highlighted

3.4.1 Frequency

The number of times an activity is performed in a certain period of time will vary per activity. Most of the activities occurring in office based organisations are regularly performed by employees. Activities like *have a meeting* or *get a drink* are performed more times on a day or occur every couple of days. Other activities, however, are only performed every now and then, for example *give an external presentation*.

3.4.2 Duration

The duration of an activity ranges from a couple of minutes (e.g. *get a drink*) to a couple of hours (e.g. *have a meeting*). The duration of a certain type of activity is not constant; it varies each time the activity is performed. Variances in the frequency and in the duration of an activity cause the total time spent on this activity to differ per working day.

3.4.3 Priority

Not every activity is of equal importance to an employee. Some activities are perceived as more important to perform during a working day than other activities. These activities have a higher priority and will, for example, be less often interrupted by other activities. The priority is strongly influenced by role and place in organisation and in lesser extent by the personal context. In other words, employees who have the same role will have more or less the same perception of importance of activities.

3.4.4 Location

Each activity occurs at a certain location in the building space. Dependent on the activity a certain type of location is needed. An employee will choose an activity location that matches with the characteristics of an activity.

Example
For a solo activity normally a workplace will suffice, for a group activity a meeting or presentation room has to be arranged and for a social activity a lunch room or refreshment point (e.g. coffee corner) will be chosen.

3.4.5 Facilities

Finally, most activities require one or more facilities in terms of technical equipment, like a computer for *write a publication* or a projector for *give a presentation*.

3.5 Identification of processes to be modelled

Based on the description and classification of activities occurring in office based organisations given in this chapter, it is now possible to identify those processes which are essential for modelling the space utilisation in relation to this research. The identified processes will be used for assessing the relevance of different modelling approaches for simulating space utilisation of office buildings for any given organisation (see chapter four). Moreover, it will be used as a starting point for defining the USSU modelling approach (see chapter five).

3.5.1 Activity scheduling

In order to model the space utilisation of office based organisations, the modelling approach should include all different types of activities occurring in an organisation. This means that not only the job related activities should be included in the model, but also social and psychological activities. The job related activities are highly dependent on the role and place of employees in an organisation. Consequently, to realistically schedule job related activities (e.g. to determine their order and timing on a working day), the USSU modelling approach needs to incorporate a method of modelling the structure of an organisation, in terms of roles and organisational units. The occurrence of social and

psychological activities is strongly influenced by personal characteristics of employees (i.e. their personal context, see section 3.2.3). This has to be taken into account in order to realistically model these types of activities.

3.5.2 Interaction between activities

As mentioned earlier in this chapter interaction between employees and their activities plays an important role in an organisation. Consequently, employee interaction should play an important role in the modelling approach, ideally with regard to all types of activities (i.e. job, social or psychological activities).

3.5.3 Activity location and route choice

The last processes to model refer to interaction between the built environment and human behaviour. To perform an activity normally a number of resources are required, the most important one being its location. For each activity there is usually a group of locations available of a certain type. In other words, from the possible set of relevant and available locations a location has to be chosen. This choice can be based on proximity (i.e. the location nearest to a workplace is chosen) or preference/habit (e.g. an individual can prefer a certain location over other locations). Related to activity location choice modelling is route choice modelling. The aim of route choice modelling is to determine the route between the locations of activities.

3.6   Conclusions

Human activity behaviour in office buildings is complex. The activities conducted by office based organisations are influenced by many factors. Factors, like role and place in an organisation, have a direct, understandable influence on the activities performed in an office building. The influence of physical setting and personal context on human behaviour is less easy to understand. These factors influence individual behaviour, but in which way and to which extent is not completely understood yet and is still matter of research. A second outcome of this chapter is the classification of activity behaviour. The classification was based on a taxonomy of human behaviour using three classifications of activities, namely planned/unplanned, solo/group and social/ physiological/job related. This is illustrated by a matrix using examples of activities occurring in office based organisations. Next, the activity attributes were discussed that will play a role in the modelling approach to simulate human activity behaviour in office buildings. Finally, based on the description and classification of activities processes were identified which are essential for modelling the space utilisation in relation to this research. The identified processes will be used for assessing the relevance of different modelling approaches for simulating space utilisation of office buildings for any given organisation (see chapter four) and as starting point for defining the USSU modelling approach (see chapter five).

C4 Human behaviour modelling

4.1 Introduction

This chapter discusses three approaches for modelling human (activity) behaviour in relation to office based organisations, namely pedestrian behaviour simulation, workflow modelling, and activity based modelling. Pedestrian behaviour simulation is discussed because of its ability to model interaction between the built environment and human behaviour. Workflow modelling is treated for modelling activities that occur within an organisation. Activity based modelling is of interest because it treats travel and activity forecasting processes as a group decision making process introducing interaction between individuals. Each approach will be introduced and its relevance for modelling human behaviour in the context of office buildings will be discussed. The relevance is assessed by comparing each approach with the set of processes that were identified in chapter three as essential to be modelled in this research project.

This chapter is organised as follows. First, pedestrian behaviour simulation will be introduced. It will describe the different types of models that have been developed for modelling pedestrian traffic flows. Next, in the section on workflow modelling, different ways of modelling the workflow dependent activities are investigated. Then, an in depth discussion of activity based modelling is given; it will highlight among other things the recent interest in modelling interaction between household members in this research field. This chapter ends with conclusions on the applicability of the three approaches for simulating the space utilisation of office buildings.

4.2   Pedestrian behaviour simulation

Pedestrian behaviour simulation is part of the broader research area of traffic flow modelling which focuses on modelling traffic flows on different levels of the built environment. In the last decade much research effort has been made to understand and model pedestrian behaviour. Both researchers and designers are interested in the way pedestrian behaviour is influenced by changes in their environment. Their desire is to understand the relationships between planning and design decisions and the resulting pedestrian behaviour (Dijkstra et al., 2000; Dijkstra et al., 2006; Maat and Arentze, 2003).

According to Willis et al. (2003) and Blue and Adler (2000) pedestrians behave in a complex way. People can use the walkways as they desire. While some people will wander around, others will rush to get to their destination. The strict regulations with regard to roadways do not apply to pedestrian behaviour modelling. Humans vary their walking speeds and directions more quickly than vehicles can. Furthermore, human behaviour is triggered by elements in the built environment (e.g. parks, shops and other people). The behaviour of people also varies due to the situation they are faced with. Although people will normally try to steer away from other people as to avoid bumping into someone, in crowded situations they will change their behaviour when this creates possibilities to move in their desired direction.

Models developed in this research area of pedestrian behaviour modelling can be divided in three categories, namely cellular automata models, agent-based models and social force models.

Cellular automata models are used to model dynamic processes that are discrete in space and time. In a cellular automata model space is represented as a uniform lattice of cells with local states. Cell states are subject to a uniform set of rules, which drives the behaviour of the system (Dijkstra and Timmermans, 1999; Blue and Adler, 2000). Cellular automata models have been applied to model various processes, for instance road traffic. Using cellular automata it is possible to model a variety of effects known in real traffic scenarios. Cellular automata models are also suitable for modelling pedestrian dynamics. An example is the Bypass project at the University of Duisburg-Essen (Meyer-König et al., 2002) for simulating evacuation behaviour on cruise ships.

Agent-based systems are currently developed for simulating virtual human behaviour with respect to a variety of disciplines. The PEDFLOW model is an example of an agent-based evolutionary system that is able to model pedestrian behaviour (Kerridge et al.,

2001). Another example is the Streets project (Schelhorn et al., 1999), which provides a comprehensive model of pedestrian simulation. This model simulates the movement of a pedestrian population (i.e. pedestrian agents) in an urban district as influenced by the spatial configuration and predetermined activity schedules.

The third category uses social force fields to model human behaviour (Helbing and Molnar, 1995). These social (or behavioural) forces determine the amount of behavioural change (e.g. changes in acceleration or in direction) as reaction to external forces (e.g. forces exerted by the environment).

4.2.1 Relevance

This approach lends itself for modelling the interaction between the built environment and human behaviour with respect to the human dynamic walking behaviour (e.g. steering behaviour). However, research in the field of pedestrian behaviour simulation is mostly focussed on modelling flows of pedestrians on urban level (e.g. squares and shopping centres) or on modelling detailed, low level walking behaviour concerning parts of a building (e.g. for explaining crowding behaviour at an obstruction in a passageway) and less on the level of whole buildings. In addition, much research effort is put into modelling the way people move from point A to point B and the resulting interaction between people. However, for the motives behind this travel behaviour (e.g. the activities performed by people) mainly methods from other research areas (e.g. activity based modelling, see section 4.4) are applied. Research by Daamen (2004) is used as an example to illustrate this. She developed an extensive system for modelling passenger flows in public transport facilities and performed numerous laboratory experiments on pedestrian walking behaviour. Parts of her system belonged to the field of activity based modelling, for instance processes dealing with activity scheduling. However, most of these processes were assumed to be exogenous to the simulation tool. In other words, activity scheduling and interaction between activities are in most cases not an intrinsic part of pedestrian behaviour modelling.

4.3 Workflow modelling

Business process modelling is a method that has been widely applied in business management to gain an insight into, and control over, business processes. Van der Aalst and van Hee (2002) suggest a workflow modelling method from an organisational point of view, based upon coloured Petri net theory. However, (coloured) Petri nets are just one of the theories available in the field of workflow modelling. A lot of different workflow tools and specifications have been developed based on different paradigms (van der Aalst, 2003). This is largely due to the lack of a universal workflow formalism (van der Aalst and Hofstede, 2003). This section focuses on (coloured) Petri nets to introduce workflow modelling and its relevance for the simulation of space utilisation of office buildings.

4.3.1 (coloured) Petri nets

Coloured Petri nets are an extension to the basic Petri nets formulated by Carl Adam Petri in the 1960's. Petri devised Petri nets as a tool for modelling and analysing processes. Petri nets have a strong mathematical basis; they are completely formalised. The formalism makes sure that the Petri net is modelled in a precise way. This leaves no room for uncertainties and ambiguities. Furthermore, the formalism makes it is possible to analyse the behaviour of Petri nets.

Petri nets can be used for modelling distributed and concurrent systems, like telecommunication systems and document storage systems. These systems normally are very complex and difficult to design and test. Due to the graphical and mathematical nature of Petri nets, they can be used for modelling and analysing this kind of systems. The Petri net created for a system not only serves as a graphical description of the modelled system, it also gives a detailed specification of the system. In this way the model can be used for studying and presenting the system. Due to the graphical representation of a Petri net model and the fact that the model is constructed from a limited number of primitives, it is relatively simple to understand a model, even for people who are not familiar with Petri nets.

A classical Petri net consists of two types of nodes, namely places and transitions (see Figure 4.1). Directed arcs connect the nodes. When modelling a system with Petri nets the state variables of the model are represented by places. Places are passive and are used to indicate media, buffers, etc. A place contains a set of markers, called tokens. A token can be used to represent both physical objects (e.g. resources and humans) and information objects (e.g. an insurance claim). The state-changing operators are the transitions, which are the active nodes in a Petri net. They represent actions, like events or operations.
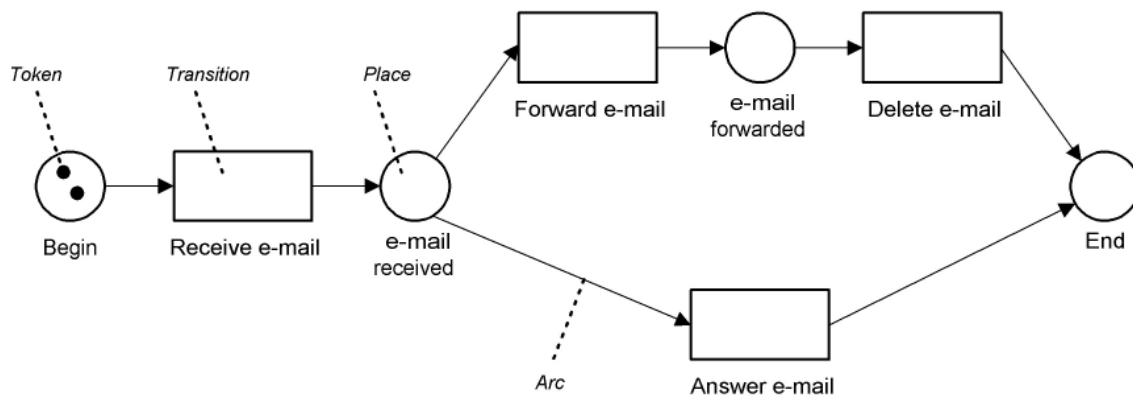
Figure 4.1: A classical Petri net.

After the formalisation of the Petri nets in the 1960's it became clear that the theory had some weaknesses or practical shortcomings. Modelling an even relative small system could result in complex and unreadable Petri nets. Several extensions to classical Petri nets have been formulated (see Jensen, 1992; Kristensen et al, 1998). In the classical Petri nets a token is a very simple data entity; it is not associated with attributes. This makes it difficult to distinguish between the several tokens found in the net. The colour extension equips each token with a data value, called the token colour (see Figure 4.2).

In this way each token can carry several attributes and it is possible to distinguish between the tokens.
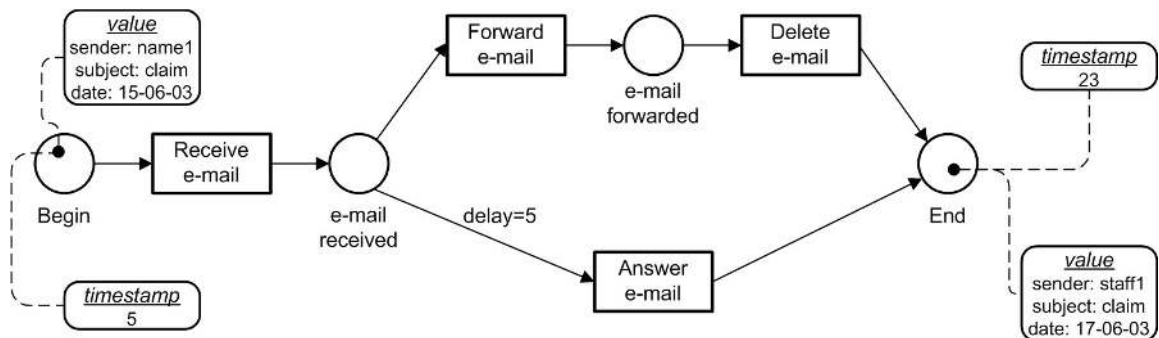
Figure 4.2: A coloured Petri net extended with time.

4.3.2 Relevance

The approach by van der Aalst and van Hee (1996) describes the important stages *what, how* and by *whom* in designing a business process. Their approach is based on coloured Petri nets. By following these stages when modelling business processes, it is more or less guaranteed that the result is a complete model, which describes in detail the types of activities, their order and who is responsible for an activity. However, in the field of workflow modelling there is no real interest in the where of an activity. Until now there are no workflow tools that take the location of an activity into account.

Workflow models describe the interaction between activities, people and resources of an organisation. It is an intrinsic part of most workflow modelling techniques. As mentioned in chapter three, interaction between activities plays an essential role in simulating human activity behaviour in office buildings. Workflow modelling seems well suited for solving this interaction. However, workflow models only deal with activities that depend on the workflow of an organisation; other activities (e.g. social activities) are not dealt with.

4.4 Activity based modelling

In the last decades many so called activity based models have been developed with the intention of predicting the performance of activities by individuals. These activity models have especially received much attention in the area of transportation. The research area of activity based modelling tries to develop models, which can predict travel behaviour by means of predicting which activities are conducted (Ettema, 1996). Based on certain factors (see below) these models are able to predict activity schedules which detail the sequence of activities and their locations. The activity schedules reveal the travel demand as derived demand from the predicted activities. Activity based models are for instance used to predict the effect of policy measures on the possibilities of individuals to participate in activities and on the resulting travel demand (Arentze and Timmermans, 2000). Examples of these policy changes are changes in the opening hours of shops or changes in infrastructure or land use planning.

People engage in activities to fulfil a need, such as social or psychological needs. Needs are influenced by the context in which a person lives, like the personal and household characteristics, social status, political and economical environment, etc. In addition, needs can be fundamental to the society in which an individual lives (e.g. people need to work to earn money to be able to buy for instance food) or it can depend on personal beliefs and wishes (e.g. meeting friends or sport). Satisfying a need yields a utility. In other words, an individual derives a certain level of utility from conducting an activity. People will usually choose that activity, which yields them the highest utility. The goal of the activity scheduling process is to find the schedule with the highest possible satisfaction (i.e. maximising the utility). Activity scheduling is a cyclic process. It starts with an almost empty schedule in which an individual keeps adding activities and subsequently evaluating the schedule until it yields the optimal (at least as the individual is concerned) utility (or satisfaction). When the person is satisfied with the schedule the process is stopped (see Table 4.1 for an example of an activity schedule).

Time	Activity
00:00 - 08:30	Sleeping
08:30 - 08:45	Eating (breakfast)
08:45 - 09:15	Travelling to work
09:15 - 12:00	Working
12:00 -12:30	Eating (lunch)
12:30 -17:30	Working
17:30 - 18:00	Travelling home
18:00 - 19:00	Eating (dinner)
19:00 - 20:30	Cleaning house
20:30 - 20:45	Travelling to cinema
20:45 - 23:00	Watching movie
23:00 - 23:15	Travelling home
23:15 - 00:00	Sleeping

Table 4.1: An example of an activity schedule.

Activity scheduling is a decision making process. People make decisions about which activity to engage in and how to travel between the activities. According to Hoogendoorn and Bovy (2004) and Hoogendoorn et al. (2002) the decision making process with respect to pedestrian behaviour can be described at three levels, namely strategic, tactical, and operational (see Figure 4.3). At the strategic level people make long-term decisions regarding the activities they want or need to perform during a certain period. The outcome of this level is a set of activities per person. At the tactical level short-term decisions are made regarding the set of activities determined at the strategic level. First the activities are scheduled (i.e. the order and timing of the activities are determined). Next, an individual chooses for each activity the most optimal or preferred location out of the total set of possible locations (i.e. activity area choice). The last process at the tactical level is route choice. This concerns the choice of routes between the locations of the activities. At the operational level people make instantaneous decisions regarding among other things the performance of activities and their walking behaviour (i.e. walking speed and direction).
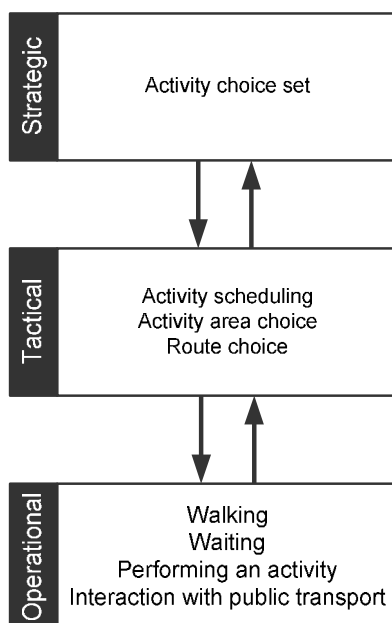
Figure 4.3: Levels of pedestrian behaviour (Daamen, 2004; Hoogendoorn et al., 2002).

There are many factors which influence the decision making process. A major factor is that humans in general cannot investigate every possible solution to the problem of finding an activity schedule for the period in question (for example 24 hour). Investigating every possible solution simply requires too much time. When an individual is scheduling his activities, he has to make many decisions, considerations and choices. The tendency to engage in an activity is another important factor. This propensity can be both stimulating and constraining. People tend to engage in activities which they like or which can improve their career. However, some personal and social characteristics, like health status or social status, can limit the number of activities they can pursue. Except the propensity also opportunity plays a roll in scheduling activities. The opportunity to engage in activities can be constrained by several factors, for example:

- Temporal constraints: e.g. no overlaps of activities or gaps between activities are possible.
- Spatial constraints: some activities can only take place on specific locations.
- Combinations of both constraints, temporal-spatial constraints: the time to travel between several locations depends on distance and transport mode.

4.4.1 Interaction in activity based modelling

Most existing approaches to model activity schedules assume an individual-based decision making process. These models do not take into account the interaction between individuals; at best only implicitly through the inclusion of explanatory variables related to household composition, such as characteristics of households. According to Scott and Kanaroglou (2002) and Vovsha et al. (2003) there is a need for incorporating interaction between household members to develop sound forecasting models. Recently, there is a noticeable growing interest in modelling intra-household interaction in the field of transportation research (Anggraini et al., 2006). According to Vovsha et al.

(2004) three categories of interaction modelling approaches can be distinguished, namely:

- Structural equation models.

  These models are used to explore the relationships between activities such as performed by male and female household-heads (Golob and McNally, 1997).

- Models that explicitly consider the intra-household interaction mechanism.

  These models are based on a joint decision making process. The activity schedule of the household is the result of a negotiation process in which the interests of the individuals are weighted against those of the group (Zhang et al., 2002).

- Models that represent a choice between individual and joint activity c.q. travel.

  These models are based on a discrete number of activities episodes c.q. trips rather than continuous activity durations. Scott and Kanaroglou (2002) have developed such a model in which the daily number of non-work, out-of-home activity episodes is modelled for household heads.

4.4.2 Relevance

Activity based model are well suited for modelling activities which are physiological or social by nature. Most activity based models also take the location of an activity into account. Furthermore, there is growing interest in modelling the interaction between people. However, so far this is limited to interaction between household members; the group decision-making process only deals with interaction between (two) household heads.

4.5 Conclusions

This chapter has discussed three different approaches for modelling human behaviour, namely: pedestrian behaviour simulation, workflow modelling and activity based modelling. Their relevance for modelling human behaviour in the context of office buildings was discussed.

Each of these approaches is in some manner relevant for modelling human behaviour in office buildings. However, none of these approaches is directly applicable, as each approach excels in one area, but is (too) limited in other areas. Table 4.2 shows a comparison of the approaches with the set of processes that were identified in chapter three as essential to be modelled in this research project. This comparison leads to the conclusion that on its own none of the modelling approaches is suited for modelling the human activity behaviour in context of building simulation. The solution: combine the approaches, primarily activity based modelling and workflow modelling, into in one approach. In this way, the strong points of each of these approaches can be combined and their weaknesses be solved.

	Activity scheduling	**Interaction between activities**	**Activity location and route choice**
Pedestrian behaviour modelling	Less suited for modelling activity behaviour.	Interaction between pedestrians is in some cases modelled.	Well suited for modelling the interaction with the built environment with respect to walking behaviour.
Workflow modelling	Well suited for modelling workflow related activities.	Well suited for solving interaction between people and activities.	Does not take the location of activities into account.
Activity based modelling	Well suited for modelling physiological or social activities.	Interaction between people is limited to household heads.	Deals with the locations of the activities.

Table 4.2: Comparison of approaches for human behaviour modelling with essential processes to be modelled in this research project (see section 3.5).

Chapter five describes in detail the approach taken in this research project for modelling human activity behaviour in office buildings. Among other things, it will show the way in which workflow modelling and activity based modelling are combined for modelling the activity behaviour found in office based organisations. As mentioned in chapter one, an enterprise building or a university staff building are examples of office buildings. The latter is applied in chapter five and subsequent chapters to illustrate the theory behind this research project and to validate the developed system.

C5 Modelling approach

5.1 Introduction

So far part one discussed human behaviour theory with respect to building simulation. Chapter two discussed several applications of building simulation with a focus on human activity and movement behaviour in buildings. Chapter three dealt with a detailed description of the complexity of human activity behaviour in office buildings. Different types of activities occur in office based organisations and these activities are influenced by many factors. Human activity behaviour is (still) not completely understood and many questions related to human behaviour are not yet answered. This makes it difficult to define a comprehensive model for simulating human activity behaviour. Finally, chapter four highlighted several general approaches to model human behaviour and compared these approaches with respect to applying them in the context of this research project.

This chapter explains the developed modelling approach to simulate human activity behaviour in office buildings. The chapter starts by discussing the two different types of activities that are distinguished with respect to human activity behaviour in office buildings, namely skeleton and intermediate activities. These two types of activities are discussed in detail in section 5.3 and section 5.4. Afterwards the approach to model the spatial conditions in which both types of activities are conducted is discussed. This chapter ends with a section on conclusions regarding the modelling approach.

5.2   Approach to human activity behaviour simulation

At the end of chapter three a taxonomy-matrix was given to describe the activities that occur in office based organisations. In this taxonomy the first classification of activities was based on the distinction between social, physiological or job related activities. In chapter four the same distinction was made in the discussion of approaches to model human behaviour, primarily workflow modelling and activity based modelling. As was shown, none of these approaches is directly applicable for modelling human activity behaviour in office buildings. While workflow modelling is well suited for modelling activities related to the workflow of an organisation, activity based modelling is well suited for modelling activities which are physiologically or socially determined. It was suggested that combining workflow modelling and activity based modelling could be the solution for modelling realistic user behaviour in office buildings. In this way, the strong points of each of these approaches are combined while solving their weaknesses.

In the USSU modelling approach each employee belonging to the analysed organisation is linked with an activity schedule. An activity schedule consists of an in time ordered set of activities. Each activity has a location and can involve, depending on the type of activity, one or more resources, like other people or facilities. In line with the above mentioned two modelling approaches the activities comprising an activity schedule can be divided in the following two types (see Figure 5.1):

1. Skeleton activities: the workflow dependent activities.
2. Intermediate activities: social and/or physiological activities.

This division is also in line with the differentiation of activities based on the impact of activities on an activity schedule. The impact of an activity on an activity schedule relates to its influence on the other activities comprising an activity schedule (i.e. the activities an employee performs before and after this activity). While certain activities have a strong impact on an activity schedule, other activities influence an activity schedule in a limited manner.

Example
The skeleton activity *give a presentation* has a bigger impact on an activity schedule than the intermediate activity *get a drink*. The former activity is most likely planned well in advance and can not be postponed, at least not as easily as the intermediate activity *get a drink*.
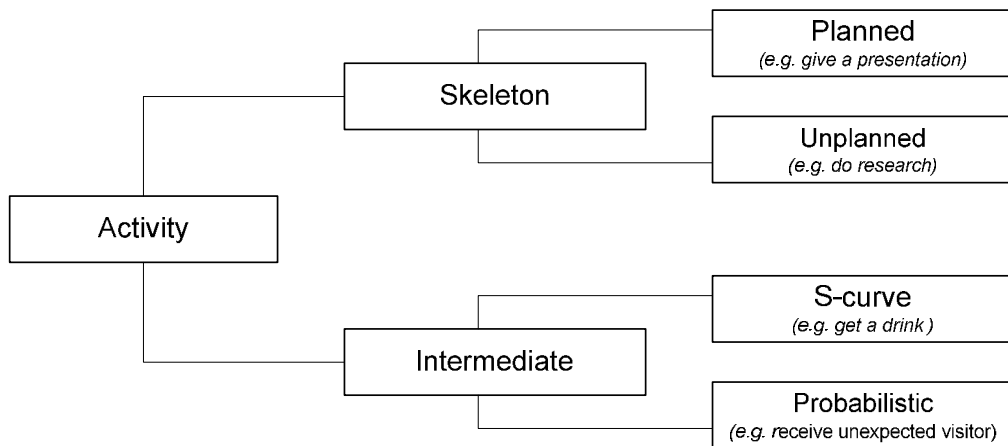
Figure 5.1: Classification of activities.

The differentiation in either workflow depended (i.e. skeleton activities) or social and psychological activities (i.e. intermediate activities) formed the basis for modelling the activity human behaviour in this research project. However, the differentiation of the activities needs to be fine-tuned, as some skeleton activities are not as strongly linked with the workflow of an organisation as others. This will become clear in the next section.

5.3 Skeleton activities

Skeleton activities are responsible for highly structuring an individual's activity schedule (as the name already suggests). Examples of skeleton activities are: *attend a meeting/presentation, do administrative work, handle complaints* or *contact clients*. They are the primary activities for modelling the human activity behaviour in office buildings. The workflow dependent activities have, in principle, a major impact on an activity schedule.

In the real world two types of skeleton activities can be distinguished:

▪ Planned

These skeleton activities are scheduled before they are executed, sometimes even months in advance. Examples: *give a presentation* or *attend a meeting/presentation*.

▪ Unplanned

These skeleton activities are conducted in the time that remains before, after and between all planned skeleton activities. The scheduling and execution process of unplanned skeleton activities coincide. Examples are: *research* or *prepare a presentation*.

For each employee the skeleton activities are to a considerable extent determined by the combination of his role and place in organisation (see section 3.2.1). From the activity schedules of all employees the workflow of the whole organisation can be deduced (see Figure 5.2).
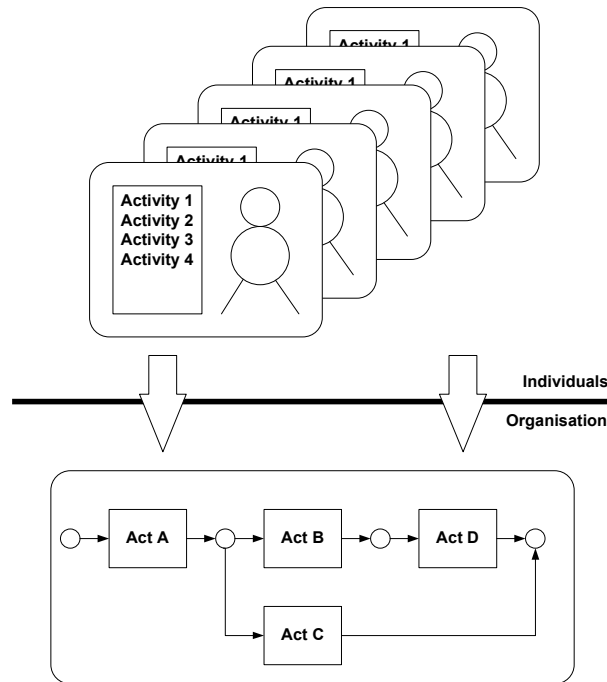
Figure 5.2: Link between activity schedules and organisational workflow.

Some skeleton activities are not directly a consequence of someone's role and place in the organisation. Activities like *walk to printer* or *walk to the library* can be considered as a side effect of skeleton activities belonging to an employee. Although these activities are in principle job related, the scheduling and frequency of these activities do not strictly depend on role or place in organisation. In addition, the impact of these activities on an activity schedule is low. These activities are not considered to be skeleton activities, but are intermediate activities (see section 5.4).

5.3.1   The impact of skeleton activities

The impact of the skeleton activities on an activity schedule varies per skeleton activity. The consequences of interrupting or postponing unplanned skeleton activities are not as severe as for planned skeleton activities. Planned activities (e.g. *have a meeting*) are planned in advance because they are linked with a group of employees or a certain type of resource is required to perform this activity. This makes postponing or interrupting planned activities by other activities more difficult. In addition, a group activity (e.g. *give a presentation*) influences the activity schedules of all employees involved in this skeleton activity. As a result, group activities have a bigger impact on activity schedules than solo activities (e.g. *research*).

In the modelling approach no distinction is made between planned or unplanned skeleton activities. Instead, the impact of an activity on an activity schedule is modelled using a priority attribute (see Figure 5.3). The value of this attribute determines the impact of an activity. The higher the value of this attribute the stronger the influence of an activity on an activity schedule and the smaller the chance that this activity is postponed or interrupted by other activities.

The skeleton activity *give a presentation* is likely to have a higher priority than the skeleton activity *research* as this skeleton activity influences the activity schedule of the presenter as well as the activity schedules of all employees who are attending this presentation.
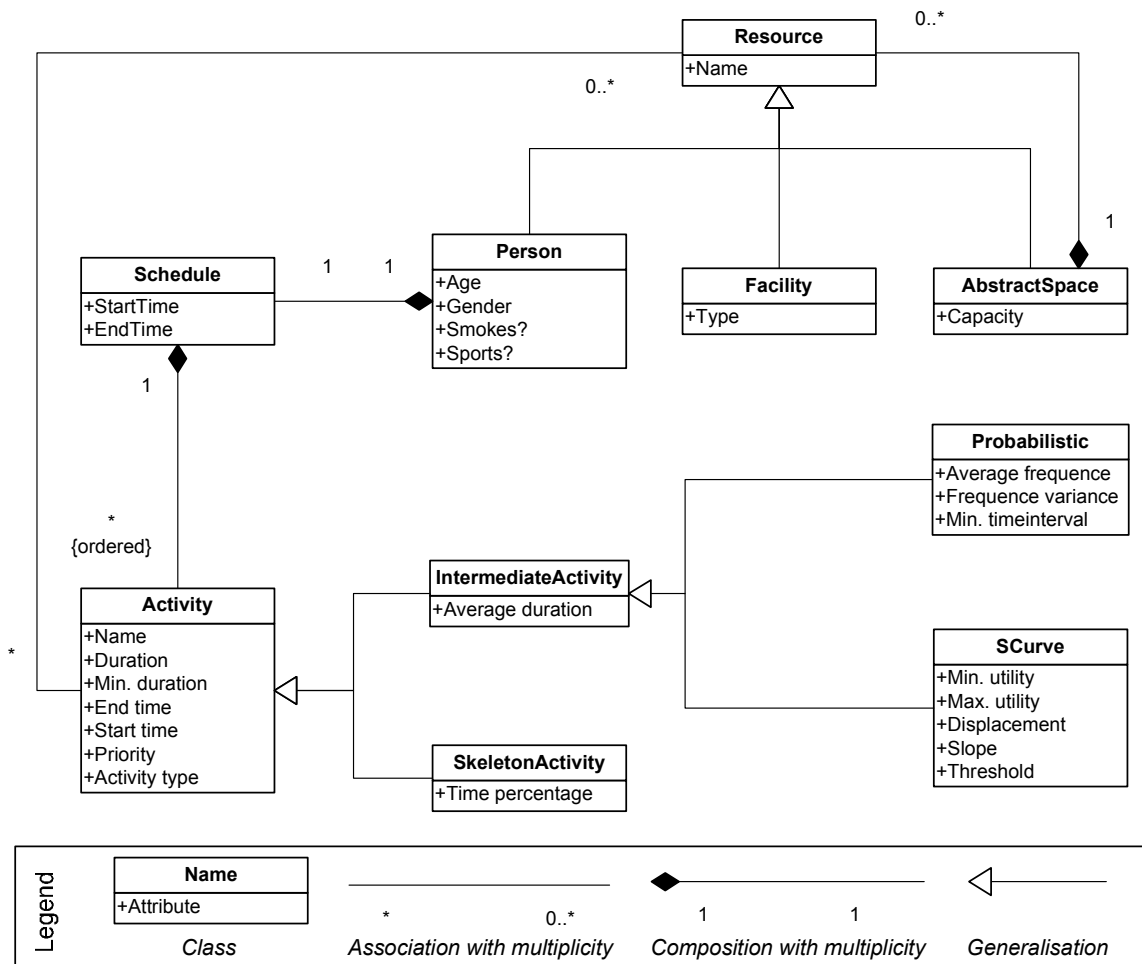
Figure 5.3: Simplified class diagram, displaying activity, schedule and resource class.

5.3.2   Interaction

Interaction between skeleton activities plays an essential role in the USSU modelling approach. Although a member of an organisation often executes activities alone (e.g. *prepare a presentation*), many skeleton activities require interaction between people (e.g. *give a presentation*).

Assume an employee has the skeleton activity *give a presentation* in his activity schedule. This skeleton activity requires the presence of other employees within the organisation to attend this presentation. This means that other employees should have a skeleton activity such as *attend presentation* in their activity schedules. Rescheduling this type of skeleton activities is more difficult than skeleton activities that do not involve a group of people, like *prepare a presentation*.

5.4   Intermediate activities

The second type of activities comprising activity schedules is the intermediate activity type. Intermediate activities strongly depend on the psychological or social needs and wishes of employees. Intermediate activities adjust and complement the skeleton activities in the sense that an intermediate activity can interrupt a skeleton activity or even postpone it. To which extent an intermediate activity can interrupt or postpone a skeleton activity depends on among other things the type of skeleton activity (see section 5.4.1.1).

Example

In the real world a skeleton activity like *research or do administrative work* is easily interrupted by intermediate activities such as *get a drink* or *have a break*. At least more easily than interrupting or postponing skeleton activities *like attend meeting* or *give presentation*.

In the USSU modelling approach the intermediate activities are limited to the types as given in Table 5.1. Scheduling the intermediate activities is done using two different methods, namely the S-curve method and the probabilistic method. Each intermediate activity type was assigned to a method based on its characteristics. This will be explained in the following two sections.

Type	Prediction method	Frequency depends on
Have lunch	S-curve	S-curve parameters (values differ per intermediate activity): - slope - displacement - maximum utility - minimum utility
Sport (during workday)	S-curve	
Get a drink	S-curve	
Smoke (not at workplace)	S-curve	
Have a break	S-curve	
Go to toilet	Probabilistic	Gender and age
Receive unexpected visitor	Probabilistic	Role
Walk to printer	Probabilistic	
Walk to mailbox	Probabilistic	

Table 5.1: Intermediate activity types.

5.4.1 S-curve

The occurrence of certain types of intermediate activities strongly depends on the time elapsed since the last time these intermediate activities were performed.

Example
The longer ago an employee performed an intermediate activity like *get a drink* or *smoke*, the more urgent this intermediate activity becomes due to, in this case, physiological reasons.

The S-curve intermediate activities are conducted to satisfy certain needs, such as physiological or social needs. According to Arentze and Timmermans (2006) satisfying a need yields a utility. In other words, an individual derives a certain level of utility from conducting an intermediate activity. The theory for predicting the S-curve intermediate activity types is based on the framework developed by the same authors (Arentze, Timmermans, 2008). Their needs-based theory can be applied for generating activities while taking the nature of the need and characteristics of individuals and households into account. According to Nijland et al. (2008):
"The model predicts a multi-day activity pattern for a given person for a period of arbitrary length. Rather than solving some resource allocation optimisation problem, the model assumes that individuals make activity selection decisions on a daily basis".

In this research project a simplified needs-based theoretical framework is applied which focuses on predicting intermediate activities on sub-daily basis. The goal of this framework is to determine the timing of the intermediate activities. The need of an intermediate activity builds up over time. It is assumed that the utility of an intermediate activity is a function of time elapsed since the previous occurrence of this intermediate activity on a (working) day. This implies that the longer ago an intermediate activity is executed the more urgent this intermediate activity type becomes. When an intermediate activity is performed, the need for it is satisfied; the need is diminished and starts to build up again (see section 5.4.1.2).

According to Nijland et al. (2008) and Joh (2004) there are several possible functional forms for the utility growth curve. The most basic shape of the utility function is a linear function. This means that the utility of an activity increases in a constant way. However, in most cases this is not a suitable form. Most activity utility functions rely on the assumption of ever-diminishing growth of the utility associated with an activity (Kitamura et al., 1996), resulting in a logarithmic function. In this research project the utility growth function is derived from the following assumptions with respect to the growth of need over time. The minimum size of a need can be arbitrarily set (as only differences on a need scale have an effect on activity behaviour). Arbitrarily it is assume that the minimum size of a need is smaller than zero. This represents the utility of an intermediate activity in its initial situation. This relates to the start of the workday or to the situation directly after an intermediate activity is conducted (see section 5.4.1.2). Next the utility (i.e. needs) of an intermediate activity increases with time elapsed since this intermediate activity was last conducted. It is assumed that the rate of increase is not constant. First the utility growth is assumed to be slow, but the growth speed increases with every elapsed time step (e.g. minute). In other words, the rate at which the need of an intermediate activity grows, increases with every minute. Joh (2004) calls

this the 'warming up' period. However, the growth speed will not increase indefinitely. There is a point when a saturation effect is reached. This is when the rate of increase reaches its maximum value (inflection point). Although the need of an intermediate activity will still increase, it increases at an ever diminishing rate. The maximum utility of the intermediate activity represents the utility derived from the intermediate activity if time increases indefinitely. The maximum utility value is bigger than zero. Overall this results in an S-shape form of the utility growth function.

Based on similar assumptions Arentze and Timmermans (2006) and Joh (2004) applied an S-shaped utility function. The actual form of an S-shape is not the same for each intermediate activity. The form is assumed to depend on the characteristics of an intermediate activity and on the context in which it is performed, relating to culture, type of organisation (e.g. office based or not), etc.

The total utility of intermediate activity a is defined as follows:

$$U_a = V_a + \varepsilon_a \tag{5.1}$$

where:

V_a is structural (or systematic) utility of activity a

ε_a is random utility (or error term)

The random utility (ε_a) is applied to model the intermediate activity behaviour more realistically. It adds variation to the outcome of this model representing effects of unobserved factors from the analyst point of view (see section 5.4.1.2).

Based on Joh (2004) and Arentze and Timmermans (2006) the following logistic growth function for V_a is proposed:

$$V_a = V_{\min} + \frac{V_{\max}}{1 + \exp(\beta(\alpha - t))} \tag{5.2}$$

where:

V_a is structural utility of activity a as function of time t

$V_{\max}$ is maximum utility of activity a

β is slope of the S-curve

α is horizontal displacement of the S-curve

$V_{\min}$ is minimum utility of activity a

See Figure 5.4 and Figure 5.5 for explanation of the influence of the α and β parameters on the shape of the S-curve.
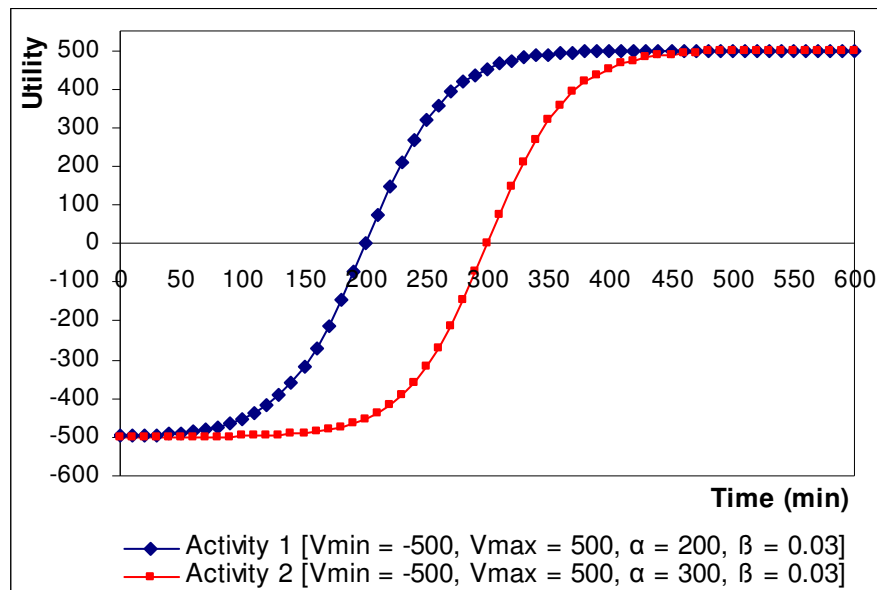
Figure 5.4: The influence of the α parameter on structural utility V_a.
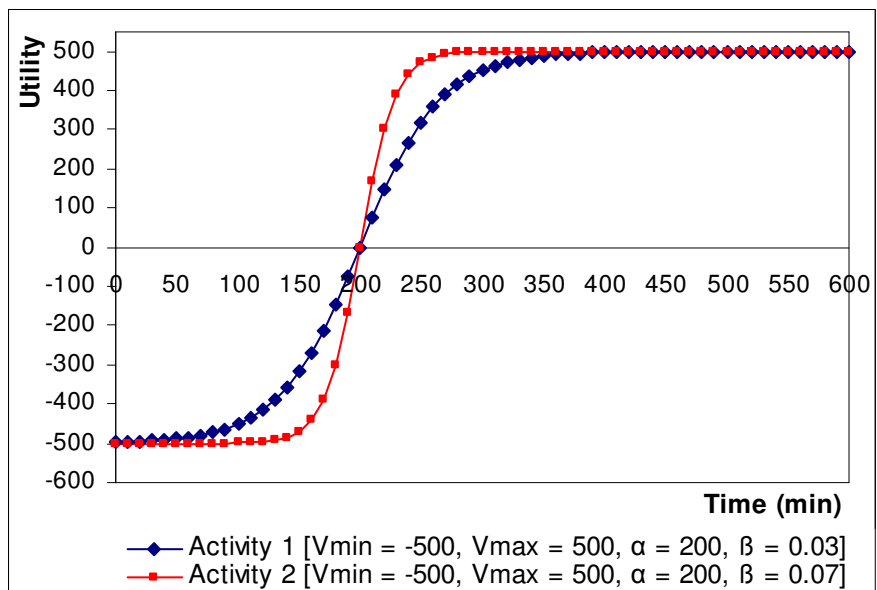
Figure 5.5: The influence of the β parameter on structural utility V_a.

5.4.1.1 Context of intermediate activities

The values of the α and β parameters and the values of the V_{max} and V_{min} variables depend on the type of intermediate activity (i.e. the values differ per type). However, the utility of an activity is also influenced by the context in which the activity is performed. The characteristics of the day, like previous performed activities, time pressure or the type of skeleton activity an employee is currently performing influences the likelihood that an employee engages in an intermediate activity. The context is modelled using two

effects, namely the type-of-day and type-of-activity effect. These two effects are explained in the following two sections.

Type-of-day effect

It is assumed that the set of skeleton activities conducted by an employee on a working day has an influence on his intermediate activity behaviour for that day. This influences his propensity for conducting intermediate activities.

Example
Suppose that the working day of an employee mainly consists of solo job related activities and to a lesser degree of group activities, like meetings. In other words, he has been working on his own for a considerable time. In this case he is more willing to engage in intermediate activities, as a welcome interruption of his skeleton activities, than compared with a day mainly consisting of meetings.

It is assumed that if a working day is dominated by meetings an employee is less likely to perform intermediate activities than on a day consisting of solo activities. On a day consisting of mainly meetings he has less time to perform his other job related activities; he is less willing to accept the distraction of intermediate activities to interrupt the little time he has to perform these activities. On such a day, an employee has less need for intermediate activities. In other words, the type-of-day effect limits the utility of an intermediate activity (chapter 9 will test this assumption based on the analysis of data collected in the real world).

Type-of-activity effect

The nature of the skeleton activity that an intermediate activity is going to interrupt affects the utility of the intermediate activity. The more formal a skeleton activity is, the higher the utility of an intermediate activity needs to be before it is executed. In this case an employee is less inclined to let an intermediate activity disrupt the skeleton activity he is engaged in, it is more likely that he postpones the intermediate activity.

Example
When an employee is performing the skeleton activity *attend a meeting* he is far less likely to get a cup of coffee than when he is sitting behind his desk performing the skeleton activity *research*.

Both effects combined

The type-of-day and type-of-activity effects combined describe the context in which intermediate activities occur. The context influences the structural utility level of an intermediate activity. It is represented by the $V_{context}$ variable in function 5.3.

$$V_a = (V_{min} + \frac{V_{max}}{1+\exp(\beta(\alpha - t))}) - V_{context} \qquad \textbf{(5.3)}$$

The outcome of the variable $V_{context}$ is a function of the two mentioned effects:

$$V_{context} = f(\text{type-of-day, type-of-activity effect}) \quad \textbf{(5.4)}$$

$V_{context}$ is (conveniently) assumed to be the sum of both effects. The following function is proposed:

$$V_{context} = x_a + y_a \quad \textbf{(5.5)}$$

where:

x_a is type-of-day effect of intermediate activity a

y_a is type-of-activity effect of intermediate activity a
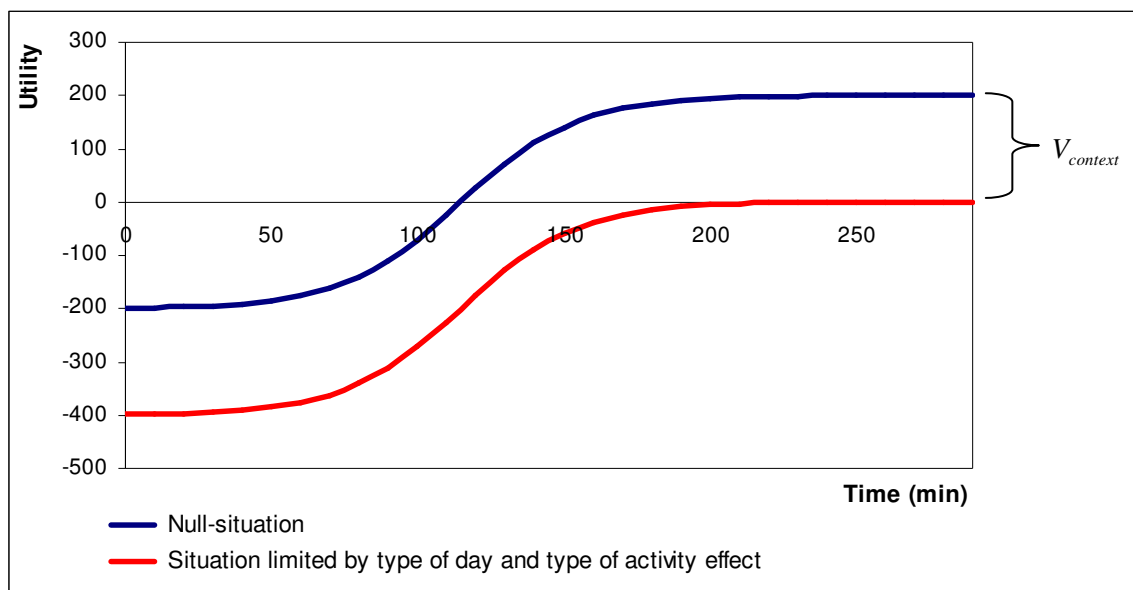
Figure 5.6: The influence of $V_{context}$ on the utility of an intermediate activity.

The $V_{context}$ variable causes a vertical downward displacement of the S-curve compared with the so-called null situation (see Figure 5.6). This relates to the situation in which the utility of an intermediate activity is not limited by both effects; the combined effect is neutral. In other words, the nature of the skeleton activity that an employee currently is engaged in does not reduce the willingness of an employee to perform intermediate activities and the context of the day also does not limit his opportunity to perform intermediate activities.

5.4.1.2 The occurrence of intermediate activities

A threshold parameter is used to decide when an intermediate activity should be included in an employee's activity schedule. In other words, an intermediate activity is only executed after its utility (i.e. need) has a reached a certain level. In this model the threshold value is $U_a = 0$ for all intermediate activities. An intermediate activity is added

to the activity schedule of an employee at the first moment in time when the total utility (i.e. the structural utility combined with the random utility and the constant utility) of this intermediate activity is zero or bigger than zero. In other words, an employee performs intermediate activity a, when the following criterion is met:

$$U_a = V_a + \varepsilon_a \geq 0 \qquad\qquad\text{(5.6)}$$

The properties of the intermediate activities types in conjunction with the type-of-day and type-of-activity effects determine the occurrence of intermediate activities (i.e. they determine the shape of the S-curve). Although the characteristics of an intermediate activity do not differ per day, the context of the day varies, because an employee performs a different set of skeleton activities on each working day. This causes some variation in the outcome of the model. In the real world the intermediate activity behaviour of an employee strongly differs from day to day in terms of types of intermediate activities, their order and timing. The random utility (ε_a) is applied to model the intermediate activity behaviour more realistically (i.e. to add extra variation to the outcome of this model). It is to be assumed to be a double exponential distributed random value.

When the context variable ($V_{context}$) is determined and the random utility (ε_a) is calculated the occurrence of the S-curve intermediate activities can be determined. The exact moment in time when $U_a \geq 0$ is calculated using formula 5.7 provided that $V_{max} > -V_{min}$.

$$t = -\frac{\ln(\dfrac{V_{max}}{-(V_{min} + V_{context} + \varepsilon_a)} - 1)}{\beta} + \alpha \qquad\qquad\text{(5.7)}$$

The calculated time value t represents the time elapsed since the previous occurrence of an intermediate activity type (i.e. the previous moment in time when $U_a \geq 0$) or it represents the time elapsed since the start of the working day if the intermediate activity has yet to occur (see also below). An intermediate activity is added to the activity schedule on the calculated t value, provided that $t > 0$. After the occurrence of the activity the S-curve is basically reset (i.e. the S-curve is returned to its initial situation and starts to grow again). The next time that $U_a \geq 0$ can, again, be calculated after the context variable ($V_{context}$) and the random utility (ε_a) are determined; for that moment again an intermediate activity is added to the activity schedule. This process starts at the beginning of the workday and continues until the end of the working day is reached. Due to the fact that the context of the day ($V_{context}$) varies during the day and due to the occurrence of intermediate activities (activity reset), the actual shapes of the S-curve belonging to these intermediate activity types have an erratic shape (see Figure 5.7).

The shape of the S-curve of an intermediate activity type (i.e. α and β parameters and V_{max} and V_{min} variables) and, to a lesser extent, the context variable (i.e. $V_{context}$) have

an influence on the frequency of this intermediate activity. Figure 5.7 shows two S-curves belonging to two intermediate activity types; the utility of intermediate activity type 1 increases faster than intermediate activity type 2, resulting in intermediate activity type 1 being more often executed on a working day than intermediate activity type 2. This means that there is a strong relationship between the shape of the S-curve of an intermediate activity type and its frequency. The frequency of an intermediate activity strongly depends on the values for the α and β parameters and the V_{max} and V_{min} variables. In the real world the (mean) frequency of an intermediate activity will vary per employee.

Example
Some people will perform an intermediate activity like *get a drink* more often than others on a working day due to for instance personal preferences.
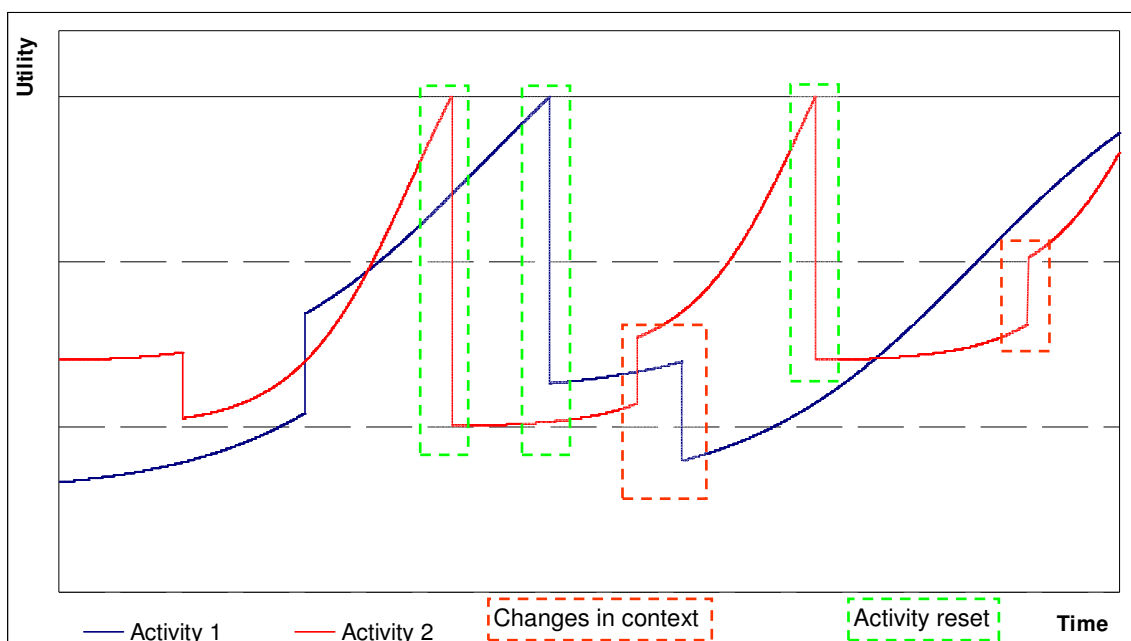
Figure 5.7: The complex erratic shape of two S-curves taking into account changes in the context of the day and the performance of activities (activity reset).

In other words, not everyone performs an intermediate activity the same number of times during a workday. To realistically model intermediate activity behaviour the shape of the S-curve of an intermediate activity type depends on the frequency with which employees perform this intermediate activity. This means that there will be a different set of values for the α and β parameters and the V_{max} and V_{min} variables of function 5.3 per frequency of an S-curve intermediate activity. Each employee will be stochastically assigned to a frequency (see section 6.6.5.1). Finally, it is assumed that an employee will behave differently in the situation when he performs an intermediate activity for the first time on a working day than compared with the situation when he already performed the intermediate activity during his working day. In other words, the shape of the S-curve of an intermediate activity depends on if it is the first occurrence of this intermediate activity during a working day or one of its subsequent occurrences. The differences between the two S-curve shapes will vary per S-curve intermediate activity.

Consequently, there will be two sets of data for each frequency per intermediate activity type, namely a data set for determining the first occurrence of an intermediate activity and another data set for determining all subsequent occurrences of an intermediate activity on a workday.

5.4.2   Probabilistic

While the occurrence of some intermediate activities strongly depends on the time elapsed since the previous occurrence of an activity, other intermediate activities occur more or less randomly during a workday, like *receive an unexpected guest* (see Table 5.1). Instead of using an S-curve function, the model uses a random function to determine the start time of this type of intermediate activities. With this function the start time of these intermediate activities are randomly spread over the duration of the workday, while taking into account a minimum time-interval between activities. The number of occurrences of each intermediate activity during a workday (the desired frequency) depends on the mean frequency and a certain extent of variance.

5.4.3   Data collection

The parameters and variables of the S-curve intermediate activities and the probabilistic activities are estimated based on data collected via a web-based survey (see section 9.4). The aim of USSU is to simulate the activity behaviour occurring in office buildings. Consequently, the survey was held under (Dutch) employees currently working in an office building. Also data about the mean duration of each intermediate activity was collected. The collected data is not specific for an organisation or building, but can be applied to all Dutch office based organisations.

5.5   Approach for modelling the building space

This research project is not only interested in *what*, *how* and *by whom* suggested by van der Aalst and van Hee (1996). To simulate the human activity behaviour of office based organisations, an extra aspect was added to this approach, namely where. In the USSU modelling approach the continuous space in a building is discretised using a network of nodes and edges, a so-called graph (see Figure 5.8). The node object plays a central role in the building model. All spatial resources, including activity locations, are modelled using nodes. Nodes are linked with each other using edges.

In the context of this research project *where* is mainly limited to activity locations and routes. These are discussed below.

5.5.1   Activity locations

Each skeleton and intermediate activity occurs at a certain location in the building space. This means that for each activity a location has to be chosen which matches with the type of skeleton or intermediate activity and when relevant the size of the group of

employees involved in an activity. A building will normally consist of a number of locations which meet the location requirements of an activity. From all relevant activity locations only one has to be selected. This is the responsibility of the activity location choice algorithm. First, the activity location choice algorithm creates a choice set consisting of all relevant locations for an activity in an employee's activity schedule. Next, the algorithm calculates for each activity location in the choice set the distance to the location of the previous activity in his activity schedule (see below). Finally, the activity location associated with the shortest distance is chosen and allocated to the activity. It is assumed that all employees have the same preference for an activity location. Consequently, the activity location choice algorithm does not have to take individual preferences into account when selecting an appropriate activity location.

- ◆ Start node (entrance)
- ● End nodes (belongs to facility, workplace or meetingspace)
- ● Connector node (belongs to hallways etc)
- ● Node belonging to external abstractspace
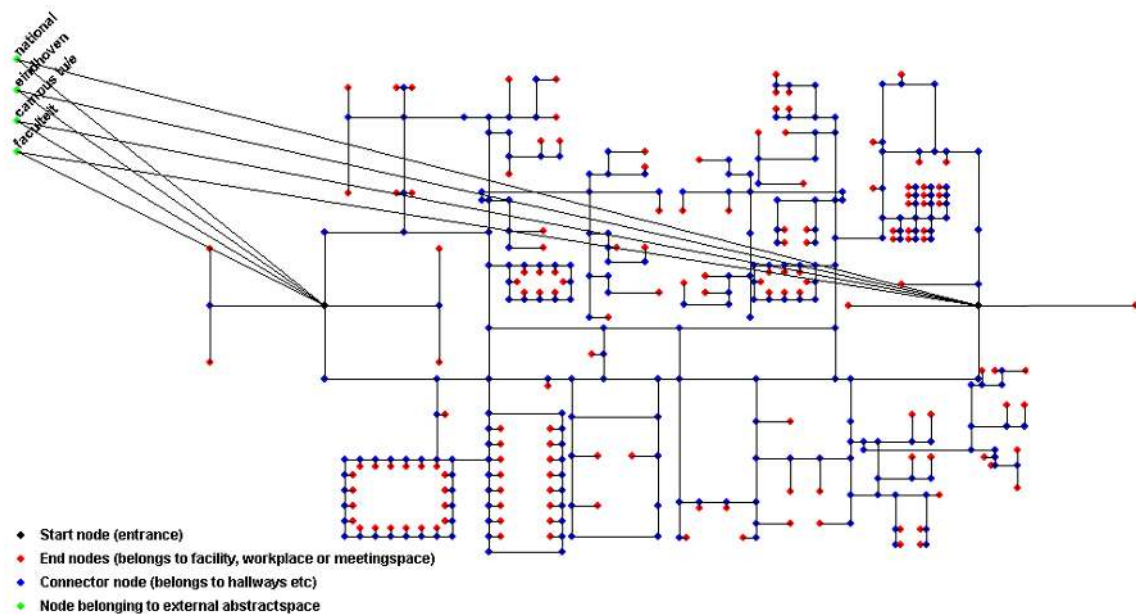
Figure 5.8: Graph with nodes and edges.

5.5.2   Routes

In order for USSU to realistically simulate human movement behaviour in office buildings the modelling approach also has to deal with the routes that are followed by employees between the locations of activities. These routes are necessary to calculate accurate walking times and to analyse a building (design) in terms of for example usage of hallways. A route consists of an ordered set of nodes connecting two consecutive activity locations. From all possible routes between the location of an activity and the location of the next activity in an activity schedule the shortest route is selected. Route choice is based on a shortest path algorithm similar to Dijkstra's algorithm (Dijkstra, 1959). The selected route is static and fixed; there is no dynamic rerouting (i.e. adaptive route choice behaviour) while employees are moving between activity locations due to for instance crowding or congestion on edges in the graph. The shortest path algorithm is also used by the activity location choice algorithm.

5.5.3   Building data model

Ideally data about activity locations and routes in a building space are imported from a CAD (Computer Aided Design) package in which (the design of) the office building that is analysed has been modelled. Using CAD packages it is possible to create a detailed three dimensional building model and export it to other software packages using comprehensive Building Information Models (BIM) (Howard and Bjork, 2007; Eastman, 1999). As this project is only interested in limited data about office buildings (i.e. activity locations and routes), the decision was made to opt for a simple building data model containing only the necessary data about the simulated building.

5.6   Conclusions

This chapter introduced the approach in which activity based modelling and workflow modelling are combined for modelling the different types of activities that occur within an organisation. These two approaches are considered complementary. While workflow modelling is used to model skeleton activities, activity based modelling is applied to model the intermediate activities. The combination of these two methods is assumed to provide a solid basis that ensures process consistency, inclusion of individual re-scheduling behaviour and allows for execution in real time or compressed time intervals.

The final classification of the two types of activities in the modelling approach is as follows:

- Skeleton activities: the direct workflow dependent activities.
- Intermediate activities: other activities, among other things social and psychological activities.

This chapter explained both types of activities in detail. With regard to the intermediate activities attention was paid to how these activities are predicted. This chapter also discussed how the spatial conditions within the building that is simulated are modelled. The building model basically consists of a graph, consisting of nodes and edges. Using the graph the activity locations are modelled. The graph is used to determine the routes between activity locations and to select a location for each activity in an activity schedule.

Based on the modelling approach introduced in this chapter a detailed system design of USSU was created. This will be discussed in chapter six.

PART 2 PROTOTYPE

C6 System design

6.1 Introduction

The previous chapter introduced the modelling approach to simulate human activity behaviour in office buildings. Based on this modelling approach a detailed system design of USSU was created. It describes how the various aspects perceived as essential in the modelling approach should be implemented. The USSU system is subdivided in a number of sub-systems. Each of these sub-systems is responsible for one aspect in predicting the space utilisation of office buildings. This chapter discusses the system design. It will discuss all sub-systems comprising USSU, with a focus on the scheduler sub-system. This sub-system plays a central role in USSU, because it is responsible for organising the scheduling process. The scheduler is composed of a number of so-called scheduler-modules which take care of scheduling the skeleton and

intermediate activities. This chapter also describes which data is needed by the USSU system to predict the space utilisation of an organisation housed in an office building.

First, the structure of sub-systems comprising the USSU system is introduced and the input and the output of the USSU system are explained. Next, each of the USSU sub-systems is discussed in detail, among other things the input and output of a sub-system is explained. The scheduler sub-system will be discussed in more detail in section 6.6. This section introduces and discusses all scheduler-modules and explains the scheduling process of the skeleton and intermediate activities. This chapter ends with conclusions on the USSU system design.

6.2   System structure

Figure 6.1 shows the conceptual diagram of the USSU system. The system predicts the corresponding space utilisation based on two forms of input, namely the structure of the organisation and the design of the building in which the organisation is (or will be) housed (i.e. spatial conditions).
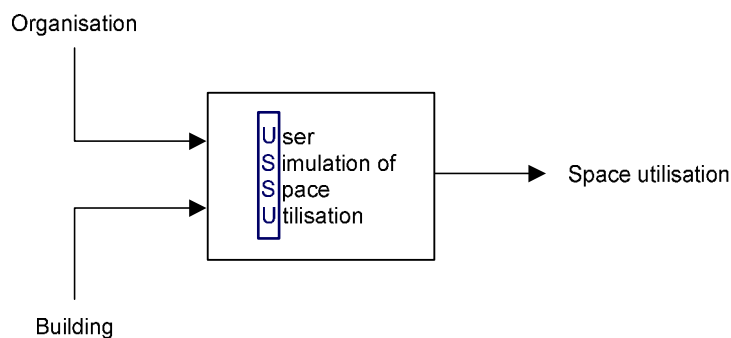
Figure 6.1: Conceptual diagram of USSU system.

The USSU system comprises a number of sub-systems. Figure 6.2 shows the structure of the USSU sub-systems. The organisation sub-system and the building sub-system need input from the user. The output of the organisation and building sub-systems is combined by the resource management sub-system. The scheduler takes care of producing the desired output of the system, namely a movement pattern for each simulated working day. A movement pattern not only describes which activities are performed by employees on a working day, but also details the routes between the locations of these activities.
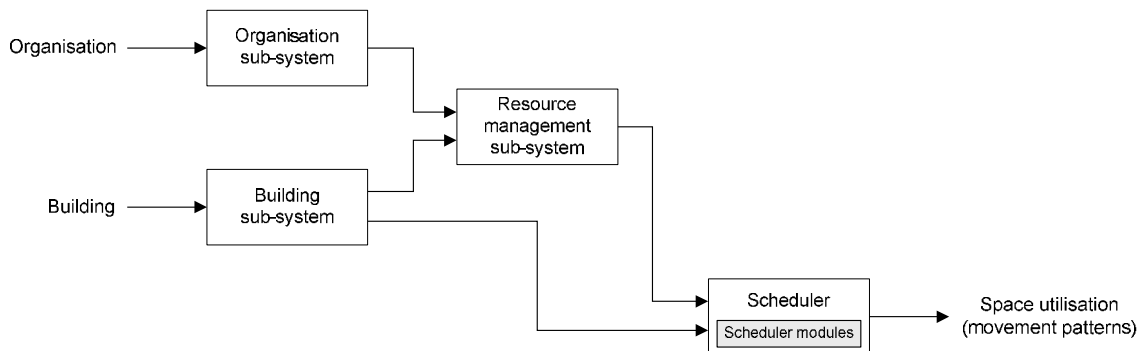
Figure 6.2: Structure of sub-systems of the USSU system.

To know which activities are performed by employees in the organisation, each employee is linked with an activity schedule. An activity schedule not only describes the order of activities for an employee for a certain period (i.e. a workday), it also specifies the location of each activity (see Table 6.1). Based on the activity schedules the system knows the location of each activity for an employee, but not yet which route he should follow to move from an activity location to the next activity location. Therefore, information about activities in the activity schedule is combined with information regarding the routes between consecutive activities. The result is a movement pattern: an activity schedule including all relevant routes.

Activity	Start time	End time	Location	Activity-type	Priority
Research	09:29:06	09:35:36	Workplace 9.13 (office)	work	1
Get a drink	09:35:36	09:38:24	Pantry	coffee corner	5
Research	09:38:24	09:41:06	Workplace 9.13 (office)	work	1
Teach	09:41:06	12:18:54	Lecture hall 2	meeting	8
Research	12:18:54	13:02:31	Workplace 9.13 (office)	work	1
Lunch	13:02:31	13:27:31	Canteen	canteen	6
Research	13:27:31	13:58:50	Workplace 9.13 (office)	work	1
Attend meeting	13:58:50	17:00:00	Meeting room 9.20	work	6

Table 6.1: An activity schedule of a PhD student
(activities depicted in gray are skeleton activities).

The sub-systems comprising the USSU system are discussed in more detail in the following sections.

6.3   Organisation sub-system

The organisation sub-system is responsible for modelling the skeleton activities of all employees belonging to the simulated organisation. The user of the system has to specify the structure of the organisation in detail, because the occurrence of skeleton activities mainly depends on the organisation structure. Each organisation has its own specific workflow. Not only will the workflow strongly differ between types of organisations (e.g. compare for example an insurance company with a consultancy

firm), but also the workflow of organisations belonging to the same organisation-type will vary (e.g. not every insurance company has exactly the same workflow).

An organisation consists of a number of roles (e.g. secretary, PhD student or manager) and a number of organisational units (e.g. sales department, research chair or complaints unit). Roles and organisational units are associated with the resource *employee* in the resource management sub-system (see section 6.5). An employee can fulfil more than one role and an employee can belong to more than one organisational unit. Each organisational unit and each role is linked with a set of tasks (see Figure 6.3). A task is a logical unit of work and belongs to a specific combination of an organisational unit and a role. Furthermore, a task is associated with a task-type. While a task is unique (i.e. it has its own specific values of its properties), task-types are general. All tasks belong to a limited set of task-types and each task-type is associated with multiple tasks. The USSU system is able to track each task to its corresponding task-type. In this way when tasks of a certain type are needed (for example when solving the interaction between people) the system (i.e. scheduler) can determine which tasks to select. In addition, all tasks-types are abstracted to a small set of activity-types, like: *meeting, work, concentrated work* and *external*. The activity-type is used by the scheduler sub-system to find an appropriate location for an activity (see section 6.6.9).
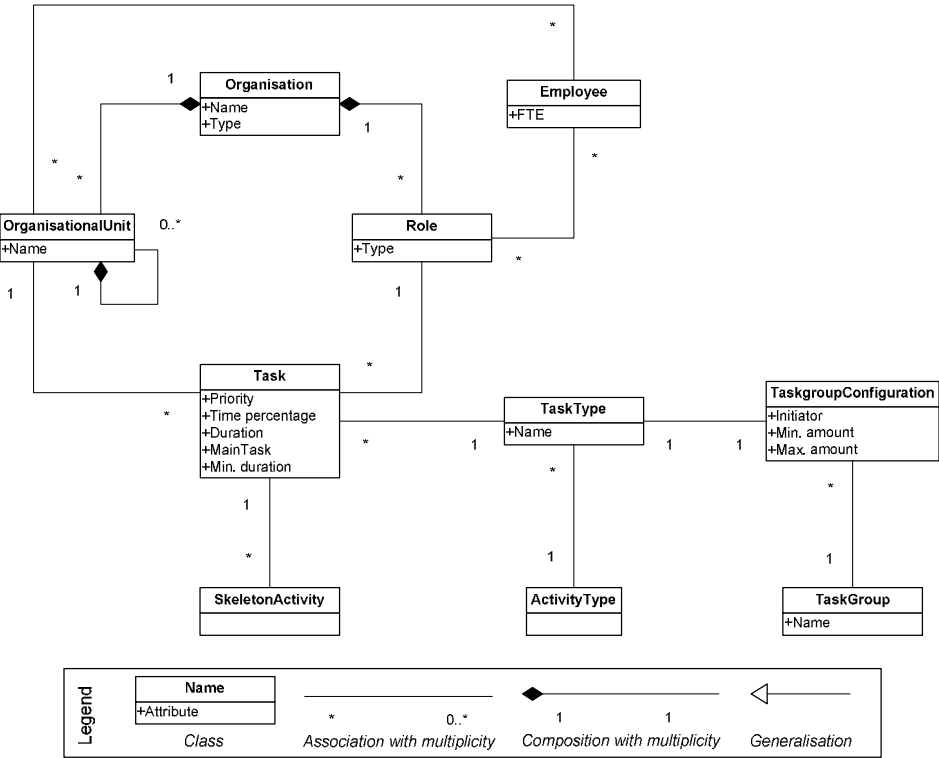
Figure 6.3: Simplified class diagram of the organisation structure.

The combination of roles of an employee and the organisational units he belongs to determines the set of tasks for which he is responsible (i.e. this combination determines his workflow). A skeleton activity is an instance of a task. Each task is associated with multiple skeleton activities. The set of tasks belonging to each employee is used by the USSU system to determine which skeleton activities he can perform during a working day (see section 6.3.3).

6.3.1   Interaction between employees

Many tasks require interaction between people (see section 5.3.2). To determine which tasks are related, the concept task-group is introduced. A task-group is a collection of task-types which are related to each other in the context of employee-interaction (see Table 6.2). Each task-group is unique; the composition of the task-group differs per group.

Example

The task-group *PhD coaching* consists of two task-types, namely *give PhD coaching* and *get PhD coaching*. The task-group *DDSS meeting* comprises three task-types: *attend meeting, chair meeting* and *take minutes*.

In general, task-groups will consist of 2-3 different task-types. Not only does the number of task-types associated with a task-group vary, also the number of employees involved with task-types differs per task-group.

Example

For the task-type *give PhD coaching*, belonging to the task-group *PhD coaching*, 1 or 2 employees has to be selected to perform the associated skeleton activity. The task-type attend meeting belonging to the task-group *DDSS meeting* requires the involvement of for example 5 or more employees.

The example above makes clear that each task-type belonging to a task-group requires the involvement of a certain number of employees who can perform the associated skeleton activities. In other words, each task-type is related to a certain number of tasks and for each of these tasks an employee has to be selected who has this task in his set of tasks. In the end, this results in a number of skeleton activities that have to be scheduled. The composition of each task-group is specified using a so-called task-group configuration. This specifies the number of skeleton activities that have to be scheduled for each task-type. In the task-group configuration the number of related tasks is set using a minimum and maximum limit. These limits specify the minimum and maximum number of employees that should be involved with a task-type (see Table 6.2). Based on the upper and lower limit the scheduler determines the required number of employees who should perform the related skeleton activities.

Finally, not all tasks in a task-group are equal in the context of employee-interaction.

Example

Assume a university faculty building is analysed using the USSU system. A PhD student has to be employed by the organisation housed in this building in order for a task-group like *PhD coaching* to be relevant. Without PhD students there is no need for *PhD coaching*. Consequently, there is no need for the interaction-scheduler to take this task-group into account. However, when one of the employees in the organisation is a PhD student and he has the skeleton activity *get PhD coaching* in his activity schedule, interaction between employees is triggered. In other words, this task *get PhD coaching* is the initiator of interaction between employees.

Each task-group contains one task-type that activates the scheduler to look for related tasks. This is specified by the initiator attribute in the corresponding task-group configuration (see Table 6.2).

Task-types	Task-group	Task-group configuration		
		Minimum number of related tasks	Maximum number of related tasks	Initiator
Get PhD coaching	PhD coaching	1	1	X
Give PhD coaching		1	3	
Attend presentation	Presentation	5	∞	
Give presentation		1	1	X
Attend meeting	Meeting DDSS	5	∞	
Chair meeting		1	1	X
Take minutes		1	1	

Table 6.2: Interaction between task-types and task-groups.

6.3.2 User input

For the organisation sub-system the user has to input data related to the structure of the organisation he wants to simulate. Among other things, the user has to specify the roles and organisational units belonging to the organisation and he has to specify a set of tasks for each role and organisational unit. Each task has the following set of properties (see Table 6.3):

- Time percentage

   The time an employee spends on this task as a percentage of his total work time.

- Priority

   This attribute determines the importance of an activity (see section 3.4.3).

- Average duration

   This specifies the average duration of a task, ranging from a couple of minutes to a couple of hours. The actual duration of the skeleton activity will vary per occurrence.

- Minimum duration

   This property sets the absolute minimum value of the duration of a task. The actual duration of an instance of this task (i.e. skeleton activity) will never be shorter than this value.

- Main task

   Each role is associated with one task that is marked as main task. An employee spends most of his time on this task. The main task plays an important role in the scheduling process of skeleton activities (see section 6.6.6).

- Task-type

   Finally each task is associated with a task-type.

For each task-group the corresponding configuration has to be specified. The user has to specify the task-types comprising a task-group and for each task-type the minimum and maximum number of related tasks has to be set. Finally, one of the task-types belonging to a task-group has to be marked as initiator (see Table 6.2).

Task-type	Time percentage (%)	Priority	Average duration (minutes)	Minimum duration (minutes)	Main task
Get PHD coaching	8	9	60	30	
Research	50	1	30	15	X
Give presentation	5	7	60	30	
Write publication	1	4	60	30	

Table 6.3: Examples of a set of tasks of a PhD student.

Input data for the organisation sub-system can be constructed from job descriptions stated by the organisation which is simulated. The values of some task properties (e.g. time percentage) can be calculated based on data of the time registration system of the organisation. Other property values have to be determined using bespoke data collections.

6.3.3   Output information

The output of the organisation sub-system is a set of skeleton activities for each employee for a specific workday. These skeleton activities are stochastically drawn from the total set of tasks associated with an employee based on the time percentages of these tasks. The higher the time percentage, the more time an employee spends on this task and the higher the probability that this skeleton activity will be selected. The organisation sub-system can only draw tasks associated with task-types that are the initiator of a task-group (e.g. *get PhD coaching*) or tasks that do not belong to a task-group, e.g. *research* or *prepare education*. The latter tasks do not require any interaction between employees and can be independently scheduled of all other tasks. The set of drawn skeleton activities is used by the scheduler as starting point for scheduling the skeleton activities for a workday.

6.4   Building sub-system

The building sub-system is responsible for modelling the spatial conditions in which the skeleton and intermediate activities take place (see Figure 6.4). The node object is the central object in the building sub-system. All spatial and physical resources (e.g. workplaces, printers) are located at nodes. All nodes are linked with each other by edges. The total system of nodes and edges is called a graph (see section 5.5).

Figure 6.4: An office environment with a section of a graph.
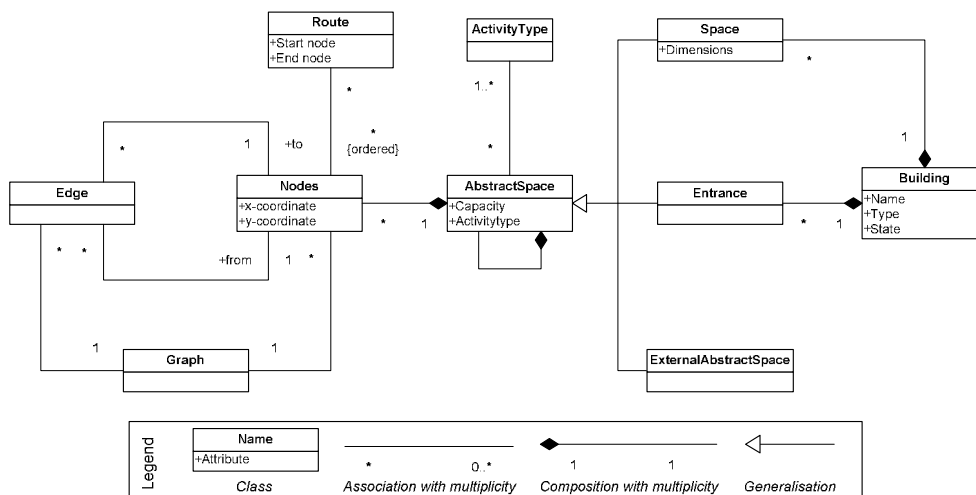
Figure 6.5: Simplified class diagram of the building structure.

6.4.1 Abstract-space

Each skeleton or intermediate activity occurs at a certain location, a so-called abstract-space. An abstract-space has no dimensions. Abstract-spaces form the abstraction of real spaces in office buildings. Each abstract-space is linked with a set of nodes. The size of the set of nodes specifies the capacity of an abstract-space, for instance the number of available seats in a meeting room. In addition, an abstract-space itself can contain one or more abstract-spaces (see Figure 6.5 and Figure 6.6).

Three different sub-types of abstract-spaces can be distinguished, namely spaces, external abstract-spaces and entrances. These sub-types are discussed below.

6.4.1.1 Space

A building consists of a number of physical spaces, like office rooms, meeting rooms or hallways. In the USSU system these physical spaces are represented by the sub-type space.

Example
An example of a space is an office room. This office room, however, can contain two or more abstract-spaces, like a workspace and a meeting space (see Figure 6.6).
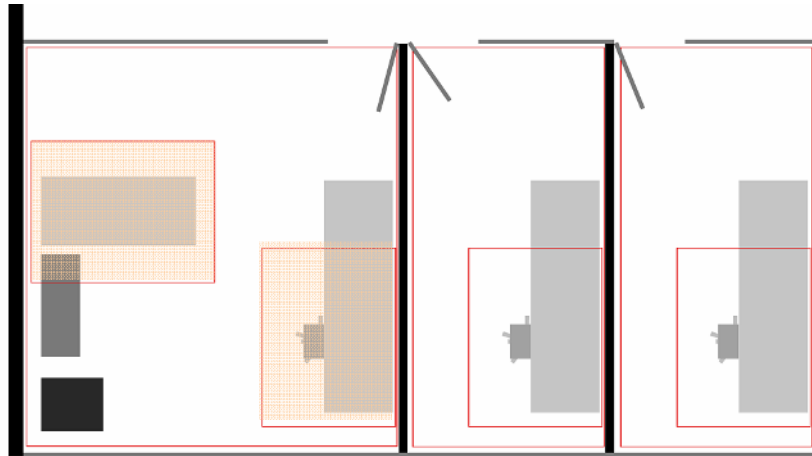
Figure 6.6: Examples of abstract-spaces (office on the left contains two abstract-spaces).

6.4.1.2 External abstract-space

Although employees perform most of their activities in the building in which they have their workplace, they also perform activities outside of this building, like external meetings and presentations. For the USSU system this means that the activity schedule of an employee will consist of skeleton activities associated with the activity-type external. This means that not all activity locations are located within the building that is simulated. These skeleton activities can be conducted in close proximity of the building, for instance in the same city or region, but they can also take place abroad. Furthermore, the USSU system can also be used to simulate parts of an office building, instead of a whole building. When USSU is applied for only simulating a part of an office building, the other parts of this building are of minor interest. However, these parts still need to be incorporated in the building model for predicting the occurrence of external skeleton activities and associated travel times.

Example
If someone is only interested in predicting the space utilisation of one floor of a total office building, the building sub-system will only consider the abstract-spaces located on this office floor. However, the (virtual) employees will also perform activities on other floors of this building (and outside of this building). The locations of these activities need to be modelled in order to be able to calculate the required time to reach a location of one of these 'external' activities.

The locations of skeleton activities that are conducted outside of (the part of) the building that is analysed are modelled using so-called external abstract-spaces. A limited set of external abstract-spaces is incorporated in the building sub-system to model all external activity locations. While some of the external abstract-spaces will be located in close proximity of the analysed building (or even in the building itself if only a part of the building is analysed), other external skeleton activities are executed further away from this building (e.g. outside of the city where the building is located or even abroad). Although the first activity locations can still be reached on foot, the latter can not. Calculating the routes to external abstract-spaces can not be done in the same way as for abstract-spaces which are located inside an office building (see section 5.5.2). In order to consistently deal with all external abstract-spaces, the time required to reach an external abstract-space is determined using a pre-defined movement-time.

6.4.1.3 Entrance

Entrances are the third sub-type of abstract-spaces. In the real world a person can enter or leave a building in a limited number of ways because he has to use one of the few available entrances. To simulate the way employees enter and leave a building each building is linked with a limited set of entrances. The entrances form the starting (and end) points of the graph (see Figure 5.8). While a person in the real world can have a preference for a certain entrance, the USSU system chooses the entrance nearest to the location of the first activity after he entered the building.

6.5   Resource management sub-system

The resource management sub-system provides the interface for the scheduler sub-system with the organisation sub-system and building sub-system. This sub-system keeps track of all information related to resources available either in the simulated organisation or office building. The following three different types of resources are distinguished:

- Person

  This type can be subdivided in two sub-types, namely employees and guests. The most important sub-type is the employee and is linked with the organisation sub-system and the scheduler. The second sub-type, guests, plays a role in the scheduler sub-system.

- Abstract-space

  The locations of both skeleton and intermediate activities are modelled using abstract-spaces, which are associated with the building sub-system.

- Facility

  The last type of resources represents facilities for employees to perform their activities, such as a printer or a pc.

6.6   Scheduler

Interaction between employees (e.g. meetings or presentations) has major impact on the scheduling process, as skeleton activities have to be inserted in the activity schedules of all people involved. Interaction also influences the location finding process (i.e. the activity location choice algorithm), because the activity location should be able to accommodate the total number of employees involved in a group activity. Determining which skeleton activities require interaction is one of the responsibilities of the scheduler sub-system. Each activity schedule is associated with a separate instance of the scheduler (and scheduler-modules). The architecture of the scheduler and its scheduler-modules is presented in Figure 6.7. Next section gives a short introduction to each of the scheduler-modules.
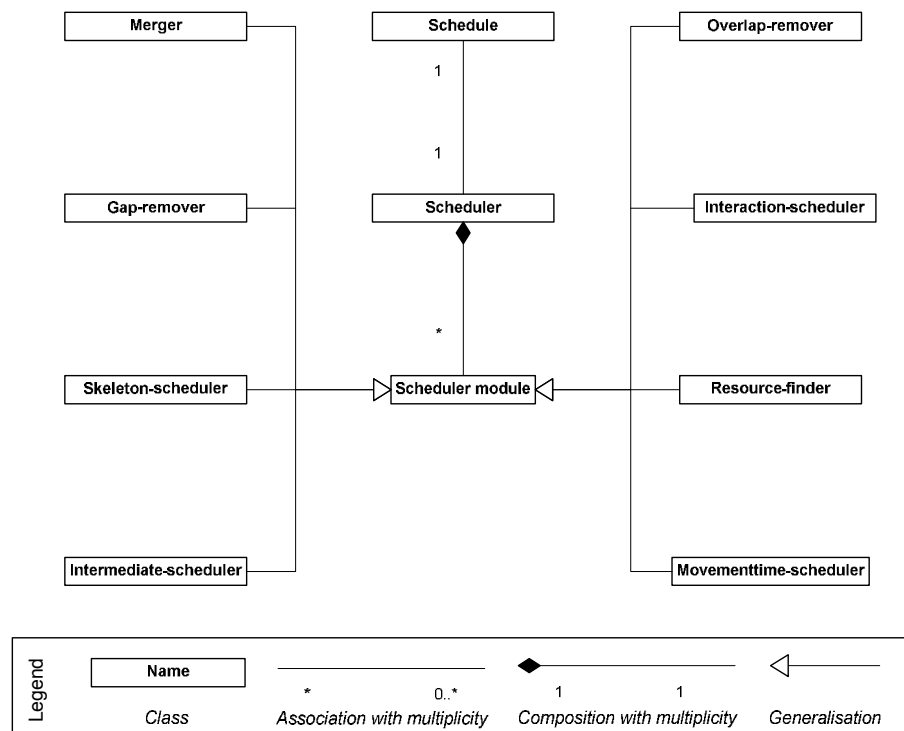
Figure 6.7: Structure of the scheduler.

6.6.1   Scheduler-modules

The scheduler consists of eight scheduler-modules. Each scheduler-module is responsible for a separate task in the scheduling process, namely:

- Skeleton-scheduler: schedules the skeleton activities.

  This scheduler-module determines the start time and end time of each of the skeleton activities selected by the organisation sub-system.

- Interaction-scheduler: determines interaction between activities.

  This scheduler-module determines for each skeleton activity whether it requires interaction with other employees or not. If a skeleton activity requires interaction, the scheduler-module determines which other skeleton activities have to be scheduled,

which individuals should be involved and adds these skeleton activities to the appropriate activity schedules.

- Intermediate-scheduler: schedules intermediate activities.

  The different types of intermediate activities are scheduled by this scheduler-module. Scheduling these activities is done using two different methods, namely the S-curve method and the probabilistic method (see section 5.4). Each intermediate activity was assigned to a method based on its characteristics.

- Gap-remover: repairs gaps in an activity schedule.

  This scheduler-module finds and repairs time-gaps in the activity schedule by creating new skeleton activities with the duration of the time-gaps.

- Overlap-remover: repairs overlaps in an activity schedule.

  As a result of actions taken by some scheduler-modules (e.g. the interaction-scheduler or the intermediate-scheduler) activities in an activity schedule can overlap each other. An activity schedule contains an overlap if the start time of one of its activities lies before the end time of the previous activity in the activity schedule. The overlap-remover repairs an overlap in the activity schedule by rescheduling one (or more) activities related to this overlap.

- Merger: joins several activities into one activity.

  During the scheduling process an activity schedule can consist of several consecutive skeleton activities that belong to the same task-type. If certain criteria are satisfied these activities are joined into one skeleton activity by the merger.

- Resource-finder: selects an appropriate location.

  Each activity requires a number of resources. This is primarily the location of an activity. However, other resources (e.g. facilities) can also be required to perform an activity. The resource-finder selects the appropriate resources and allocates these to each activity in the activity schedule.

- Movementtime-scheduler: calculates the required movement-time.

  This scheduler-module is responsible for adding the movement-times to the activities in the activity schedule.

Each of these modules will be discussed in detail. Next section, however, will first give an insight in the scheduling process. It discusses how, when and why the different scheduler-modules are activated.

6.6.2 The scheduling process

The process of scheduling the skeleton and intermediate activities is determined by the order in which the scheduler-modules are activated when creating a movement pattern. First, from all activity schedules for which the activity scheduling process is not finished yet, one activity schedule is chosen at random and the corresponding scheduler is activated. After activating the scheduler the corresponding scheduler-modules are asked to determine their importance (see Figure 6.8).
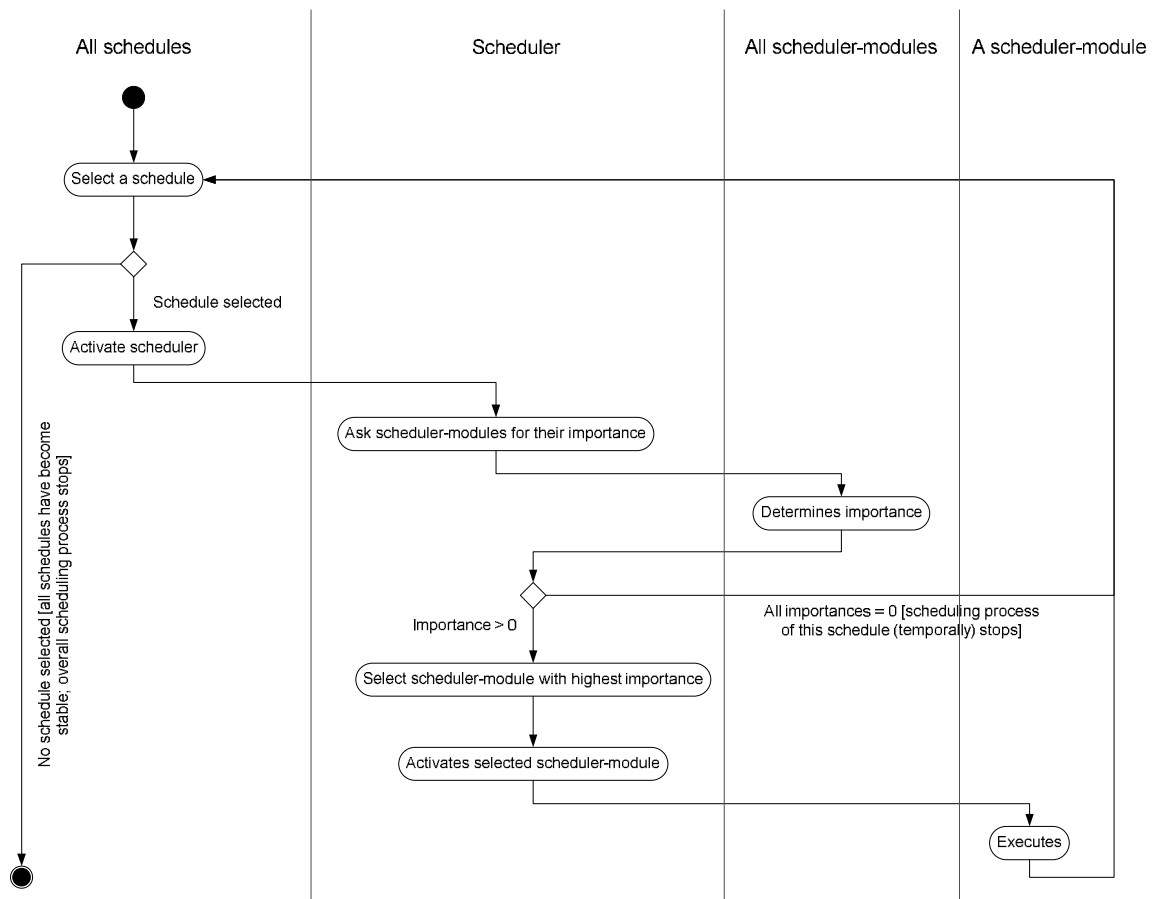
Figure 6.8: Activity diagram of the activity scheduling process.

The scheduler-modules determine their importance based on the state of the activity schedule and its activities. Each scheduler-module uses a rule based algorithm to test the current activity schedule against a set of predefined criteria. If the criteria are satisfied than the importance is > 0, else it is 0. For each scheduler-module the value of the importance is preset (in the system configuration file); the value does not vary during the scheduling process (see section 7.3.4). The scheduler selects the scheduler-module with the highest importance. The user of the USSU system does not have any control over the order in which the scheduler-modules are activated. Next, the selected scheduler-module is activated. When the scheduler-module has made its modifications to the activity schedule (i.e. it is finished), all scheduler-modules are asked to determine their importance and a scheduler-module is selected once again. The scheduling process is a cyclic procedure, which stops when all criteria are satisfied. Meaning that the activity schedules of all employees can not be improved anymore within the given constraints, (i.e. all scheduler-modules report an importance equal to zero). In other words, the scheduling process with respect to the skeleton and intermediate activities stops when all individual activity schedules have become stable. When the scheduling process is finished, the scheduler has generated a movement pattern. The movement pattern describes the space utilisation of the organisation for a working day. Figure 6.9 shows an example of the scheduling process for one employee. It shows a realistic order of scheduler-modules which are activated for scheduling the activities belonging to this employee.
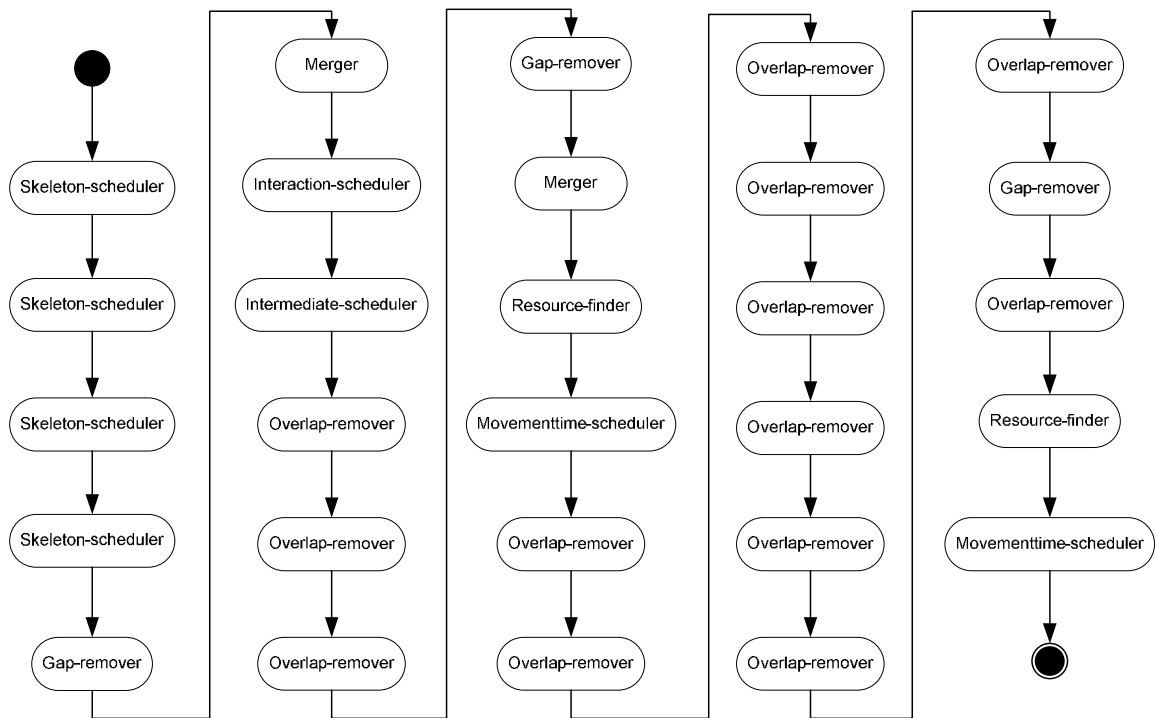
Figure 6.9: A realistic example of the scheduling process for an employee.

Next, the scheduling modules are described in detail, illustrated with examples.

6.6.3   Skeleton-scheduler

The skeleton-scheduler is responsible for determining the start time and end time for each unscheduled skeleton activity. This section discusses the step-by-step plan for scheduling skeleton activities (shown in Figure 6.10).
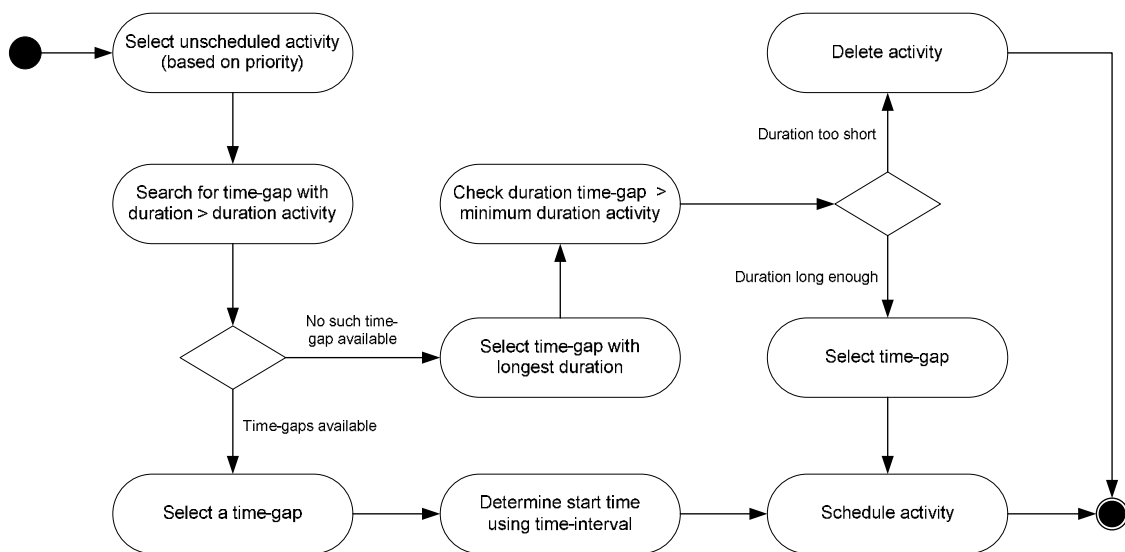
Figure 6.10: Activity diagram of skeleton-scheduler.

6.6.3.1 Step-by-step plan

When the skeleton-scheduler is activated only one skeleton activity at a time is scheduled. First one of the unscheduled skeleton activities is selected. From all unscheduled skeleton activities the activity with the highest priority is selected (i.e. the priority attribute of skeleton activities determine the order in which they are scheduled). Next, the skeleton-scheduler has to select a time-interval which is not yet occupied by a skeleton activity and that can accommodate the skeleton activity. The skeleton-scheduler searches for time-intervals with a duration longer than the duration of the selected skeleton activity (i.e. the skeleton activity fits within this time-interval). If the activity schedule has one or more time-intervals which satisfy this criterion, one of these intervals is selected at random. Next, the skeleton-scheduler has to determine the start time of the skeleton activity within this time-interval. The skeleton-scheduler only considers those start times which equal to multiples of a certain amount of time, the so-called scheduler-time-interval (e.g. 15 or 30 minutes). From the set of possible start times a start time is randomly selected and the skeleton activity is scheduled accordingly.

Example

Assume, the skeleton activity *do administrative work* of employee X is not scheduled yet. The duration of the skeleton activity is 120 minutes. The activity schedule has time-intervals from 9:15 until 9:30 and from 13:15 until 16:00 (see Table 6.4). The duration of the first time-interval is too short; the second time-interval is long enough to fit the skeleton activity.

Time	Activity
09:15 - 09:30	
09:30 - 12:00	Attend meeting
12:00 - 13:15	Lunch
13:15 - 16:00	
16:00 - 17:00	Attend meeting

Time	Activity
09:15 - 09:30	
09:30 - 12:00	Attend meeting
12:00 - 13:15	Lunch
13:15 - 14:00	
14:00 - 16:00	Do administrative work
16:00 - 17:00	Attend meeting

Table 6.4: Adding a new skeleton activity.

Scheduling the skeleton activities is based on a scheduler-time-interval of 30 minutes. Based on this value and on the fact that the skeleton activity has to end on or before the end time of the time-interval, only the following start times are feasible: 13:30 and 14:00. From the possible start times the skeleton-scheduler randomly selects one, in this case 14:00. This means that the skeleton activity *do administrative work* start at 14:00 and lasts until 16:00.

If no time-interval is available that can entirely accommodate the selected skeleton activity, the scheduler-module selects the largest available time-interval and checks if the duration of this time-interval is longer than the pre-defined minimum duration of the skeleton activity. If so, this time-interval is used to schedule the skeleton activity. The duration of the skeleton activity is set to the duration of the time interval; the remainder of the original duration of the skeleton activity is discarded. Ultimately, the skeleton

activity will be deleted from the activity schedule if no time-gap in the activity schedule can be located that can accommodate the skeleton activity,

6.6.4 Interaction-scheduler

Some skeleton activities require interaction between people. It is the responsibility of this interaction-scheduler to determine which skeleton activities require interaction and how to solve this.

6.6.4.1 Step-by-step plan

If an employee has a skeleton activity in his activity schedule which corresponds to a task-type that is the initiator of a task-group and the associated interaction is not solved, the interaction-scheduler has to solve the employee-interaction for this skeleton activity. The interaction-scheduler selects the skeleton activity with the highest priority. After a skeleton activity has been selected, the interaction-scheduler has to determine which other skeleton activities should be scheduled and which employees should be involved. First, the interaction-scheduler determines for each task-type in the task-group who are the employees that can perform these tasks (i.e. skeleton activities). To this end the scheduler searches for employees who have this task in their set of tasks and who are available at the moment during the working day. Next, the interaction-scheduler determines the number of related tasks that should be scheduled for each task-type. This is based on the lower and upper limit of related tasks as set in the corresponding task-group configuration. The interaction-scheduler maximises the required number of employees for each task-type.

Example
Assume an employee has the skeleton activity *give presentation* in his activity schedule. This skeleton activity is related with the skeleton activity *attend presentation*. The minimum number of related tasks for the task-type *attend presentation* is 1, the maximum number is 3. The interaction-scheduler will try to find three employees who can perform this skeleton activity. If not enough employees are present to perform this skeleton activity, the interaction-scheduler also accepts fewer employees to be involved with this skeleton activity with a minimum of 1 (the lower limit of related tasks).

Finally the interaction-scheduler has to select the required number of employees from the previously determined set of employees. They are stochastically selected using the number of organisational units each employee shares with the initiator (i.e. the employee who is responsible for initiating the interaction) as probability (see Table 6.5). The more organisational-units someone shares with another employee, the bigger the chance that he will perform an activity together with this employee. For each selected employee a skeleton activity is added to his activity schedule with the same start time and end time of the skeleton activity that triggered the interaction-scheduler to solve the employee-interaction.

Employee	Organisational-units					Shared units
	A	B	C	D	E	
1	X	X	X			-
2	X	X	X		X	3
3	X	X	X			3
4	X				X	1
5	X	X		X		2

Table 6.5: Matrix of five employees and their organisational-units. The last column shows the number of units each employee shares with employee 1, the initiator.

6.6.5 Intermediate-scheduler

The different types of intermediate activities (see Table 5.1) are scheduled by this scheduler-module. Scheduling these activities is done using two different methods, namely the S-curve method and the probabilistic method. The approach to scheduling these activities is given in section 5.4. The intermediate-scheduler does not schedule intermediate activities which take place during external skeleton activities, as intermediate activities interrupting external activities are not of interest for predicting the space utilisation of an office building.

6.6.5.1 S-curve method

The occurrence of S-curve intermediate activities is determined using function 5.7. The α and β parameters and the V_{max} and V_{min} variables are for each intermediate activity type set in the system configuration file, except the $V_{context}$ variable. This variable relates to the context in which the intermediate activities are performed and depends on the type-of-day and type-of-activity effect (section 5.4.1.1).

In relation to the type-of-day effect there are only two activity-types of interest, namely the activity-types *(concentrated) work* and *meeting*. The activity schedule of an employee normally consists of both work and meeting related skeleton activities. To which extent an activity schedule consists of skeleton activities of either one of these two activity-types will vary per working day. In order to make the context of a working day quantifiable, the activity schedule of an employee for that working day is abstracted to either mainly existing of:
- Skeleton activities of activity-type *meeting* or
- Skeleton activities of activity-type *(concentrated) work*.

In other words, the type-of-day effect consists of a two level variable.

The second effect, type-of-activity effect, is based on the attributes of the skeleton activities that employees are performing during a working day. This effect mainly depends on the activity-type of the skeleton activity which an intermediate activity tries to interrupt. In addition, if the activity-type is *meeting*, the effect also depends on if the employee is the initiator of the corresponding task-group. The type-of-activity effect is represented by a variable with the following four levels:

- Activity-type is *work*.

  This level relates to job related solo activities, like *research* or *prepare education*. When an employee is performing such a skeleton activity, he is approachable by other employees. Skeleton activities of this type are easily interrupted by intermediate activities.

- Activity-type is *concentrated work*.

  Skeleton activities associated with this activity-type are also solo job related skeleton activities, but in this case an employee is not approachable by other employees. These skeleton activities are more difficult to interrupt or postpone by intermediate activities than skeleton activities associated with the activity-type *work*.

- Activity-type is *meeting* and the skeleton activity is not the initiator of this task-group.

  This level represents skeleton activities that are associated with task-types belonging to a task-group. These task-types are not the initiator of the task-group. In other words, the concerned employee is not responsible for initiating employee-interaction; he is merely attending a meeting or presentation. An employee will be less willing to interrupt one of these skeleton activities than skeleton activities belonging to the previous two levels.

- Activity-type is *meeting* and the skeleton activity is the initiator of this task-group.

  This level also relates to skeleton activities belonging to a task-group, but in this case the associated task-types are the initiator of the task-group. This means that an employee associated with one of these skeleton activities is responsible for initiating employee-interaction. These skeleton activities are the most difficult skeleton activities to interrupt by an intermediate activity.

The values of the levels of both variables (i.e. type-of-day and type-of-activity effect) are estimated with a data set collected via a web-based survey (see section 9.4).

Step-by-step plan

First, the frequency with which an employee performs an S-curve intermediate activity type on the simulated working day is stochastically set, based on data collected in the real world (see section 9.4). Next, for each intermediate activity type the α and β parameters and the V_{max} and V_{min} variables corresponding to the determined frequency are retrieved from the system configuration file.

Prior to scheduling the intermediate activities, the intermediate-scheduler has to set the value of the $V_{context}$ variable. In other words, the scheduler-module has to determine the type-of-day and type-of-activity effects. Because the intermediate-scheduler will only be activated after all skeleton activities are scheduled, the type-of-day effect will not vary. This means that the level of this variable only has to be determined once. As mentioned above, the level of the type-of-day effect variable depends on the abstraction of the working day in either meeting or work related skeleton activities. When the level is determined than the scheduler-module can assign the corresponding value which is set in the system configuration file.

The value of the type-of-activity effect variable is dynamic and has to be determined for each skeleton activity. The first step is to determine the activity-type of the skeleton activity. If the activity-type is *meeting* than the scheduler-module further has to check if

the employee is the initiator of this skeleton activity. After this is done the level of this variable is assessed and the value corresponding to this level is set using the values given in the system configuration file.

When the value of the $V_{context}$ variable is determined for an intermediate activity type, the occurrence of the corresponding intermediate activities can be predicted. The exact moment in time when $U_a \geq 0$ is calculated using formula 5.7. This represents either the time elapsed since the previous occurrence of an intermediate activity type or the time elapsed since the beginning of the working day if this intermediate activity type has not occurred yet. An intermediate activity is added to the activity schedule on the calculated time value. Afterwards, the next occurrence of the intermediate activity type is determined and an intermediate activity is again added to the activity schedule. This process starts at the beginning of the workday and continues until the end of the working day is reached.

6.6.5.2 Probabilistic method

For the probabilistic intermediate activity types the following step-by-step plan is followed. First, the intermediate-scheduler determines the frequency of a probabilistic intermediate activity type for the simulated working day. The frequency is calculated based on the mean frequency and standard deviation of the intermediate activity type as set in the system configuration file. As a result, the number of times a probabilistic intermediate activity is conducted varies per simulated working day. After the frequency is determined, all occurrences of the intermediate activity type are scheduled. As mentioned in section 5.4.2 the start times of the probabilistic intermediate activities are randomly spread over the duration of the workday, while taking a minimum time-interval into account. The minimum time-interval is used to prevent two (or more) instances of an intermediate activity type from occurring too close in time, for example within one minute.

6.6.5.3 Final remarks

The intermediate activities associated with the various intermediate activities types are scheduled independently of each other. Interaction between intermediate activities is not taken into account. The duration of an intermediate activity is based on the mean duration as set in the system configuration file.

6.6.6   Gap-remover

The scheduler aims at completely filling an activity schedule with activities. In other words, an activity schedule usually should not contain a time-interval which is not occupied by a skeleton or intermediate activity, a so-called time-gap. However, at certain stages in the scheduling process an activity schedule can exhibit one or more time-gaps, for instance as a result of an activity deleted by one of the other scheduler-modules. These time-gaps are repaired by the gap-remover.

First, the gap-remover selects all time-gaps in an activity schedule. Then, each time-gap is repaired by creating a new skeleton activity with the duration of the time-gap. The newly created skeleton activity corresponds to the main task of the concerned employee. The gap-remover randomly selects a main task when an employee has two (or more) main tasks (i.e. he has more than one role).

6.6.7   Overlap-remover

As a result of actions taken by some scheduler-modules (e.g. the interaction-scheduler or the intermediate-scheduler) activities in an activity schedule can overlap each other. An activity schedule has an overlap if the start time of one of its activities lies before the end time of the previous activity in the activity schedule. The overlap-remover removes these overlaps, by rescheduling (some of) the activities related to an overlap.

6.6.7.1 Step-by-step plan

First, the overlap-remover has to select one of these overlaps if an activity schedule has more than one overlap. From all activities that create an overlap with another activity, the overlap-remover selects the activity with the highest priority. The selected activity can overlap more than one activity. From these activities the overlap-remover again chooses the activity with the highest priority. The overlap-remover has now selected two activities. Only one of these activities has to be rescheduled to solve the overlap. The activity with the highest priority is called the major-activity and will be left untouched; the other activity, the so-called minor-activity, will be rescheduled.

Methods of rescheduling

There are two ways in which a minor activity can be rescheduled. It depends on the duration of the overlap in relation to the so-called maximum-overlap interval (set in the system configuration file) which way is chosen. If the duration of the overlap is minimal (i.e. shorter than the maximum-overlap interval), the overlap can be adapted by slightly modifying the start or end time of the minor-activity. If the minor-activity starts after the major-activity, the start time of the minor-activity is set to the end time of the major-activity, otherwise the end time will be set to start time of the major-activity.

When an overlap is too extensive (i.e. duration is longer than the maximum-overlap-interval), the overlap can only be removed by (drastically) rescheduling the minor-activity. If the minor-activity is a skeleton activity and it is related to other skeleton activities (i.e. it is part of a task-group), only modifications to the whole group of skeleton activities are allowed. The overlap-remover tries three different methods for solving an overlap, namely:

▪ Rescheduling the activity.

   The scheduler will search for a new start and end time for the minor-activity by creating an overlap with an activity which has a lower priority than the minor-activity. After this the overlap-remover will be executed at least once more to remove the newly created overlap.

- Splitting the activity.

  If both the start and end time of the major-activity falls between the start and end time of the minor-activity, the latter activity will be split.

- Removing the activity.

  When the first two methods can not be applied for rescheduling the minor-activity, the only way to repair the overlap is by removing the minor-activity from the activity schedule.

6.6.8 Merger

As a result of actions performed by some scheduler-modules (e.g. the gap-remover), an activity schedule can consist of several (un)scheduled skeleton activities which belong to the same task-type. The aim of the merger is to simplify an activity schedule. This is done by processing the whole set of activities in an activity schedule and where possible merging skeleton activities into one skeleton activity.

Two activities are joined into one activity if the following criteria are satisfied:

- Both skeleton activities have to belong to the same task-type (i.e. both corresponding tasks are instances of the same task-type)
- Both skeleton activities have to be consecutive (i.e. the end time of an activity corresponds with the start time of the next activity in the activity schedule).

6.6.9 Resource-finder

Each activity in an activity schedule is performed at a certain location in the building space. In addition, some activities require one or more resources (e.g. facilities). It is the responsibility of the resource-finder to search for all required resources (i.e. abstract-space, facilities and people). If appropriate resources are found, they are selected and allocated to an activity for its total duration. If a skeleton activity belongs to a task-group these resources are allocated to all skeleton activities associated with this task-group.

6.6.9.1 Step-by-step plan

The resource-finder only treats those activities for which the employee is the initiator of the corresponding task-group or activities that do not belong to a task-group.

For those activities that take place within the building itself (i.e. the activity-type is not external) the activity location choice algorithm (see section 5.5.1) only considers abstract-spaces which satisfy the following requirements:

- The activity-type of the abstract-space has to match with the activity-type of the activity.
- The resource should not be allocated to another activity during the duration of the activity.
- In the case of an activity of the activity-type *meeting*: the capacity of the abstract-space should be at least equal to the group of employees involved in this activity.

Next, the activity location choice algorithm selects one location of all abstract-spaces that satisfy these requirements. If for some reason no resource can be selected (e.g. all meeting rooms are occupied) the activity is deleted from the activity schedule. Selecting the required facilities is done in a similar way.

The resource-finder only considers external abstract-spaces for the location of an activity if its activity-type is external. Other types of resources required by this activity are ignored. From all possible external abstract-spaces an external abstract-space is stochastically selected using the pre-defined movement-time as probability. In other words, the longer it takes to reach the external abstract-space the smaller the chance this location will be chosen. It is assumed that external abstract-spaces are always available.

6.6.10 Movementtime-scheduler

After the locations of all activities in an activity schedule are determined, the movementtime-scheduler can calculate the time it takes an employee to move from the location of an activity to the location of the next activity in the activity schedule.

6.6.10.1 Step-by-step plan

The movement-time is calculated based on the length of the route between the locations of two consecutive activities, if both activities occur in the same office building. If one of the two activities is performed at an external abstract-space, the movement-time is set to the pre-defined movement-time associated with the external abstract-space. The length of the route is calculated by the shortest path algorithm (see section 5.5.2). Afterwards, the length of the route is multiplied by the mean walking speed. The calculated (or pre-defined) movement-time is used to adjust the start and end time of the activities. This will lead to overlaps in the activity schedule, as there is no time available 'to squeeze in' the required movement-time. The overlap-remover is responsible for (again) rescheduling the activity schedule.

6.7   Conclusions

This chapter gave a detailed description of the User Simulation of Space Utilisation system. It described how the system takes care of producing the output of the system, namely a movement pattern for each simulated working day. Attention was paid to the structure of sub-systems comprising the USSU system. Each sub-system was discussed in detail, among other things the input and output of each sub-system was treated. A large part of this chapter was devoted to an in-depth discussion of the scheduler. The scheduler consists of a number of scheduler-modules which are responsible for scheduling the skeleton and intermediate activities.

Next chapter will discuss the implementation of the system design into a prototype.

C7 **Prototype**

7.1 Introduction

Chapter six gave a description of the design of the User Simulation of Space Utilisation-system. The chapter discussed the structure of sub-systems comprising USSU and described each of these sub-systems. By doing so it gave an in-depth insight in how the system should work when implemented. Next, a prototype was implemented based on the developed system design.

The system design formed a guideline for the implementation of the USSU prototype. The prototype is a restricted implementation of the system design. The main reason to restrict the implementation was to reduce the complexity of the prototype. On certain points it proved necessary and more feasible to deviate from the original system design. However, only restrictions or deviations were made with regard to the system design

when this would not impede the usage of the prototype for the validation of USSU. In other words, the prototype has the basic functionality to be able to predict the space utilisation (i.e. movement patterns) required for the validation of USSU as discussed in part three of this thesis.

The focus of this chapter is to describe the prototype and its implementation. Deviations and restrictions concerning the system design will be argued. This chapter also discusses the input data required by the prototype and how the prototype can be applied to create a movement pattern.

7.2   Overview prototype

As mentioned in the introduction a prototype was developed based on the system design discussed in chapter six. The prototype was implemented in Java (version 5). Each run of the prototype results in a prediction of the activity behaviour of all employees in an organisation for one working day. In other words, each time the prototype is activated a movement pattern will be created belonging to one working day. The movement pattern is an XML (Extensible Markup Language) file describing not only the activity schedule of each employee for that particular day, but also the routes between the locations of the activities (see appendix A3 for one of the movement patterns belonging to the validation of USSU). This section will describe which actions are performed when a movement pattern is created by the USSU prototype.

First, the prototype is initialised by loading data specified in three separate input files (see appendix A2 for the three input files belonging to the validation of USSU), namely:

- Organisation input file

    This input file contains all data related to the organisation for which the space utilisation is predicted. This data is used to setup the organisation structure as specified in section 7.3.1.

- Building input file

    All data related to the building in which the organisation is (or will be) housed is specified by this input file (see section 7.3.2).

- Configuration input file

    The prototype needs also data which are not organisation or building specific. This refers to the following three types of data:

    o Parameters which are used by the scheduler-modules to modify an activity schedule (e.g. the time-interval for the skeleton-scheduler). This also includes the mean walking speed used by the movementtime-scheduler. The value of the mean walking speed was based on research by Daamen (2004) and Fruin (1971).

    o Parameters which belong to the intermediate activities. These parameters are used by the intermediate-scheduler to predict the intermediate activities.

    o The general set of activity-types (see Table 7.1). Each task-type and intermediate activity type is associated with one of these activity-types. Each abstract-space is associated with one or more activity-types (see section 6.3).

Activity-types	
Meeting	Coffee corner
Work	Printer
Work-concentrated	Mailbox
External	Sport
Canteen	Break
Toilet	Smoke

Table 7.1: Activity-types.

The three input files have to be selected by the user itself (see Figure 7.1). While the input files are loaded a number of consistency checks are performed. Next, if the input files do not contain inconsistencies or errors (i.e. they pass all consistency checks), a set of skeleton activities is selected for each employee belonging to the organisation for which the movement pattern is created. These sets of skeleton activities are the starting point for predicting the space utilisation of the organisation. Selecting the skeleton activities is done by the organisation sub-system (see section 7.3.1).
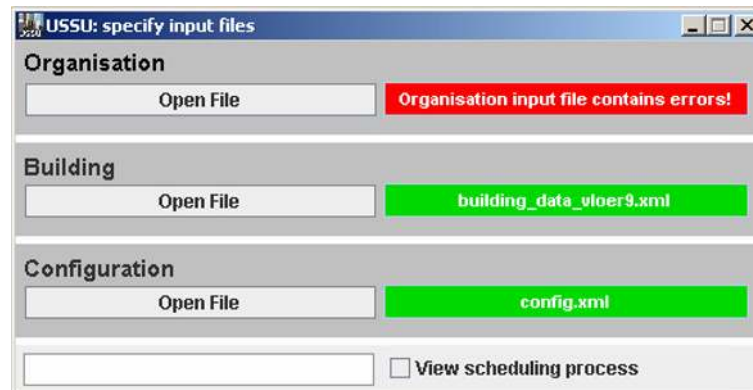
Figure 7.1: USSU input selection - displaying an error message with regard to an inconsistency in the chosen organisation input file.

Next, the scheduling process is started. The scheduler and its scheduler-modules schedule all skeleton and intermediate activities, plan all the required resources and determine the routes between the locations of the activities. This is a cyclic process that stops when the activity schedule of an employee can not be improved anymore within the given constraints. When the scheduler is finished all activities are scheduled and a movement pattern is created (see Figure 7.2).
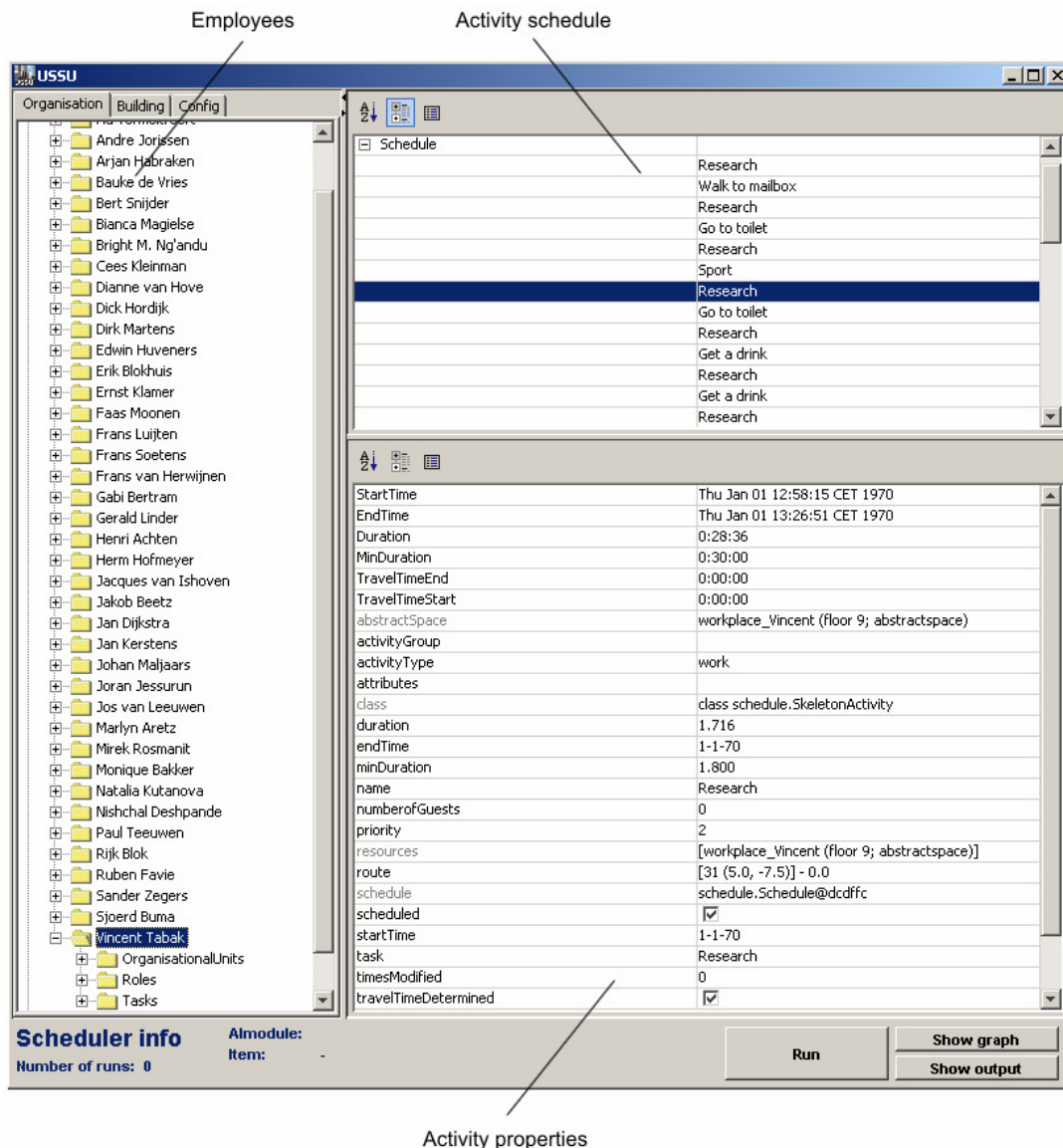
Figure 7.2: USSU output viewer - displaying the activity schedule of an employee.

7.3 Implementation of sub-systems

The USSU system comprises a number of sub-systems. This section discusses the implementation of each of the sub-systems with regard to the USSU prototype. Some features of sub-systems were not implemented and sometimes the implementation deviated (slightly) from the system design. This mainly refers to the resource management sub-system and the scheduler (and its scheduler-modules). The reasons for these restrictions and deviations are treated per sub-system in the following sections.

7.3.1 Organisation sub-system

The organisation sub-system is fully implemented in the prototype. Any restriction to this sub-system would severely limit the capability of the prototype in predicting the human activity behaviour. The sub-system requires detailed input regarding the structure of the organisation. First, the required input data is discussed.

7.3.1.1 Input

The structure of an organisation is specified by the organisation input file. An organisation consists of a number of roles and organisational units. Each organisation will comprise a different set of roles and organisational units. In other words, the structure of organisation will differ per organisation, even when they belong to the same organisation-type (e.g. an insurance company). This structure of an organisation is specified using an XML input file. The organisation input file created for the validation of USSU is located in appendix A2.

This input file covers six different sections. Each of these sections describes an important aspect of the structure of an organisation:

- Organisation properties

  This relates to data about the organisation in general, for example the mean number of holidays and the mean duration and mean start time of working days.

- Task-types

  A task is a logical unit of work belonging to one organisational unit and one role. Each task occurring in the organisation is associated with a task-type as specified in the input file. The most important parameter of a task-type is the activity-type.

- Roles

  An organisation includes a number of roles. For each role a set of tasks has to be specified. The set of tasks determines which tasks a role can perform during a workday. Each task is described by a set of properties, e.g. time percentage and average duration (see section 6.3.2 for the complete set of properties).

- Organisational units

  This is the (hierarchical) structure of organisational units comprising the organisation. For each organisational unit a set of tasks has to be specified, identical to the set of tasks per role.

- Employees

  Each employee belonging to the organisation has one or more role(s) and belongs to one or more organisational unit(s). For each employee the input file has to specify the corresponding roles and organisational units.

- Task-groups

  A task-group is a collection of task-types which are related to each other in the context of employee-interaction (see section 6.3.1). For the organisation a set of task-groups has to be defined. The configuration of each task-group is specified by a so-called task-group configuration. These task-groups are used by the scheduler to determine the employee-interaction.

7.3.1.2 Step-by-step plan

After the prototype has dealt with the input files (i.e. all input data is loaded), the first actual steps in predicting the space utilisation are performed by the organisation sub-system. First, the sub-system determines for each employee if he is present. The chance that an employee is present on a working day is based on the mean number of working days of the organisation and the mean number of holidays per year. Then, if the employee is present during the working day, the start and end time of his working day are stochastically determined based on data belonging to the organisation in general (i.e. the mean duration of a workday and mean start time of a working day). Finally, a set of skeleton activities is drawn from the total set of skeleton activities associated with the roles and organisational units of an employee. These are drawn from the total set of skeleton activities based on the time percentage of each skeleton activity (i.e. task). The higher the time percentage, the more time an employee spends on this skeleton activity and the higher the probability that this skeleton activity is selected.

7.3.2   Building sub-system

Only limited data about (office) buildings is needed for simulating the human activity behaviour, namely primarily the locations at which activities can occur and the possible routes between these locations. This meant that it was not necessary to incorporate functionality for importing (comprehensive) three dimensional (3D) models. Instead, an abstract building representation was applied for specifying the spatial conditions in which the activities are performed, as described in section 6.4.

The building input file for the USSU prototype consists of two sections, namely:
- The total set of abstract-spaces comprising the simulated building, including a set of external abstract-spaces.
- The graph. This specifies the total set of nodes and edges used to model the movement behaviour of employees (see Figure 7.3).

See appendix A2 for the building input file created for the validation of USSU.

An abstract-space can contain other abstract-spaces. Figure 7.4 shows a section of a building input file describing a space (sub-type of the abstract-space class) comprising two other abstract-spaces, namely a meeting space and a workplace. Each abstract-space comprising a workspace is linked with one employee. In other words, each employee has a fixed workplace. This restricts the application of the prototype. The prototype can not be applied for simulating organisations which use a more flexible housing concept. Although this limits the situations in which the prototype can be applied, this approach was chosen to reduce the complexity of the prototype. This restriction proved not to be a problem with regard to the validation of USSU.
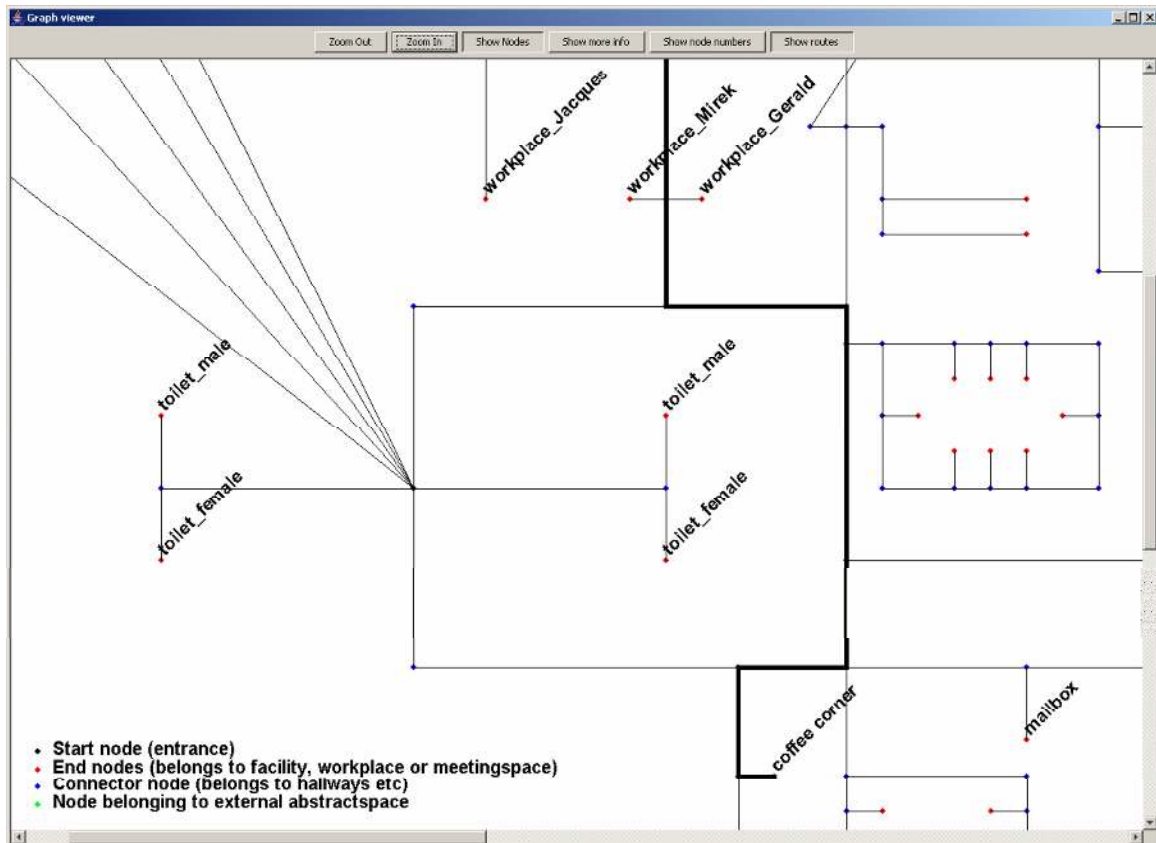
Figure 7.3: USSU graph viewer - displaying part of the graph with a route.

```
<abstractspace type="space" name="9.10: office room">
    <node xcoordinate="9" ycoordinate="-7.5" ID="62"/>
    <abstractspace name="workplace_Employee1" employee="Employee1">
        <activitytype type="work"/>
        <node xcoordinate="11" ycoordinate="-7.5" ID="14"/>
    </abstractspace>
    <abstractspace name="meetingspace" capacity="2">
        <activitytype type="meeting"/>
        <node xcoordinate="9.75" ycoordinate="-8.5" ID="50"/>
    <node xcoordinate="9.75" ycoordinate="-9.5" ID="51"/>
</abstractspace>
</abstractspace>
<abstractspace name="toilet_female">
    <activitytype type="toilet"/>
    <node xcoordinate="-10" ycoordinate="4" ID="116"/>
    <facility type="toilet" name="Toilet"/>
</abstractspace>
```

Figure 7.4: Example of a section of a building input file, describing among other things a space consisting of a workplace and a meeting space belonging to an employee.

The specification of each abstract-space contains at least one node. Each node belongs to the total graph. Nodes are linked to each other by bi-directional edges (i.e. a person

can move in both ways across an edge). Some nodes are only a joint in the graph and are not occupied by employees. An employee passes these nodes while he is moving between activity locations and does not spend time on these nodes. Examples of these connection nodes are nodes belonging to hallways and stair cases (see blue nodes in Figure 7.3). Other nodes are occupied by employees for some time during a working day. These nodes are the end (or start) points of the graph, except for the entrances to a building. This second type of nodes belongs to meeting spaces or workplaces of employees (see red nodes in Figure 7.3). In the case of meeting spaces the size of the set of nodes specifies the capacity of the meeting space; the nodes could be viewed as the seats in the meeting space. Finally, an abstract-space is specified by one or more activity-types. This specifies the types of activities that can occur in the abstract-space.

7.3.3   Resource management sub-system

The resource management sub-system was meant to provide the interface for the scheduler sub-system with the organisation and building sub-system. In the prototype the resource management system was not developed as a separate system, but it was distributed over all other sub-systems where necessary. This will become clear when each of the resources is discussed in the next sections.

7.3.3.1 People

One of the tasks of the resource management sub-system is to keep track of all information related to resources available in the organisation, among others employees and guests.

Employees

All employees in the organisation are linked with an activity schedule containing the activities they perform during a working day. In the prototype the activity schedule is an essential object. All information related to the activities of an employee (e.g. facilities and the location) is maintained and can be accessed through the activity schedule of an employee.

In most cases the set of activity schedules belonging to all employees contains all data required by the scheduler and its scheduler-modules to schedule the activities. However, for certain steps in the scheduling process the scheduler needs more data, for example when solving the interaction between employees by the interaction-scheduler. The interaction-scheduler needs data of the organisation sub-system with regard to the total set of tasks of all employees as it has to select employees who are qualified to perform a certain task (see section 6.6.4). In the prototype the interaction-scheduler itself is responsible for selecting the proper candidates to perform an activity (i.e. employees who can perform a certain task and who are present during that working day).

Guests

All people who are not housed in the simulated (part of the) building are considered to be quests. This can either be people like visitors or employees belonging to the same organisation but who are housed in a different part of the building. Guests are always available and in an unlimited supply. In other words, each time a guest is required the system does not check if guests are available, simply a new guest is instantiated and allocated to the activity.

7.3.3.2 Abstract-spaces

Another type of resources to keep track of during the scheduling process are resources related to the building sub-system. The world outside the simulated (part of the) building is abstracted using a set of external abstract-spaces (see section 6.4.1.2). As they are an abstraction it is assumed that all external abstract-spaces are always available. When the resource-finder is trying to select a location for an external activity, it considers all external abstract-spaces and stochastically selects one based on the pre-defined movement-time. The longer the movement-time (i.e. the further away the external abstract-space), the smaller the chance this abstract-space is chosen.

Selecting an appropriate abstract-space for activities that take place within the building is more complicated. Especially when an employee is the initiator of a group-activity and the resource-finder has to select an abstract-space for this activity. Abstract-spaces like meetings spaces can be allocated to other activities (i.e. they can be occupied by other groups of employees). To check if an abstract-space is available at a certain moment, the resource-finder parses all activity schedules belonging to the organisation. If an abstract-space is not allocated, the resource-finder can claim this abstract-space.

As mentioned in the previous section each employee has a fixed workplace set in the building input file. This makes selecting an abstract-space for activities that do not require interaction (i.e. which are performed individually) much more simple. For these activities the resource-finder automatically selects the workplace allocated to the employee in question. A workplace is only (and always) available for the dedicated employee.

7.3.3.3 Facilities

To correctly simulate the usage of facilities by employees, the USSU system should deal with phenomena like queuing and interaction.

Example
When in the real world an employee wants to perform the intermediate activity *get a drink*, he tends to wait when the coffee machine is used by another person, at least for a certain while. Furthermore, there is chance that people querying at for instance a coffee machine start talking to each other and have a small break. In other words they will stay longer at this facility than strictly necessary to perform the activity.

For the prototype the decision was made to opt for a more simple approach and to assume that facilities are always available. Each facility in a building is associated with

an abstract-space (e.g. the facility coffee machine is located in the coffee corner) and is inputted via the building input file. An abstract-space can contain more than one resource, for example an abstract-space can contain two or more printers/copiers and a bathroom can consist of more than one toilet.

7.3.4 Scheduler

This project aims to model the scheduling behaviour of employees as realistically as possible. It mimics the behaviour of real human employees when scheduling activities. This approach influenced the way in which a scheduler-module performs actions when it is executed (i.e. its step-by-step plans as discussed in section 6.6) as well as the importance values returned by the scheduler-modules each time a scheduler-module has to be selected for execution (see section 6.6.2). To recapitulate: each scheduler-module determines its importance based on the state of the activity schedule and its activities. A scheduler-module uses a rule based algorithm to test the current activity schedule against a set of predefined criteria. If the criteria are satisfied then the importance is > 0 else it is 0. For each scheduler-module the value of the importance is preset (value between zero and hundred); the value does not vary during the scheduling process. The importance values returned by the scheduler-modules are used by the scheduler to determine which scheduler-module should be executed next. The scheduler selects the scheduler-module with the highest priority. This determines the order of execution of the scheduler modules. The order of the execution of the scheduler-modules will change, if the preset importance values are changed. Furthermore, this will have an effect on the movement patterns created by the prototype.

	Scheduler-module	Importance
1	Merger	90
2	Skeleton-scheduler	80
3	Gap-remover	70
4	Overlap-remover	60
5	Interaction-scheduler	50
6	Intermediate-scheduler	40
7	Resource-finder	30
8	Movementtime-scheduler	20

Table 7.2: Values of importance returned by scheduler-modules.

7.3.4.1 Determining the importance values

Considerable time was spent on determining the importance values of the scheduler-modules (see Table 7.2). The ordinal importance values of the scheduler-modules were determined by placing each scheduler-module in context of the scheduling process. Certain scheduler-modules (e.g. skeleton-scheduler) are more important for the overall process and should be executed before other modules are executed. Some modules (e.g. intermediate-scheduler) should only be executed if other modules (e.g. overlap-remover) are not required to be activated. This will become clear in this section which discusses the considerations behind the importance values of the scheduler-modules.

1 Merger

To reduce the complexity of an activity schedule, the scheduler should try to merge activities whenever possible. This is why the merger returns the highest importance of all scheduler-modules. Merging activities does not affect the activity behaviour of employees; they still spend the same amount of time on the activities. The merger merely simplifies the activity schedule; making it easier to understand and reducing the number of times some of the other scheduler-modules have to be executed.

2 Skeleton-scheduler

The first real step in the scheduling process is scheduling the skeleton activities which were selected by the organisation sub-system. Most other scheduler-modules (e.g. interaction and intermediate-scheduler) can only be executed when the skeleton activities are scheduled. This makes the skeleton-scheduler the second most important scheduler-module.

3 Gap-remover

The final goal of the scheduler is to create a movement pattern which is totally filled with activities. In other words, the activity schedules of an employee should not contain time-gaps. At the start of the scheduling process an activity schedule consists of one time-gap comprising the total duration of the schedule. When the skeleton-scheduler is finished (i.e. all skeleton activities are scheduled) the activity schedule usually contains several time-gaps with a relative short duration. These time-gaps could not be used by the skeleton-scheduler for scheduling skeleton activities. After the execution of other scheduler-modules (e.g. overlap-remover) an activity schedule may also consist of several time-gaps. These time-gaps have to be repaired before another scheduler-module can be allowed to perform its role in the scheduling process. The gap-remover is the third most important scheduler-module in the scheduling process.

4 Overlap-remover

After the skeleton-scheduler is finished there remain two scheduler-modules which have a considerable impact on an activity schedule, namely the interaction and intermediate-scheduler. The interaction-scheduler determines if the skeleton activities comprising an activity schedule require interaction. For each skeleton activity that requires interaction the scheduler-module determines which other skeleton activities have to be scheduled and adds these skeleton activities to the appropriate activity schedules, which results in one or more overlapping skeleton activities. These activity schedules, however, can in turn also contain one or more skeleton activities which require interaction. Prior to solving the interaction, the overlaps have to be repaired. In other words, the interaction-scheduler should only be activated when an activity schedule does not contain overlaps. Removing the overlaps is done by the overlap-remover and that is why the overlap-remover is the fourth most important scheduler-module. As the overlap-remover only treats one overlap at a time, the overlap-remover is often executed several times in a row.

5 Interaction-scheduler

The occurrence of intermediate activities depends on the type of skeleton activities that the intermediate activity is trying to interrupt, because the skeleton activity is partly responsible for setting the context variable (see section 6.6.5.1). So before the intermediate activities can be scheduled all skeleton activities should be completely scheduled, including the interaction between employees. Solving the interaction between skeleton activities is the responsibility of the interaction-scheduler. This makes the interaction the fifth most important scheduler-module.

6 Intermediate-scheduler

The intermediate activities can only be scheduled when the skeleton activities are completely scheduled (i.e. the interaction is also solved) and all overlaps and/or time-gaps are repaired. Although this gives the intermediate-scheduler a low importance, it still has a considerable impact on the activity schedule. The intermediate-scheduler is responsible for creating many overlaps between intermediate and skeleton activities. Consequently, the intermediate-scheduler is followed by many occurrences of the overlap-remover. In other words, there is a strong link between the occurrence of the intermediate-scheduler and the overlap-remover.

7 Resource-finder

When all skeleton and intermediate activities are scheduled, it is the responsibility of the resource-finder to select and allocate the required resources. Only after all required resources (e.g. abstract-space and facilities) for each activity are determined and allocated, can the movementtime-scheduler perform the last remaining action in the scheduling process, namely adding the movement-times to each activity.

8 Movementtime-scheduler

The movementtime-scheduler is associated with the lowest importance value of all scheduler-modules. In other words, this scheduler-module is executed at the end of the scheduling process when all activities are scheduled and when for each activity a suitable location is determined. This scheduler-module calculates the required time to move from the location of one activity to the location of the next activity. The execution of this scheduler-module leads to a number of overlaps in an activity schedule. In other words, there is a strong link between the movementtime-scheduler and the overlap-remover.

7.3.4.2 Order of execution of scheduler-modules

Although the importance values of the scheduler-modules are based on the (logical) order in which the scheduler-modules should be executed, the actual order in which the scheduler-modules are executed varies each time the prototype is run. The importance values of the scheduler-module are not the only factor influencing the order of execution of scheduler-modules. Another important factor is variation in the properties of the activity schedule and its activities, for example variation in the set of skeleton activities

drawn by the organisation sub-system and variation in the presence of employees per working day. This influences which scheduler-modules should be executed and the number of times each individual scheduler-module is executed. As a result of the varying properties of an activity schedule, also the actions performed by each scheduler-module differ. This is because each scheduler-module determines its actions based on the properties of an activity schedule and its activities. Some scheduler-modules (e.g. the overlap-remover) have several methods for solving their dedicated task, which method is chosen depends on the properties of the activity schedule. In other words, differences in the properties of an activity schedule will influence the changes made by a scheduler-module to an activity schedule, which in turn again varies the order of execution of the scheduler-modules. So the scheduling process (i.e. the order of execution of the scheduler-modules) is not preset by the importance values. The importance values are basically a guideline stipulating the way in which the activity schedules should be modified. This means that for instance skeleton activities should be scheduled before intermediate activities and time-gaps have to be repaired before overlaps.

The importance values combined with the actions performed by the scheduler-modules prevent certain combinations of scheduler-modules to occur. Other scheduler-modules, on the contrary, are strongly linked with each other. In the sense that if a certain scheduler-module (e.g. intermediate scheduler) is executed it is very likely that a certain other scheduler-module (e.g. overlap-remover) will be executed afterwards.

Example
The execution of the intermediate-scheduler can not directly be followed by the execution of the movementtime-scheduler, because prior to determining the movement-times the location of each activity has to be determined. In other words, the resource-finder has to be executed before the movementtime-scheduler can be activated. These two scheduler-modules are strongly linked.

The matrix in Figure 7.5 gives an insight in which combinations of scheduler-modules are possible. If a relationship exists between scheduler-modules, the matrix also specifies the strength of the relationship. The strength of a relationship was determined by analysing numerous runs of the USSU prototype; the result is an observed, discrete value.

After the execution of this module	The following module is activated							
	Skeleton-scheduler	Intermediate-scheduler	Interaction-scheduler	Resource-finder	Movementtime-scheduler	Overlap-remover	Merger	Gap-remover
Skeleton-scheduler	X	X	X	-	-	X	X	X
Intermediate-scheduler	-	-	-	X	-	X	-	X
Interaction-scheduler	-	X	X	X	-	X	X	X
Resource-finder	-	-	-	-	X	X	-	X
Movementtime-scheduler	-	-	-	-	-	X	-	X
Overlap-remover	-	-	X	X	-	X	X	X
Merger	X	X	X	X	-	X	-	X
Gap-remover	-	X	X	X	-	X	X	-

Frequency scales

-	Impossible
X	Never
X	Sometimes
X	Often
X	Very often

Figure 7.5: Matrix displaying scheduler-module interactions.

7.3.4.3 Implementation of scheduler-modules

Each scheduler-module was discussed in detail in chapter six, among other things their step-by-step plan was treated. For a number of scheduler-modules slight changes to their step-by-plan were made. These scheduler-modules will be discussed in this section; all other scheduler-modules are implemented as specified in the system design.

Overlap-remover

When the overlap-remover is activated for solving an overlap, the overlap-remover has to reschedule one of the activities, namely the activity with the lowest priority (the minor activity). Rescheduling an activity which is not linked with other employees (i.e. not part of a task-group) is relatively easy, only a different time-gap for this activity has to be located. However, rescheduling a skeleton activity which is related to other skeleton activities is more complicated. In this case only modifications to the whole group of skeleton activities are allowed. This means that the whole set of skeleton activities should be rescheduled, which makes the scheduling process far more complex. For the prototype the decision was made to remove a minor-activity from an activity schedule when this skeleton activity is a part of a task-group. If this results in the total number of skeleton activities related to the same task-type becoming smaller than the minimum amount set in the task-group configuration, than all activities belonging to this task-group are deleted.

Intermediate-scheduler

The mean frequency of an intermediate activity varies per person (see section 5.4.1). To realistically model the intermediate activity behaviour the shape of the S-curve of an intermediate activity depends on the frequency with which an individual performs this intermediate activity. This meant that for each frequency of an S-curve intermediate activity a different set of values for the α and β parameters and the V_{max} and V_{min} variables of function 5.3 had to be defined. However, this has several drawbacks. Not only would predicting the intermediate activities by the intermediate-scheduler be rather complex, also collecting the data required for estimating all parameters and variables of each S-curve intermediate activity and associated frequencies would be a demanding task. Therefore, mainly to reduce the extent of the data collection, in the USSU prototype frequency intervals were applied, namely:

- 0 ➔ an intermediate activity is not performed during the simulated working day.
- 1 ➔ an intermediate activity is only performed once on the simulated workday.
- 2-3 ➔ an intermediate activity is performed 2 or 3 times.
- 4-and-more ➔ an intermediate activity is performed 4 or more times.

After the intermediate-scheduler is activated an employee is assigned to a frequency interval for each S-curve intermediary activity type, based on probabilities collected in the real world (see chapter 9). The values of the S-curve parameters and variables associated with this frequency and the value of the context-of-day variable are used to determine all occurrence of an intermediate activity type using function 5.7.

Movementtime-scheduler

The time required to walk from the location of an activity to the location of the next activity is determined by multiplying the length of the route between the locations of these activities with an average walking speed. Determining the route is relatively straightforward when one of the activities is performed at a workplace and the other at a meeting place. The movement-time is based on the shortest route between these two locations. However, determining the route proved to be less straightforward if both activities are located at a meeting space. In the real world, an employee can decide to return to his workplace prior to walking to the location of the next activity, for example to get something from his desk or to check his email or agenda. In other cases employees will directly walk from one activity location to the next activity location.

It is not apparent which factors influence an employee to either decide to go back to his workplace or to go directly to the location of the next activity. For the prototype the decision was made to return each employee to his workplace after each activity prior to sending him/her to the location of the next activity.

7.4   Conclusions

This chapter discussed the implementation of the USSU prototype based on the system design as discussed in chapter six. Attention was paid to the way in which this prototype

can be applied to predict the space utilisation of an organisation. It also discussed how this prototype was implemented and which aspects of the system design were ignored and/or simplified and the reasons behind these changes to the system design. This chapter made clear that in order to be able to use the prototype for creating movement patterns (i.e. predicting the space utilisation) detailed input data is required with regard to the organisation and the building in which the organisation is (or will be) housed. Data also has to be collected for predicting the intermediate activities.

The prototype is used for evaluating the predictive quality of USSU. The third and final part of this thesis discusses the validation of USSU, among other things it will treat the data collection performed for calibrating the USSU prototype (e.g. data collected with regard to the organisation and configuration input files) and the validation setup.

PART 3 VALIDATION

C8 Validation approach

"Validation is concerned with determining whether the conceptual model (….) is an accurate representation of the system under study" (Law and Kelton, 1991).

8.1   Introduction

Part two of this thesis discussed the system design and prototype that was developed for this research project. The system design was based on the approach for modelling human activity behaviour in office buildings as discussed in chapter five. Chapter six not only introduced the structure of sub-systems comprising USSU; it also discussed each of these sub-systems in detail, in particular the scheduler sub-system and its scheduler-modules. Based on the system design a prototype was developed. Chapter seven discussed the implementation of this prototype.

The final step in this research project was to validate the USSU system. The aim of the validation was to thoroughly evaluate the system. Therefore the predictive quality of USSU was assessed in the context of a real building, organisation and actual human behaviour. For the validation of USSU an existing office-based organisation was selected. Two experiments were performed to collect data about the actual space utilisation of this organisation. The observed activity behaviour was compared with the space utilisation predicted by the USSU prototype. However, before the prototype could be applied for predicting the space utilisation (i.e. creating movement patterns) it first had to be calibrated. To this end detailed data about the selected organisation and the office building was collected. In addition, data was collected regarding the different types of intermediate activities to estimate their utility parameters.

This chapter sets out the validation approach for determining the validity (of the output) of USSU. It starts with a description of the test case chosen for the validation of USSU. Then, the validation method is detailed; this section explains how the actual validation was performed and how the goodness-of-fit was assessed. This chapter ends with conclusions on the validation approach.

8.2   Test case description

For evaluating the predictive quality of USSU, the space utilisation of an existing organisation housed in an office building had to be captured. Several private companies were contacted. However, they were reluctant to participate because of privacy reasons ('Big brother is watching you') and because participating required considerable effort on their side. Instead the decision was made to choose the ninth floor of the building of the faculty of Architecture, Building, and Planning as test floor for the two experiments. Both chairs housed on this floor, Design Systems and Structural Design, were willing to participate in the experiments. For the greater part the data required for the calibration of the USSU prototype was already available, or could readily be obtained.

8.3   Validation method

"A model should be developed for a specific purpose or use and its validity determined with respect to that purpose" (Sargent, 1998).

Validation in the context of this research related to determining the validity of the output of the USSU system. In other words, how accurately can the implemented prototype predict the space utilisation of an organisation? According to Kleijnen (1995):
"Validation, however, can not be assumed to result in a perfect model, since the perfect model would be the real system itself (by definition, any model is a simplification of reality). The model should be 'good enough', which depends on the goal of the model".

A simulation model like USSU can be validated by comparing its output with observations performed in the real world (see Figure 8.1). The validity of USSU was determined by comparing the predicted space utilisation with the observed space utilisation. Movement patterns predicted by the prototype were compared with

movement patterns observed in the real world. Before the validation process could be started two essential questions had to be answered:

- How should the actual validation be performed?

  In which way should the observed and predicted movement patterns be compared with each other?

- When is the (output of the) prototype considered to be valid?

  When is the predicted space utilisation a sufficiently accurate representation of the reality (i.e. observed space utilisation)? In other words, how should the goodness-of-fit be assessed?

These two questions are answered in the following two sections.

8.4 How should the actual validation be performed?

The validation of USSU revolves around a comparison of the predicted movement patterns with observed activity behaviour, but in which way should the comparison be performed? One approach is to compare the observed and predicted activity behaviour on the level of activities. However, this is not as straightforward as it may appear. In the real world the activity schedule of an employee differs per day, in terms of start/end time of the schedule, the order of activities, their timing and last but not least the types of activities. In other words, per working day an employee performs a different set of activities in varying sequences. As a result the real human activity behaviour differs per observed working day. Due to variation in the activity scheduling process of the USSU prototype the predicted movement patterns also vary per simulated working day. This means that both the predicted and observed movement patterns vary per observed/simulated working day. Consequently, a direct and qualitative comparison of predicted and observed movement patterns on among other things the order and timing of activities is not relevant, at least not for determining the validity of the USSU system. It is without any doubt that on these aspects the predicted and observed movement patterns will vary. It is more relevant to validate USSU on a higher, more abstract level.

As mentioned in chapter one, the USSU system could (eventually) be applied to generate input for building simulation systems, like evacuation simulations or working conditions assessments. In general building simulation tools analyse the performance of a building based on a set of performance indicators, like the walking or evacuation time per individual and number of people per space in time. The same indicators which are used for evaluating a building can also be used for validating USSU. The values of these performance indicators can be deduced from the predicted movement patterns and from observed activity behaviour. To assess the validity of the system the predicted space utilisation was compared with the observed space utilisation on a set of performance indicators, the so-called criterion variables (see Figure 8.1). These criterion variables (e.g. the usage of facilities or movement behaviour of employees) specify the aspects on which the comparison of the observed and predicted movement patterns was performed. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees.
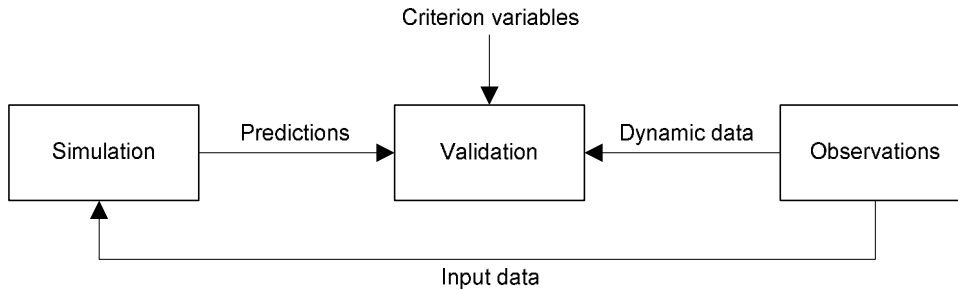
Figure 8.1: Overview of the elements of the validation process (Daamen, 2004).

The following categories of criterion variables were determined as performance indicators for human movement simulation in office buildings:

- Time percentage of use/occurrence of abstract-spaces, zones, facilities, tasks-types and intermediate activity types.
- Mean duration of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean frequency of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean walking distance of employees.

These criterion variables are discussed below.

8.4.1 Time percentage

The first category of criterion variables relates to the amount of time an abstract-space, zone or facility is used during a working day or the amount of time spent on an intermediate activity type or task-type on a working day. The time percentage is a proportion of the total simulated or observed time. With regard to a resource (i.e. abstract-space, zone or facility), the time percentage is calculated by dividing the total time the resource is used by the total simulated or observed time. In formula:

$$P_x = \frac{T_x^{resource}}{T_s} \text{, with } T_x^{resource} = \sum_{i=1}^{n_x} \Delta T_{a_{x,i}} \qquad \textbf{(8.1 \& 8.2)}$$

where:

P_x is time percentage of resource x for an average working day

$T_x^{resource}$ is total time resource x is used during simulation or observation

T_s is total simulated or observed time

$a_{x,i}$ is activity a_i using resource x

$\Delta T_{a_{x,i}}$ is duration of activity $a_{x,i}$

n_x is total number of activities using resource x

Another way to analyse the activity behaviour is not to look at the differences on the level of activities itself, but on the level of types of intermediate and skeleton activities.

Each movement pattern, either predicted or observed, consisted of intermediate and skeleton activities associated with a limited set of intermediate activity types and task-types. Although the actual number of the intermediate and skeleton activities and their duration varied per day, the total time spent on the intermediate activity types and task-types should correlate between the observed and predicted activity behaviour. The time percentage of an intermediate activity type or task-type is calculated as follows:

$$P_y = \frac{T_y^{task}}{T_s} \text{, with } T_y^{task} = \sum_{i=1}^{n_y} \Delta T_{a_{y,i}} \qquad \text{(8.3 \& 8.4)}$$

where:

P_y is time percentage of intermediate activity type or task-type y for an average working day

T_y^{task} is total time spent on intermediate activity type or task-type y during simulation or observation

$a_{y,i}$ is intermediate or skeleton activity a_i associated with intermediate activity type or task-type y

$\Delta T_{a_{y,i}}$ is duration of intermediate or skeleton activity $a_{y,i}$

n_y is total number of intermediate/skeleton activities associated with intermediate activity type or task-type y

8.4.2 Mean duration

This category of criterion variables addresses the mean length of time (i.e. duration) an abstract-space, zone or facility was used on a simulated or observed working day. This is calculated as follows:

$$\Delta T_x^{mean} = \frac{T_x^{resource}}{n_x} \text{, with } T_x^{resource} = \sum_{i=1}^{n_x} \Delta T_{a_{x,i}} \qquad \text{(8.5 \& 8.6)}$$

where:

ΔT_x^{mean} is the mean duration of resource x on a workday

$T_x^{resource}$ is total amount of time resource x was used

$a_{x,i}$ is activity a_i using resource x

$\Delta T_{a_{x,i}}$ is duration of activity $a_{x,i}$

n_x is total number of activities using resource x

The mean duration of an intermediate activity belonging to a certain intermediate activity type as well as the mean duration of a task (i.e. skeleton activity) associated with a certain task-type is calculated in a similar way:

$$\Delta T_y^{mean} = \frac{T_y^{activity}}{n_y}, \text{ with } T_y^{activity} = \sum_{i=1}^{n_y} \Delta T_{a_{y,i}} \qquad \textbf{(8.7 \& 8.8)}$$

where:

ΔT_y^{mean} is mean duration of an intermediate/skeleton activity associated with intermediate activity type or task-type y on a workday

$T_x^{activity}$ is total time spent on intermediate activity type or task-type y during simulation or observation

$a_{y,i}$ is intermediate/skeleton activity a_i associated with intermediate activity type or task-type y

$\Delta T_{a_{y,i}}$ is duration of intermediate/skeleton activity $a_{y,i}$

n_y is total number of intermediate/skeleton activities associated with intermediate activity type or task-type y

8.4.3   Mean frequency

The third category of criterion variables deals with the mean number of times a resource (i.e. abstract-space, zone or facility) was used on a simulated or observed working day. This category also relates to the mean frequency of an intermediate activity type or task-type (i.e. the mean number of intermediate or skeleton activities belonging to a certain intermediate activity type or task-type on a working day). The mean duration of a resource is calculated using this formula:

$$F_x^{mean} = \frac{n_x}{m} \qquad \textbf{(8.9)}$$

where:

F_x^{mean} is mean frequency of resource x on a working day

n_x is total number of activities using resource x during simulation or observation

m is total number of simulated or observed working days

The mean frequency of an intermediate activity type or task-type is calculated as follows:

$$F_y^{mean} = \frac{n_y}{m} \qquad \textbf{(8.10)}$$

where:

F_y^{mean} is mean frequency of intermediate activity type or task-type y on a workday

n_y is total number of intermediate or skeleton activities associated with intermediate activity type or task-type y

8.4.4   Mean walking distance

The last category of criterion variables examines the activity behaviour of an employee by looking at the resulting movement behaviour. The activity schedule of an employee reveals the required movement behaviour as a result of its activities. First, the total walking distance for all simulated or observed days is calculated as follows:

$$W_e^{total} = \sum_{i=1}^{m} W_e^{day} \text{ , with } W_e^{day} = \sum_{i=1}^{n-1} L_{[a_{e,i}, a_{e,i+1}]} \qquad \textbf{(8.11 \& 8.12)}$$

where:

W_e^{total} is total walking distance of employee e for all simulated/observed workdays

W_e^{day} is total walking distance of employee e for one simulated/observed workday

m is total number of simulated or observed working days

$L_{[a_{e,i}, a_{e,i+1}]}$ is length of route between location of activity $a_{e,i}$ and location of activity $a_{e,i+1}$

n is number of activities in the activity schedule of employee e for a workday

Next, the mean walking distance of an employee on a working day is calculated:

$$W_e^{mean} = \frac{W_e^{total}}{m} \qquad \textbf{(8.13)}$$

where:

W_e^{mean} is mean walking distance of employee e for a working day

8.5   When is the prototype considered to be valid?

The above discussed validation approach for USSU resulted in a set of observed and predicted data for each criterion variable.

Example
Table 8.1 shows fictive observed and predicted time percentages for four abstract-spaces.

Abstract-space	Observed	Predicted
A	65.1%	61.9%
B	20.3%	30.5%
C	55.0%	70.5%
D	78.5%	69.7%

Table 8.1: Fictive observed and predicted time percentages for four abstract-spaces.

For the validation of USSU the observed and predicted data sets per criterion variable were used to assess the goodness-of-fit between the predicted and observed activity behaviour. The goodness-of-fit was measured using a combination of two tests, namely:

- Student's *t*-test combined with a correlation coefficient determination.
- Variability test.

8.5.1   Student's *t*-test combined with the correlation coefficient

The *t*-test is a statistical hypothesis test in which the statistic has a Student's *t*-distribution if the null hypothesis is true. Given two data sets, each characterised by its mean, standard deviation and data samples, the *t*-test can be used to determine if the means are distinct, provided that the underlying distributions can be assumed to be normal. If the calculated *t*-value is above the threshold chosen for statistical significance (usually the 0.05 level; α =0.05), than the null hypothesis that the two groups do not differ is rejected in favour of an alternative hypothesis, which means that the groups differ. Once a *t*-value is calculated, the tail-end probability, called *P*-value, can be determined. If the *P*-value is below the chosen threshold (i.e. $P < 0.05$) than the null hypothesis is rejected.

There are different versions of *t*-test depending on whether the samples are paired or not. Samples are called paired when each member of one sample has a relationship with a member of the other sample; if this is not the case samples are called independent. Which version of the *t*-test should be performed, depends on the corresponding correlation coefficient. The (Pearson) correlation coefficient (*r*-value) is a measure to assess the correlation between two sets of data. The correlation coefficient ranges from –1 to 1. A positive correlation coefficient indicates a positive association between two sets of data. There are several guidelines available to interpret correlation coefficients; Guilford and Fruchter (1978) suggested the guideline as shown in Table 8.2. For the validation of USSU the main purpose of the correlation coefficient test was to determine which version of the *t*-test should be performed. The paired samples *t*-test can only be applied when the corresponding correlation coefficient proved to be significant, otherwise the independent samples *t*-test is applied. A correlation coefficient is statistical significant when its *P*-value is smaller than 0.05 ($P < 0.05$).

Correlation coefficient	Correlation
< 0.20	Very low correlation
0.20 – 0.40	Low correlation
0.40 – 0.70	Moderate correlation
0.70 – 0.90	High correlation
> 0.90	Very high correlation

Table 8.2: Guideline for the interpretation of correlation coefficients (Guilford and Fruchter, 1978).

Example

Table 8.3 shows four fictive data sets. In this example these four data sets are compared with each other using the correlation coefficient.

Set 1	1	2	3	4	5	6	7	8	9	10
Set 2	0.1	2	3	4	5	6	7	8	9	10
Set 3	0.1	2	3	4	5	6	7	8	9	0.1
Set 4	10	20	30	40	50	60	70	80	90	100

Table 8.3: Four fictive data sets.

Table 8.4 shows the correlation coefficients of set 1 in comparison with set 2, 3 and 4. It is immediately clear that set 4 is best correlated with set 1. The correlation coefficient indicates a very high correlation, which is not strange as the values of set 4 were calculated by multiplying the values of the first set of values by 10. The correlation coefficient of set 1 in relation to set 2 is also very high. Both correlation coefficients are significant ($P < 0.05$). The correlation coefficient of set 1 compared with set 3 is rather low, indicating a moderate correlation between both sets. The latter correlation coefficient is not significant ($P > 0.05$).

Sets compared	Correlation coefficient	
	r-value	*P*
Set 1 – set 2	0.997	0.000
Set 1 – set 3	0.491	0.149
Set 1 – set 4	1.000	0.000

Table 8.4: Correlation coefficients for set 1 in comparison with set 2, 3 and 4.

Next, the data sets are compared with each other using the *t*-test. The results of the *t*-test are shown in Table 8.5. As the correlation coefficient for set 1 compared with set 2 was significant, the paired *t*-test was applied for set 1 in relation to 2. The *t*-test results in a *P*-value > 0.05 (the chosen α level). This means that the null hypothesis is confirmed (i.e. the samples do not differ significantly). The *t*-test for set 1 in relation to set 4 results in a *P*-value < 0.05. In other words, there are significant differences between set 1 and set 4.

Sets compared	Paired-samples *t*-test	
	t-value	*P*
Set 1 – set 2	1.000	0.343
Set 1 – set 3	1.097	0.301
Set 1 – set 4	-5.745	0.000

Table 8.5: Results of the paired samples *t*-test for set 1 in comparison with set 2, 3 and 4.

According to the paired samples *t*-test there are no significant differences between set 1 and set 3. However, the correlation coefficient of set 1 in relation to set 3 was not significant (see Table 8.4). The independent samples *t*-test needs to be applied instead of the paired samples *t*-test (see Table 8.6). In this case equal variances are assumed

as the *P*-value of the Levene's Test is larger than 0.05. The independent samples *t*-test resulted in a *P*-value > 0.05. This means there are no significant differences between set 1 and set 3.

Sets compared	Levene's Test for Equality of Variances		Independent samples *t*-test	
	F	**P**	**t-value**	**P**
Set 1 – set 3	0.014	0.908	0.783	0.444

Table 8.6: Results of the independent samples *t*-test for set 1 in comparison with set 3.

8.5.2 Variability test

Although, the variability test is not a standard statistical test it gives further insight in the differences between the observed and predicted sets of data. The smaller the variability is (i.e. the closer it gets to zero) the better the match between the two data sets, e.g. the observed and predicted activity behaviour. The variability can be calculated using the following formula:

$$v^2 = \frac{\sum_{i=1}^{n} (s_{c,i} - o_{c,i})^2}{n} \tag{8.14}$$

where:

v^2 is variability

$s_{c,i}$ is predicted value i of the criterion variable c

$o_{c,i}$ is observed value i of the criterion variable c

n is the number of observations

Example
Finally, data set 1 (of the first example) is compared with data sets 2, 3 and 4 based on the variability test (see Table 8.7). Set 2 is the best match with set 1.

Sets compared	Variability	
	value	**std. dev.**
Set 1 – set 2	0.810	0.256
Set 1 – set 3	9.882	30.966
Set 1 – set 4	3118.500	2768.060

Table 8.7: Results of the variability test for set 1 in comparison with set 2, 3 and 4.

To conclude, the Student's *t*-test and the variability test revealed that set 2 is the best match with set 1; closely followed by set 3. Although the correlation coefficient for set 1 compared with set 4 is very high (basically as high as it can get), the *t*-test showed that are significant differences between the two data sets. This was confirmed by the variability test.

8.6   Conclusions

This chapter started with a description of the test case chosen for the validation of USSU, namely the ninth floor of the building of the architecture faculty of the Eindhoven University of Technology, the Netherlands. The validation of USSU was based on criterion variables. These criterion variables (e.g. the usage of facilities or movement behaviour of employees) specified the aspects on which the observed and predicted movement patterns were compared. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees. The four categories of criterion variables were:

- Time percentage of use/occurrence of abstract-spaces, zones, facilities, tasks-types and intermediate activity types.
- Mean duration of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean frequency of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean walking distance of employees.

For each of these criterion variables the mathematical definition was given. Next, this chapter focussed on the question: when is the (output of the) prototype considered to be valid? To determine the goodness-of-fit between the predicted and observed activity behaviour the following two statistical tests were applied: Student's *t*-test combined with a correlation coefficient determination and the variability test. Each of these tests was discussed and illustrated with examples. For the validation of USSU the results of the two tests had to be interrelated to determine the goodness-of-fit between the predicted and observed space utilisation.

Chapter nine will describe in detail the steps performed to calibrate the USSU prototype with respect to the chosen test case. For this purpose an extensive data collection was performed. This chapter explains how the data was collected and analysed for all three input files of the USSU prototype, namely the organisation input file, building input file and configuration input file.

C9 Model calibration

9.1 Introduction

In the previous chapter the approach to the validation of USSU was introduced. Chapter eight started with a description of the context in which the validation was performed. The validation of USSU revolved around the following two questions, namely how should the validation be performed and when is the (output of the) prototype considered to be valid? The validation of USSU is based on performance indicators similar to those used in building simulation tools. These so-called criterion variables were discussed and mathematically defined. Finally, chapter eight discussed how the goodness-of-fit between the predicted and observed activity behaviour for each of the criterion variables was determined. To this end two statistical tests were applied: the Student's *t*-test combined with a correlation coefficient determination and the variability test. Each of these tests was discussed and illustrated with examples.

However, before the USSU prototype could be applied for predicting the human activity behaviour in relation to the chosen test case the prototype had to be calibrated. For predicting the movement patterns, the USSU system requires detailed input. Chapter 7 discussed the three input files, namely the organisation input file, building input file and configuration input file. For the validation of USSU the data specified in these files had to be based on real world data with respect to the test case organisation and building. For this purpose an extensive data collection was performed. This chapter treats how the data was collected and analysed for each of these three files. The chapter starts by discussing the data collected for the organisation and building input files. The majority of this chapter focuses on the configuration input file, mainly regarding the estimation process of the parameters of the S-curve and the probabilistic intermediate activities. Finally, the conclusions on the model calibration are drawn.

9.2   Organisation input file

The organisation input file contained all data related to the test case organisation. It specified the structure of this organisation. The input file covered six different sections, each describing a different important aspect of the organisation structure, among other things task-types, roles, organisational units and employees. Most aspects of the structure of the test case organisation were specified using existing data sources. The priorities of tasks were obtained using a survey. First, this section briefly explains each of the existing data sources. Afterwards, the setup of the survey and the analysis of the collected data are described.

9.2.1   Registration of personal data by the personnel department

(in Dutch: Persoons Inzet Lijst, in short PIL)

The first data source contains data related to roles, organisational units and full time equivalences (FTE) of all employees belonging to the test case organisation. This data was used to specify the characteristics of all employees, among other things the set of roles and organisational units for each employee.

9.2.2   University Job Classification System

(in Dutch: Universitair Functie Ordenen, in short UFO)

The task set associated with each role was based on the University Job Classification system. This system was introduced in all Dutch universities in 2003. It is a set of job profiles to uniformly classify all university jobs. Each profile consists of a list of activities (e.g. integrate research results in education and coach students) per core activity (e.g. research or education). Not all core activities were relevant for the test case organisation (e.g. medical care). Most profiles have several core activities (e.g. education) in common. For USSU all relevant job profiles were analysed to find common activities and to remove non-relevant (core) activities. This resulted in a small set of task-types specific for the roles and organisational units belonging to the test case organisation. In

the USSU system each task (i.e. skeleton activity) performed by an employee is associated with one of these task-types (see section 6.3). The set of task-types was applied to define a set of tasks for each role and organisational unit in the organisation. Table 9.1 shows the set of tasks for a PhD student.

Task	Time percentage	Priority
External	1.29%	95.8
Give student coaching	0.74%	94.9
Get PhD coaching	1.12%	96.0
Follow course	1.24%	95.1
Education (preparation + evaluation)	1.21%	95.8
Teach	0.21%	94.8
Management	0.92%	93.1
Research	88.61%	97.7
Concentrated research	4.66%	96.8

Table 9.1: The set of tasks for a PhD student.

9.2.3   Time registration system (POPI)

Until 2005 all employees of the faculty registered the time they spent on activities in an online time registration system, called POPI (short for Personen Op Projecten Informatie). This kind of information lent itself perfectly for determining the time percentage for each task associated with a role. This data source contained data for all employees belonging to the total faculty, not only for employees belonging to the test case organisation. This meant that mean values for the task time percentages could be calculated by averaging all entries belonging to employees with the same role within the faculty. Table 9.1 shows the task time percentages for the role PhD student (based on entries belonging to 40 PhD students).

9.2.4   Task-sorter, a web-based survey

One of the most important properties of a task is its priority, because this property strongly influences the (re)scheduling of skeleton activities (e.g. for solving overlaps by the overlap-remover). The value of the priority property differs from task to task within one role. Table 9.1 shows the priorities of the tasks associated with the role PhD student. If two (or more) roles are associated with tasks belonging to the same task-type, the priority of these tasks may differ per role.

Example
The task sets of the roles PhD student and professor are among other things associated with the task *give student coaching*. In general PhD students will have a different opinion regarding the importance of this task than professors. For instance, PhD students consider this task to be of minor importance, while professors attach much value to this task (or visa versa). This results in a different priority value of this task for PhD students than for professors.
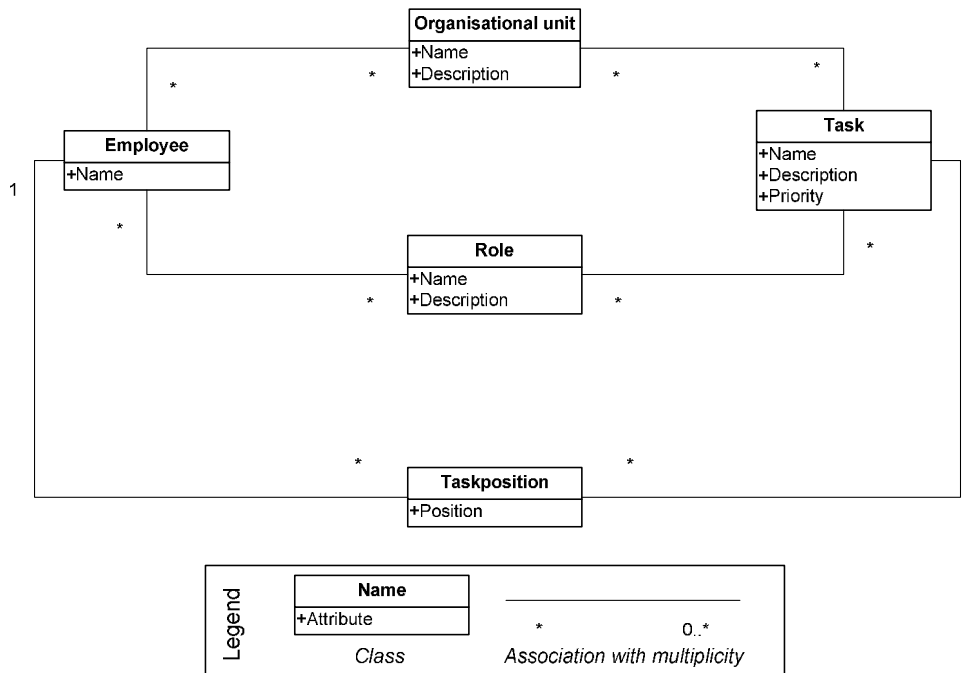
Figure 9.1: Class diagram of the task-sorter.

The priority of tasks could not be determined using existing data sources, simply because no data source was available which contained this kind of data. Therefore, a web-based survey was developed to collect data about how employees perceived the priority of tasks (i.e. skeleton activities) they perform on workdays. The class diagram of this survey is depicted in Figure 9.1. Each respondent was requested to perform one assignment in which he was asked to order his tasks according to priority, from high to low priority (see Figure 9.2). The combination of roles of an employee and the organisational units he belonged to determined the set of tasks he was requested to order. All employees belonging to the test case organisation were asked to participate. Of the in total 38 people, 33 completed the survey.

The end result of the survey was a set of mean priority values for all tasks belonging to either a role or organisational unit. The order of tasks as specified per respondent had to be translated into priorities of tasks per role or organisational unit. Each organisational unit and role was linked with a set of tasks (see Figure 9.1). Respondents who had the same role, but belonged to different organisational units had different task sets (or visa versa). Consequently, the composition of the task set varied per respondent. For each respondent the original order of tasks was converted into an order of tasks per role and organisational unit. This made it possible to properly average the priority of tasks per role or organisational unit. Next, the order of tasks was converted into priority values. This was done as follows: the most important task was associated with a priority value of 100, the second most important task with a value of 99, etc. The value of 100 is arbitrary and not of real importance; a different value could have been chosen as long as the most important task received the highest priority. Afterwards, the mean value of the priority of each task was calculated.
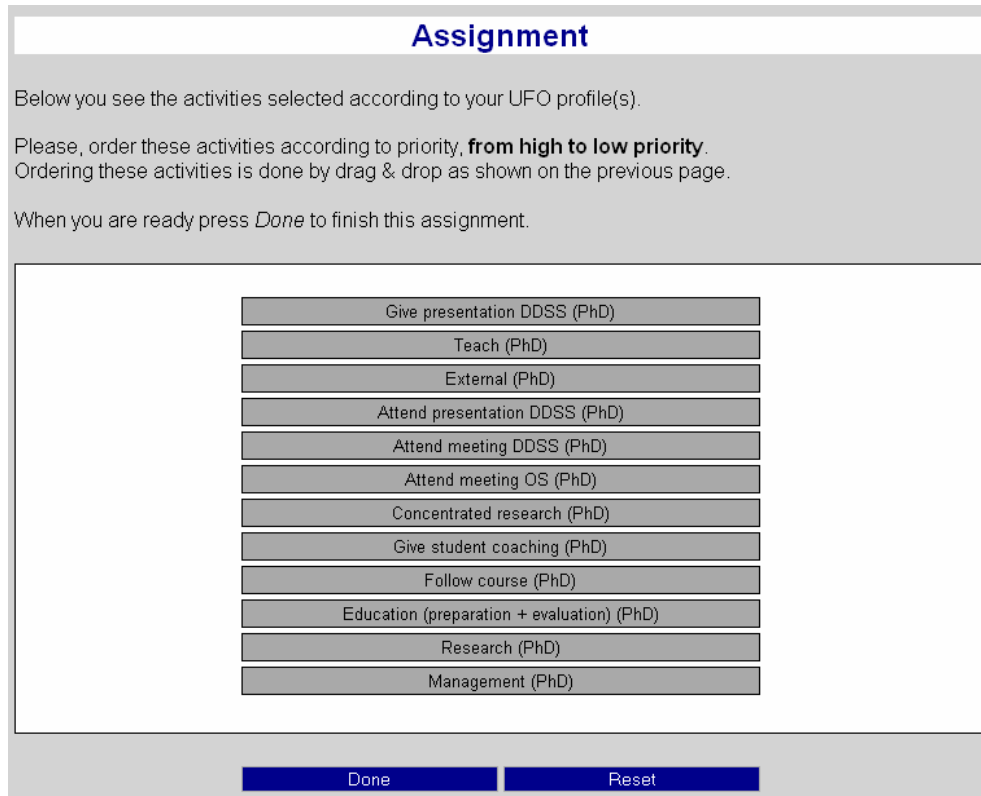
Figure 9.2: Task-sorter, a web-based survey.

Example

Employee A, B and C are PhD students. For this example the role PhD student is associated with the following four tasks: research, teach, get PhD coaching and external. Furthermore, employee A and C belong to the same organisational unit X, employee B belongs to organisational unit Y. Organisational unit X is associated with two tasks, namely attend meeting X and give presentation X; organisational unit Y is associated with the task attend meeting Y. Assume the three employees order their tasks as shown in Table 9.2.

Employee A	Employee B	Employee C	Priority
Research	Get PhD coaching	External	100
Give presentation X	Research	Research	99
Teach	Attend meeting Y	Attend meeting X	98
Get PhD coaching	External	Give presentation X	97
Attend meeting X	Teach	Get PhD coaching	96
External		Teach	95

Table 9.2: Fictive order of tasks for three employees.

Next, these tasks are reordered per role and organisational unit. Table 9.3 shows the order of tasks for the role PhD student after reordering.

Employee A	Employee B	Employee C	Priority
Research	Get PhD coaching	External	100
Teach	Research	Research	99
Get PhD coaching	External	Get PhD coaching	98
External	Teach	Teach	97

Table 9.3: Translated order of tasks for the role PhD student.

Finally, the mean value of the priority of all tasks belonging to the role PhD student was calculated, see Table 9.4. For the sake of keeping this example short and clear, the order of tasks belonging to organisational units X and Y is not analysed, but this can be done in a similar way.

Task	Priority
Research	99.3
Get coaching	98.6
External	98.3
Teach	97.6

Table 9.4: Fictive priorities of the tasks associated with the role PhD student.

9.3   Building input file

All data with respect to the ninth floor of the faculty building which housed the test case organisation was specified using the building input file. Only limited data about the building was needed for simulating the human activity behaviour. The building input file mainly consisted of the total set of abstract-spaces comprising the test case floor (including a set of external abstract-spaces) and the graph, which specified the total set of nodes and edges used to model the movement behaviour of employees. The data in the building input file was based on a digital floor plan of the test case floor. The locations of abstract-spaces (e.g. workplaces and meeting spaces) and the location of all nodes and edges (i.e. the graph) were entered by hand, no exporter was created. Finally, the fixed workplaces of all employees belonging to the test case organisation were added to the building input file.

9.4   Configuration input file

The configuration input file contained all data which was not organisation or building specific. This refers to data valid for all Dutch office based organisations. Except for the parameters used by the scheduler-modules (e.g. the time-interval and the mean walking speed) and the general set of activity-types, this file mainly consisted of parameters regarding the intermediate activities. These parameters were used by the intermediate scheduler to predict the intermediate activities. Chapter five discussed the two methods for predicting the intermediate activities, namely the S-curve method and the probabilistic method. The parameters of the S-curve and the probabilistic intermediate activities were estimated based on data collected in a (second) web-based survey,

mainly consisting of a stated choice experiment. Dutch employees working in an office building were asked to participate in the survey. In total 116 respondents completed the survey. Another 50 respondents started filling in the survey, but did not complete it. This was probably due to the large number of questions the respondents had to answer and the resulting time it took to complete the questionnaire.

9.4.1   Setup of the survey

This web-based survey consisted of three parts. First, all respondents were asked to answer a set of questions with respect to their characteristics (e.g. year of birth, occupation and if they smoked and/or sported). The second part of the survey dealt with questions related to the frequency and the average duration of both the S-curve and probabilistic intermediate activities. In the last and main part of the survey a respondent was presented with the choice scenarios related to one chosen S-curve intermediate activity. One of the S-curve intermediate activities comprising the survey was chosen at random while taking into account if the respondent smoked and/or sported. Then, based on the average frequency entered by the respondent for this activity he was assigned to one of the available sets of choice scenarios (see section 9.4.3).

The definition of stated choice experiment according to Shen (2005):
"A stated choice survey employs a carefully designed questionnaire in which respondents are given a sequence of questions or choice sets. In each choice set, they are asked to indicate their preferred option from a set of alternatives. Each alternative option is described in terms of a number of key attributes that are specified at different levels. The configuration of attribute levels that describe the alternatives follows an experimental design and varies between choice sets".

Before the remaining part of this section discusses the design and analysis of the stated choice experiment, first the data analysis of the second part of the survey will be discussed.

9.4.2   Data analysis about mean frequencies and durations

The second part of the survey focussed on obtaining data about the duration and frequency of all intermediate activities, both S-curve and probabilistic. Each respondent was asked to enter the number of times he performed each of the S-curve and probabilistic intermediate activities during a working day. For the S-curve intermediate activities he was also asked to enter the average duration of these activities. It was assumed that the average duration of S-curve intermediate activities strongly varied per respondent. The duration of a probabilistic intermediate activity varies less. The duration of a probabilistic intermediate activity is limited in comparison to the time required to walk to the location of the intermediate activity.

Table 9.5 shows the mean frequency and the corresponding standard deviation of the probabilistic intermediate activities. Figure 9.3 shows the histogram of two probabilistic intermediate activities. The following observations can be made. The standard deviation associated with the probabilistic intermediate activities is rather large in comparison to their mean values. This relates to a large variation in the frequency of the probabilistic

intermediate activities. For most probabilistic intermediate activities the frequency is normally distributed, except for the intermediate activity *walk to mailbox*.

Probabilistic intermediate activity	Frequency	
	Mean (#/day)	Standard deviation
Go to toilet	2.78	1.14
Receive unexpected visitor	2.20	2.00
Walk to mailbox	1.28	1.06
Walk to printer	3.96	1.76
Walk to secretary	2.70	1.82

Table 9.5: Frequency of probabilistic intermediate activities.
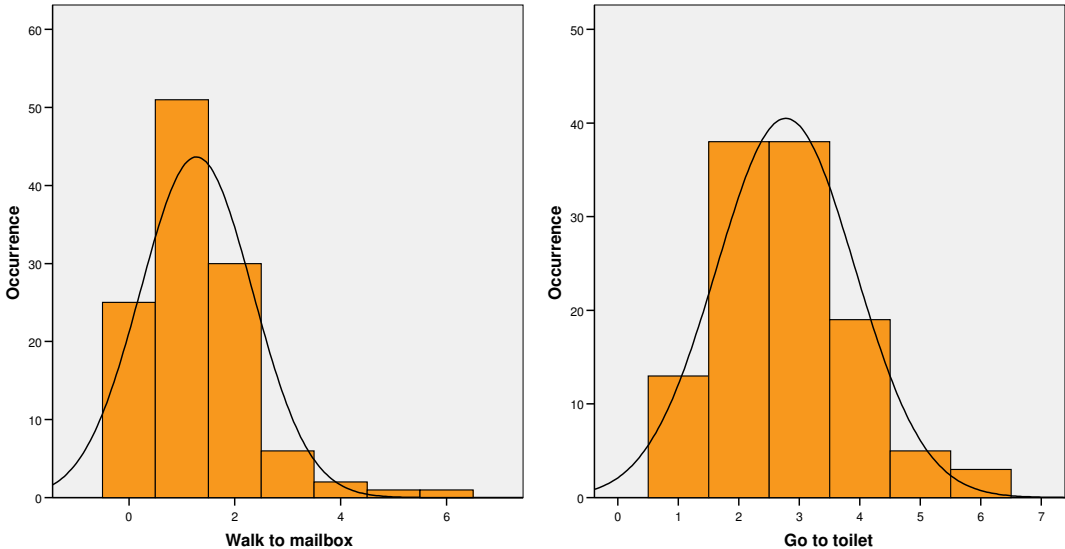
Figure 9.3: Histograms of the occurrence of probabilistic intermediate activities walk to mailbox and go to toilet.

Table 9.6 shows the mean duration and frequency of the S-curve intermediate activities combined with the corresponding standard deviation. Figure 9.4 illustrates the typical histograms of the frequency and duration of S-curve intermediate activities. The S-curve intermediate activities were also characterised by a rather large variation in both the frequency and duration. Furthermore, for most S-curve intermediate activities the distribution of the duration was left side askew. In the case of the S-curve intermediate activity *have a break* this related to a rather strong preference for short breaks, assisted by the fact that the duration of an activity can not be shorter than zero.

S-curve intermediate activity	Duration		Frequency	
	Mean (mm:ss)	Standard deviation	Mean (#/day)	Standard deviation
Have lunch	27:42	10:04	0.91	0.29
Sport	42:49	10:29	0.82	0.39
Get a drink	02:46	02:24	3.80	1.37
Smoke	06:00	02:36	2.22	1.64
Have a break	08:06	06:39	2.51	1.47

Table 9.6: Duration and frequency of S-curve intermediate activities.
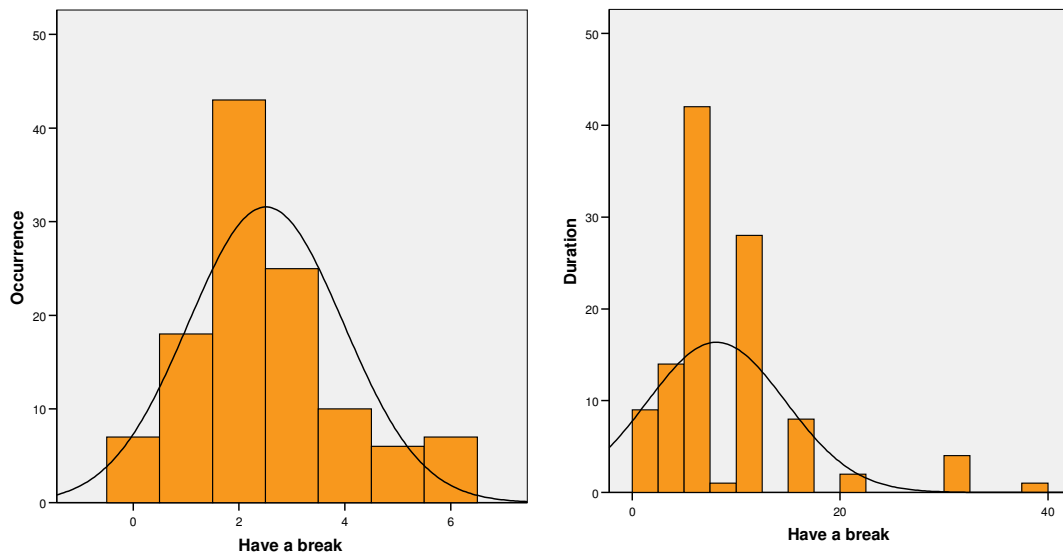
Figure 9.4: Histograms of the occurrence (left) and duration (right) of the S-curve intermediate activity *have a break*.

9.4.3   Stated choice experiment

In the stated choice experiment each respondent was presented with a series of hypothetical choice scenarios. In each choice scenario the respondent was asked to indicate the probability that he will perform the S-curve intermediate activity in a particular setting of a typical working day. In each choice scenario the setting of the working day was varied. Each choice scenario followed the same outline, namely:

The previous time you performed the activity [activity] is [time] ago.
Your working day consists of mainly [type-of-day].
You are currently busy with [type-of-activity].
No other intermediate activity is urgent.

Please, indicate the probability that you will perform this activity right now (0= certainly not, 100 = certainly yes).

Each choice scenario was described using a combination of levels of the following three attributes (see section 9.4.3.1):

- x_i Type-of-day effect (2 levels)

- y_j Type-of-activity effect (4 levels)

- z_k Time effect (4 levels)

A full fractional design was not an option, as this resulted in 32 choice scenarios. So, a fractional factorial design was used. This design resulted in a survey consisting of 16 choice scenarios. Each respondent was presented with the full set of choice scenarios, meaning that he had to enter the probability for all 16 situations.

9.4.3.1 Selection of choice attributes levels

The type-of-day effect details the context of the working day during which the intermediate activities will take place (see section 5.4.1.1). The attribute consists of two levels, namely:

- Working day mainly consisting of work related activities (corresponds to null situation) [x_0].

- Working day mainly consisting of activities of the activity-type *meeting* [x_1].

The order of these levels is based on the following assumption: if a working day is dominated by meetings an employee is less likely to perform intermediate activities than on a working day consisting of job related activities. In other words, the value of x_1 is assumed to be smaller (i.e. more negative) than the value of x_0.

The type-of-activity effect depends on the activity-type of the skeleton activity (see section 6.6.5.1). This attribute consists of the following four levels (ranging from informal to formal):

- Activity-type is *work* (corresponds to null situation) [y_0].

- Activity-type is *concentrated work* [y_1].

- Activity-type is *meeting* and the respondent is not the initiator of this activity [y_2].

- Activity-type is *meeting* and the respondent is the initiator of this activity [y_3].

The order of the levels of this attribute is based on the following assumption: the more formal a skeleton activity is, the higher the utility of an intermediate activity needs to be before being executed (see section 6.6.5). The value of $V_{context}$ with regard to the type-of-activity effect decreases with increasing formality; meaning that the value of y_3 is assumed to be smaller (i.e. more negative) than the value of y_0.

The time effect depends on the time elapsed since the previous occurrence of that intermediate activity. The time effect is represented by a discrete set of levels, namely:

- Longest elapsed time (corresponds to null situation) [z_0].

- Second longest elapsed time [z_1].
- Third longest elapsed time [z_2].

The end result of the stated choice experiment was a set of estimated values for all levels of the type-of-day effect, type-of-activity effect and time effect attributes per S-curve intermediate activity. The combined values of the attribute levels of the type-of-day effect and type-of-activity effect describe the context-of-the-day variable $V_{context}$ (function 5.5). The estimated values of the time effect attribute were used to fit the S-curve with as end result the values of the α and β parameters and the values of the V_{max} and V_{min} variables of function 5.3 per S-curve intermediate activity. The process of curve fitting involved determining the values of the α and β parameters and the V_{max} and V_{min} variables in such a way that the corresponding S-curve went in the best possible way through the data points of the estimated values of the time effect attribute levels (see Figure 9.5 for an example). In order to correctly fit the S-curve through the data points, these points should ideally be located around the (expected) inflection point and not somewhere close to asymptotes of the S-curve. This meant that the levels of the time effect attribute had to be carefully chosen.
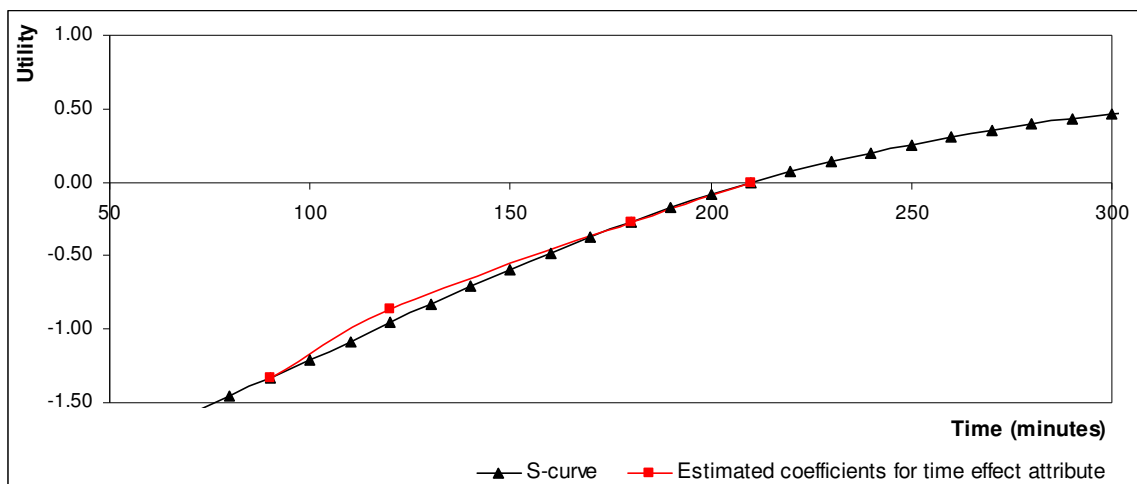
Figure 9.5: Example of curve fitting.

As mentioned in section 5.4, the number of times an intermediate activity is performed on a working day varies per person. This was confirmed by Table 9.6, which showed a large variation in the mean frequency of the S-curve intermediate activities between the respondents. In the USSU prototype frequency intervals were applied to limit the complexity of predicting the intermediate activities (see section 7.3.4.3). This also limited the complexity of the stated choice experiment as data only had to be collected for the three frequency intervals, instead for all possible frequencies. This reduced the number of sets of choice scenarios. Consequently, fewer respondents were required, because for a reliable statistical analysis a certain minimal number of respondents were required per set of choice scenarios. Table 9.7 shows the distribution of the respondents over the different frequency intervals. This distribution is used in the USSU prototype as probabilities to associate a certain frequency interval to an employee (see section 7.3.4.3).

S-curve intermediate activity	Frequency interval							
	0		**1**		**2-3**		**4-and-more**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Get a drink	-	0.0	6	5.2	44	37.9	66	56.9
Have a break	7	6.0	18	15.5	68	58.6	23	19.8
Have lunch	11	9.5	105	90.5	-	0.0	-	0.0
Smoke[1]	107	92.2	4	3.4	4	3.4	1	0.9
Sport[1]	102	87.9	14	12.1	-	0.0	-	0.0

Table 9.7: Number of respondents per S-curve intermediate activity per frequency interval.
[1] Only those respondents who respectively smoke or sport during work time were asked to fill in their mean frequency.

The survey used a different set of choice scenarios for each frequency interval. Depending on the frequency entered by a respondent for the S-curve intermediate activity in the second part of the survey, he was assigned to the corresponding choice set. The values of the time effect attribute levels varied per frequency interval (see Table 9.8). By linking the time effect attribute levels with the frequency intervals the levels (i.e. the elapsed time values) were realistically represented in relation to the frequency entered by the respondent. If an individual performs an intermediate activity once a day, other values of the elapsed time since the previous occurrence should be used, than when the same activity is performed multiple times on a working day. Finally, this made it possible to locate the data points (i.e. attribute levels) around the inflection point of the S-curve.

Example
Assume, in the third part of the survey (i.e. stated choice experiment) the S-curve intermediate activity *get a drink* was assigned to a respondent and he had previously stated that he performed this activity two times a day. This meant that he was assigned to frequency interval 2-3. The choice scenarios belonging to this frequency interval used the values 1½, 2, 3 and 3½ hours for the time effect attribute levels; these values represented the time elapsed since the previous occurrence of *get a drink*.

However, for activities that were performed only once a day (frequency =1) this would have resulted in one set of time effect attribute levels for the whole day. This was not desirable as this meant that either the data points (i.e. attribute levels) were too wide spread to correctly fit the S-curve or the levels focussed only on a part of a day (i.e. the levels lied in close proximity). In the latter case there was the strong possibility that these levels were not located near the inflection point, but somewhere close to the asymptotes which is not recommended for the curve fitting process. The solution to this problem was to use timeframes for this frequency interval (see Table 9.8). Although this had disadvantages (e.g. increasing the number of choice scenarios) this was required in order to properly fit the S-curve.

Example

A respondent entered that he performed the S-curve intermediate activity *have lunch* only once a day. If this activity was selected in the stated choice experiment, he then was asked to specify the most likely timeframe in which he would perform this activity (e.g.11:00-14:00). Subsequently, the presented choice scenarios used the values associated with this timeframe as time effect attribute levels, namely 3½, 4, 4½ and 5 hours.

Time level	Frequency interval & timeframe					
	1				2-3	4-and-more
	8:00 - 11:00	11:00 - 14:00	14:00 - 16:00	16:00 - 18:00	8:00 - 1800	8:00 - 1800
1	0.5	3.5	5	7	1.5	0.5
2	1	4	6	7.5	2	1
3	2	4.5	6.5	8	3	1.5
4	2.5	5	7	8.5	3.5	2

Table 9.8: Values of the time effect attribute levels (i.e. hours passed since the last activity occurrence) for each frequency interval.

For an S-curve intermediate activity with a frequency bigger than 1 the levels of the time effect described the time elapsed since the previous occurrence of an intermediate activity. For activities that are only performed once a day this is illogical. In these cases the time levels represent the time elapsed since the start of the working day. The same applies for an intermediate activity with a frequency bigger than one, but which is not previous performed during the working day. This relates to the time frame between the start of the working day and the first occurrence of the intermediate activity. In this case it was also illogical to use the time level as elapsed time. Furthermore, it was assumed that people will behave differently in the situation when they perform an intermediate activity for the first time on a working day than in the situation when they already performed this activity during their working day (see section 5.4.1). This means that the shape of the S-curve depends on whether an intermediate activity is already performed or not. Assumed was that the S-curve with respect to the first occurrence of an intermediate activity on a working day lays above the S-curve for subsequent occurrences of the same intermediate activity. To verify this assumption each choice scenario consisted of two parts. In the first part a respondent was asked to enter the probability assuming that he had yet to perform the intermediate activity (i.e. this related to the first occurrence of this activity). In this case the levels of the time effect represent the time elapsed since the start of his working day. In the second part the respondent was asked to assume that he already had performed the intermediate activity (i.e. this related to subsequent occurrences of this activity). In this case he had to enter the probability in relation to the elapsed time since the previous occurrence. This resulted in two sets of estimated values for the frequency intervals 2-3 and 4-and-more for each S-curve intermediate activity.

9.4.3.2 Analysis of results stated choice experiments

Using a stated choice experiment the utility of an intermediate activity can not be observed directly. It is assumed to consist of a structural component and a random term (similar to function 5.1), namely:

$$U_a = V_a + \varepsilon_a \tag{9.1}$$

where:

U_a is utility of intermediate activity a

V_a is structural (or deterministic) utility of intermediate activity a

ε_a is error term (or random utility)

The structural utility V_a, including the levels i, j and k for intermediate activity a, can be expressed as:

$$V_{a,ijk} = C_a + x_{a,i} + y_{a,j} + z_{a,k} \tag{9.2}$$

where:

$x_{a,i}$ is type-of-day effect of intermediate activity a for level i

$y_{a,j}$ is type-of-activity effect of intermediate activity a for level j

$z_{a,k}$ is time effect of intermediate activity a for level k

C_a is constant utility in null situation

The null situation relates to the situation were the utility of an intermediate activity is not limited by the type-of-day effect, type-of-activity effect and the time effect. The first level of the three attributes (i.e. x_0, y_0 and z_0) correspond to the null situation; the contribution of these levels to the overall utility is set to zero. The null situation leads to the maximum utility represented by the constant utility (C_a). This is the utility compared with the situation where the intermediate activity is not performed by an individual; the utility for not performing an intermediate activity is assumed to be zero.

The probability that an individual performs an intermediate activity can be expressed using a standard MNL model as follows:

$$P_r(V_{a,ijk} + \varepsilon_{a,ijk} > 0) = \frac{\exp(V_{a,ijk})}{1 + \exp(V_{a,ijk})} \tag{9.3}$$

where:

P_r is probability that $U_a > 0$, $P_r \in \langle 0,1]$

The probabilities entered by the respondents for each intermediate activity were used to estimate the values of the type-of-day effect ($x_{a,i}$), type-of-activity effect ($y_{a,j}$) and time

effect ($z_{a,k}$) attribute levels of function 9.2. The values were estimated in an econometrics package called Limdep using dummy variables (see appendix A1 for the dummy-coding scheme). These values were estimated per intermediate activity and per group of respondents belonging to a certain frequency interval. In other words, for each frequency interval only the probabilities stated by those respondents who were assigned to this interval were taken into account. The estimated values represent the mean values with regard to all people belonging to a frequency interval.

The estimated values for the type-of-day and type-of-activity effect attribute levels (i.e. x_1, y_1, y_2 and y_3) represent the value of the context-of-the-day variable of function 5.5 for the levels as discussed in section 6.6.5.1. Table 9.9, Table 9.10 and Table 9.11 show the estimated values and associated *P*-values of the attribute levels of the type-of-day effect and the type-of-activity effect per frequency interval, illustrated by Figure 9.6 - Figure 9.11. The *P*-value specified the statistical significance of the corresponding estimated coefficient: if the *P*-value was smaller than 0.05 (threshold for statistical significance) than the value significantly differed from zero. All estimated values significantly differed from zero, except for the estimated value of x_1 belonging to the intermediate activity *get a drink* for frequency interval 4-and-more.

S-curve intermediate activity	x_1		y_1		y_2		y_3	
	value	**P**	value	**P**	value	**P**	value	**P**
Get a drink	No data							
Have a break	No data							
Have lunch	0.13	0.00	-0.74	0.00	-1.44	0.00	-1.24	0.00
Smoke	No data							
Sport	0.75	0.00	-1.08	0.00	-1.64	0.00	-2.12	0.00

Table 9.9: Estimated values of the context-of-the-day attribute levels (function 9.2) for frequency interval 1.
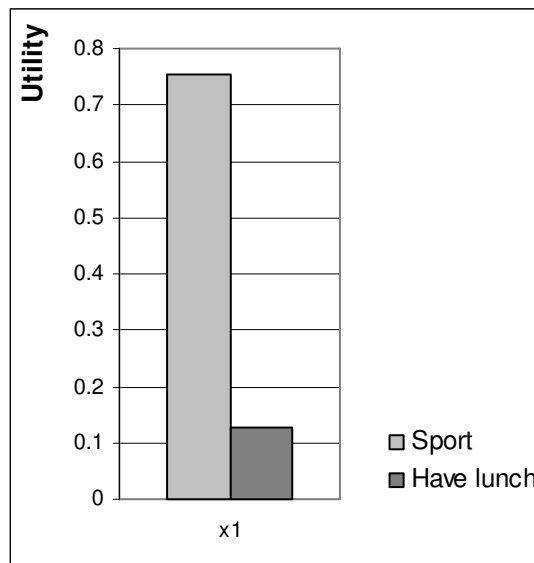
Figure 9.6: Estimated values of the type-of-day effect attribute level (function 9.2) for frequency interval 1.
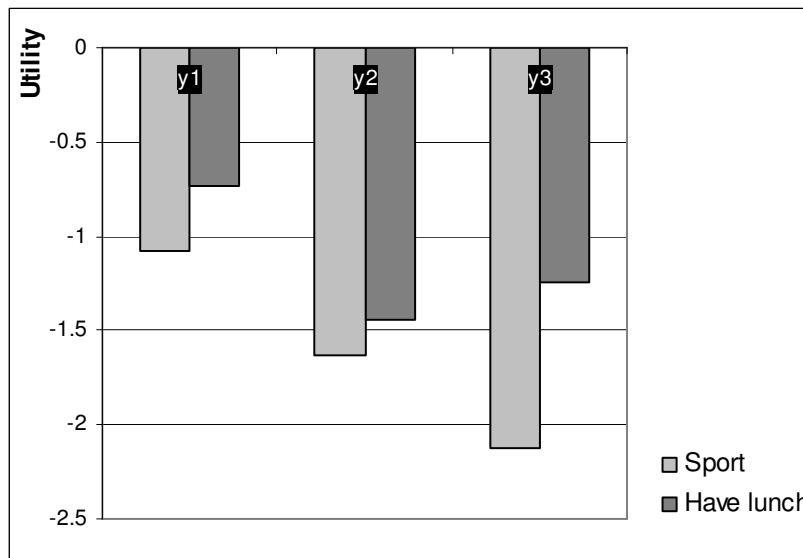
Figure 9.7: Estimated values for the type-of-activity effect attribute levels (function 9.2) for frequency interval 1.

S-curve intermediate activity	x_1		y_1		y_2		y_3	
	value	**P**	value	**P**	value	**P**	value	**P**
Get a drink	0.062	0.00	-0.54	0.00	-1.13	0.00	-0.66	0.00
Have a break	0.045	0.02	-0.57	0.00	-1.16	0.00	-0.94	0.00
Have lunch	No data							
Smoke	0.67	0.00	-1.15	0.00	-1.27	0.00	-1.39	0.00
Sport	No data							

Table 9.10: Estimated values of the context-of-the-day attribute levels (function 9.2) for frequency interval 2-3.

Figure 9.8: Estimated values of the type-of-day effect attribute level (function 9.2) for frequency interval 2-3.
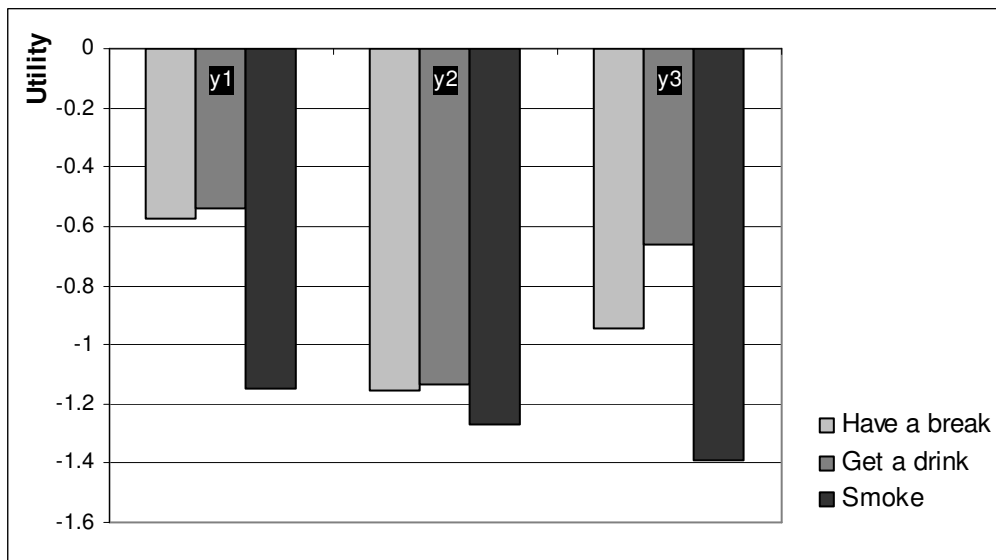
Figure 9.9: Estimated values for the type-of-activity effect attribute levels (function 9.2) for frequency interval 2-3.

S-curve intermediate activity	x_1		y_1		y_2		y_3	
	value	P	value	P	value	P	value	P
Get a drink	0.02	0.07	-1.37	0.00	-1.61	0.00	-1.37	0.00
Have a break	0.20	0.00	-0.84	0.00	-1.32	0.00	-0.91	0.00
Have lunch	No data							
Smoke	No data							
Sport	No data							

Table 9.11: Estimated values of the context-of-the-day attribute levels (function 9.2) for frequency interval 4-and-more.
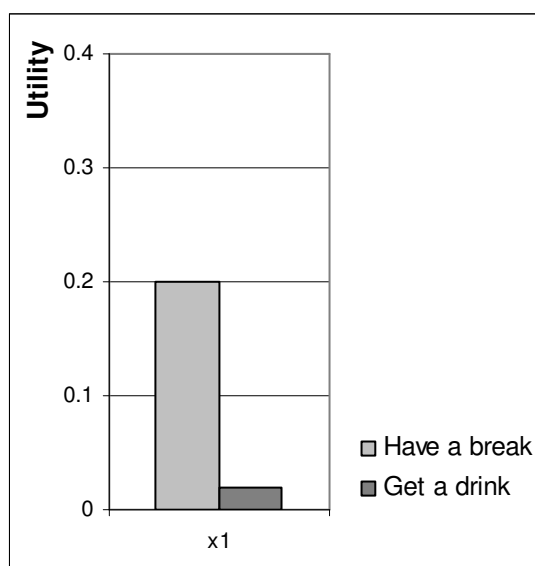
Figure 9.10: Estimated values of the type-of-day effect attribute level (function 9.2) for frequency interval 4 or more.
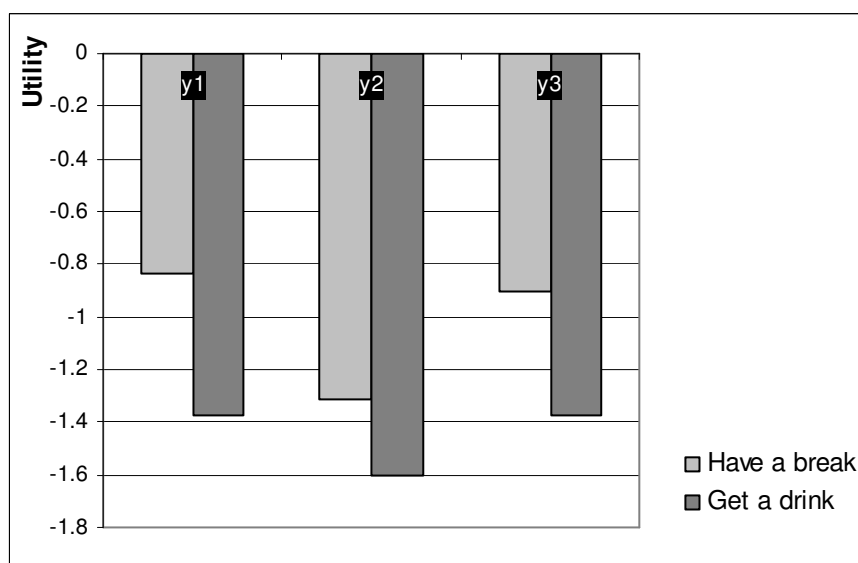
Figure 9.11: Estimated values for the type-of-activity effect attribute levels (function 9.2) for frequency interval 4-and-more.

It is now possible to test both assumptions made about the context-of-the-day variables (i.e. type-of-day and type-of-activity effect) against the estimated values of the attribute levels. The first assumption concerned the type-of-day effect. It was assumed that people are less likely to participate in intermediate activities on a working day dominated by meetings. In other words, the value of attribute level x_1 was assumed to be smaller (i.e. more negative) than the value of x_0. However, the opposite was true. Table 9.9, Table 9.10 and Table 9.11 show that the value of attribute level x_1 was bigger than the value of x_0 for all frequency intervals. This meant that on working days consisting of mainly meetings, people were more willing to participate in intermediate activities than on a day consisting of work related activities. The second assumption was related to the type-of-activity effect. Assumed was that an employee is more likely to interrupt or postpone an informal skeleton activity than a formal skeleton activity. Meaning that the value of y_3 is assumed to be smaller (i.e. more negative) than the value of y_0. The overall trend of the estimated values of the attribute levels for the type-of-activity effect corresponded with this assumption.

S-curve intermediate activity	$z_{a,1}$		$z_{a,2}$		$z_{a,3}$	
	value	P	value	P	value	P
Get a drink	No data					
Have a break	No data					
Have lunch[1]	-0.07	0.01	-0.10	0.00	-0.22	0.00
Smoke	No data					
Sport[1]	0.55	0.00	0.79	0.00	1.83	0.00

Table 9.12: Estimated values for the time effect attribute levels (function 9.2) for frequency interval 1.
[1] Only data observed for the time interval 11:00 - 14:00.

In addition to the estimated values of the attribute levels belonging to the context-of-the-day variable, the estimation process also resulted in estimated values of the levels of the time effect attribute (i.e. $z_{a,k}$ for k =1,2 & 3). Table 9.12 shows the estimated values and the associated *P*-values of the time effect attribute levels for the first frequency interval. Apparently, no respondent performed the intermediate activities *get a drink*, *smoke* or *have a break* only once a day. The estimated values for the activities *have lunch* and *sport* significantly differed from zero. The estimated values of the time effect attribute levels for the intermediate activity *have lunch* resulted in an anticipated shape of the S-curve (see Figure 9.12, the rightmost data point relates to the null situation). However, the estimated values for the intermediate activity *sport* resulted in a totally unexpected S-curve shape (see Figure 9.13). Evidently the utility decreased with time for this intermediate activity, instead of increasing with time. For activities with a frequency of 1 the time effect attribute levels represent the time elapsed since the start of the working day. These attribute levels can be converted to real clock times. Let's assume that an individual starts working around 8:30, the first attribute level with a value of 3½ means 12:00, the second attribute level with a value of 4 means 12:30, etc. The probability that an individual engaged in the intermediate activity *sport* around 12:00 was relatively high. However, the later it got the less likely it became that he performed this

intermediate activity. The most plausible reason for this is that a respondent weighted the probability of performing this intermediate activity on basis of the clock time and not on the time elapsed since the start of his working day. Apparently, the occurrence of this activity was strongly influenced by a clock time effect, which was not taken into account in this model. For estimating the occurrence of the intermediate activity *sport* in the context of the validation of USSU this activity was treated as a probabilistic intermediate activity.
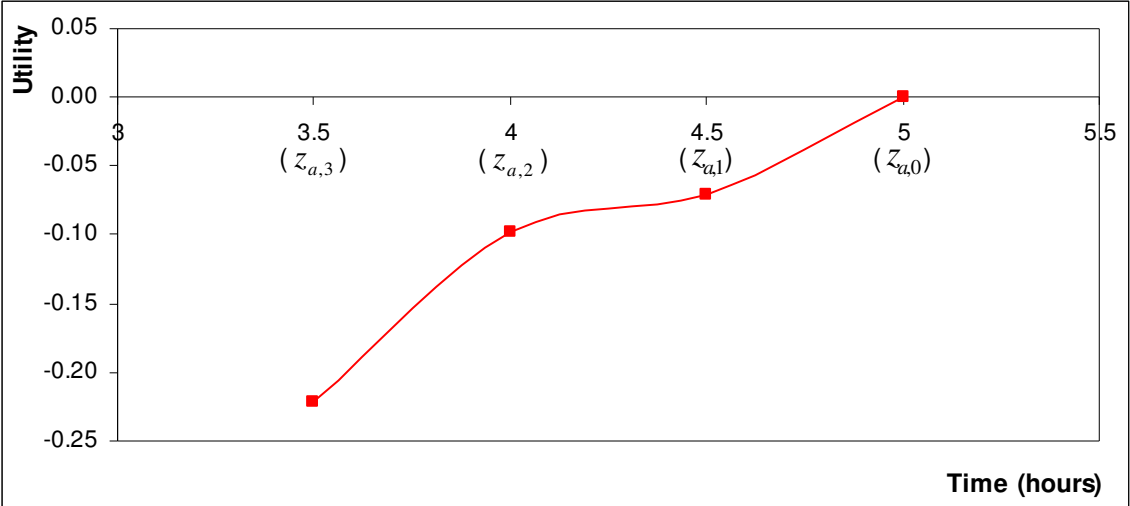
Figure 9.12: S-curve based on the estimated values of the time effect attribute levels (i.e. hours passed since start of working day) for intermediate activity *have lunch*.
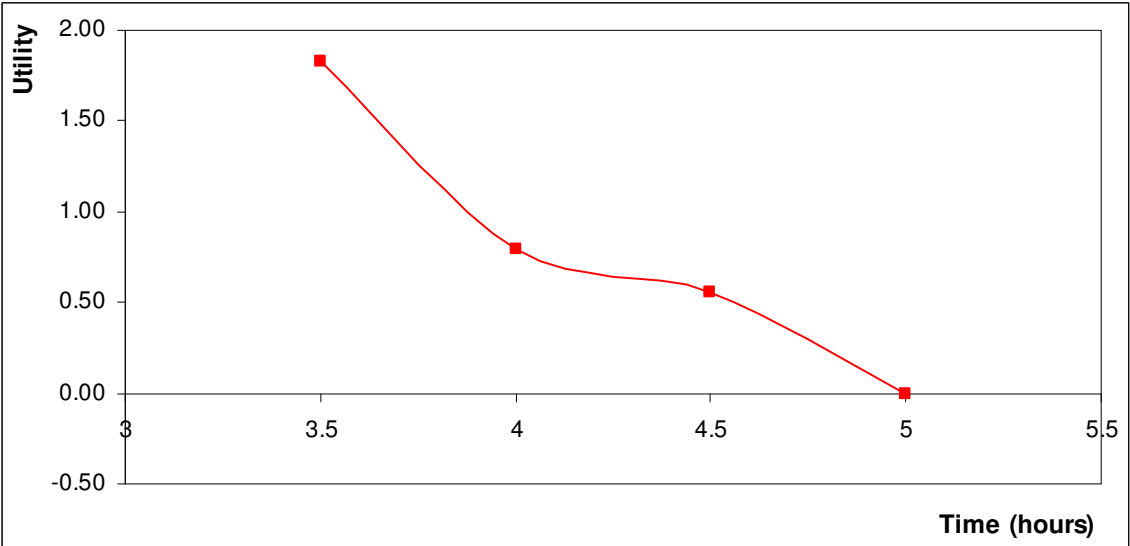
Figure 9.13: S-curve based on the estimated values of the time effect attribute levels (i.e. hours passed since start of working day) for intermediate activity *sport*.

S-curve intermediate activity	$z_{a,1}$		$z_{a,2}$		$z_{a,3}$	
	value	P	value	P	value	P
Get a drink	-0.03	0.31	-0.45	0.00	-1.04	0.00
Have a break	-0.28	0.00	-0.68	0.00	-1.40	0.00
Have lunch	No data					
Smoke	-0.63	0.00	-0.34	0.02	-0.60	0.00
Sport	No data					

Table 9.13: Estimated values for the time effect attribute levels (function 9.2) for frequency interval 2-3, first occurrence.

S-curve intermediate activity	$z_{a,1}$		$z_{a,2}$		$z_{a,3}$	
	value	P	value	P	value	P
Get a drink	-0.27	0.00	-0.87	0.00	-1.34	0.00
Have a break	-0.30	0.00	-0.83	0.00	-1.46	0.00
Have lunch	No data					
Smoke	-1.01	0.00	-1.13	0.00	-1.71	0.00
Sport	No data					

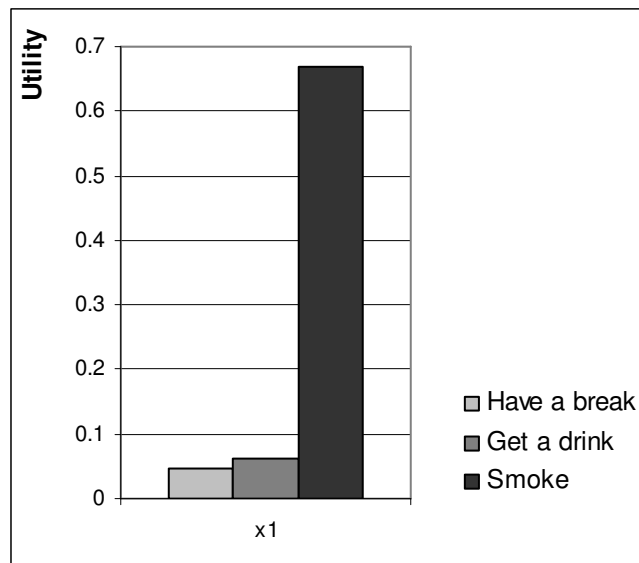**Table 9.14: Estimated values for the time effect attribute levels (function 9.2) for frequency interval 2-3, subsequent occurrences.**

Table 9.13 and Table 9.14 show the estimated results for the frequency interval 2-3. The following observations can be made. All estimated values significantly differed from zero, except for the value of the $z_{a,1}$ attribute level belonging to the intermediate activity *get a drink* for the first occurrence. At the end of the previous section the assumption was made that the shape of the S-curve of an S-curve intermediate activity depends on whether the intermediate activity is already performed on a working day or not. This assumption was correct. The S-curve for the situation in which the intermediate activity was not previous performed indeed lay above the S-curve for subsequent occurrences of the intermediate activity (see Figure 9.14, the rightmost data points relate to the null situation). However, the estimated values for the time effect attribute with regard to the intermediate activity *smoke* revealed an unexpected shape of the S-curve (see Figure 9.15). The utility of the $z_{a,1}$ attribute level in the situation that the intermediate activity was not previous performed is smaller (i.e. more negative) than the utility of the $z_{a,2}$ attribute level. An explanation for the unexpected drop in the S-curve can be found by again taking the corresponding clock times into account. The $z_{a,2}$ attribute level relates to a clock time of approximately 11:30. This was just before most people had lunch. Evidently smokers did not find it worthwhile to smoke just before they had lunch; they postponed the intermediate activity and combined it with going away for lunch. This led to a lower utility for the intermediate activity around lunch time as seen in Figure 9.15. Again, in this situation the behaviour of people was strongly influenced by a clock time effect. As this shape could not be properly fitted with an S-curve shape the decision was made to treat this intermediate activity as a probabilistic intermediate activity in the context of the validation of USSU.
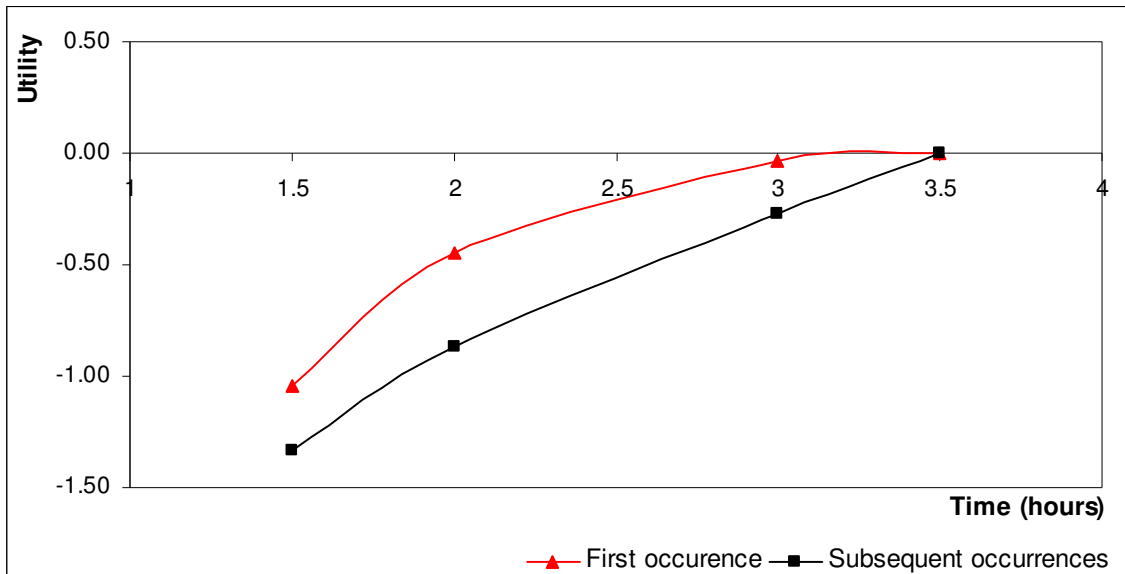
Figure 9.14: Estimated values of time effect attribute levels (i.e. hours passed since last activity occurrence, see function 9.2) for intermediate activity *get a drink*.
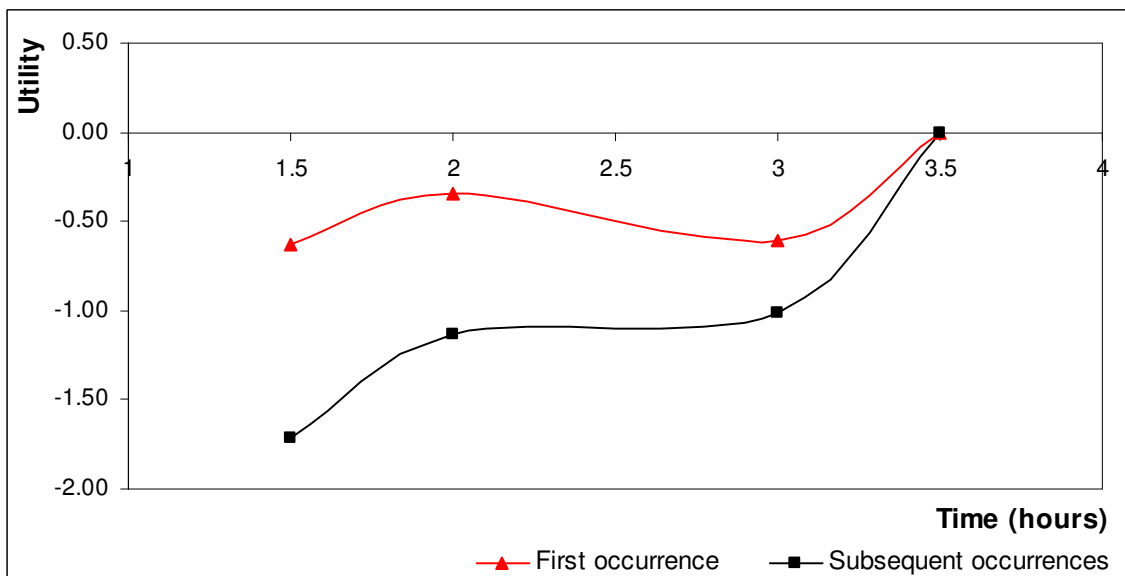
Figure 9.15: Estimated values of time effect attribute levels (i.e. hours passed since last activity occurrence, see function 9.2) for intermediate activity *smoke*.

S-curve intermediate activity	$z_{a,1}$		$z_{a,2}$		$z_{a,3}$	
	value	P	value	P	value	P
Get a drink	-0.10	0.00	-0.49	0.00	-0.95	0.00
Have a break	-0.35	0.00	-1.08	0.00	-2.38	0.00
Have lunch	No data					
Smoke	No data					
Sport	No data					

Table 9.15: Estimated values for the time effect attribute levels (function 9.2) for frequency interval 4-and-more, first occurrence.

S-curve intermediate activity	$z_{a,1}$		$z_{a,2}$		$z_{a,3}$	
	value	P	value	P	value	P
Get a drink	-0.91	0.00	-1.44	0.00	-1.85	0.00
Have a break	-0.41	0.00	-0.70	0.00	-1.10	0.00
Have lunch	No data					
Smoke	No data					
Sport	No data					

Table 9.16: Estimated values for the time effect attribute levels (function 9.2) for frequency interval 4-and-more, subsequent occurrences.

Finally, Table 9.15 and Table 9.16 show the estimated values for the levels of the time effect attribute for the frequency interval 4-and-more. All estimated values significantly differed from zero.

The estimated values for the time effect levels combined with the level of the null situation led to 4 data points to fit the S-curve. The curve fitting process resulted in values of the α and β parameters and the V_{max} and V_{min} variables (see function 5.3) that belonged to S-curves that went in the best possible way through the data points (i.e. estimated time effect attribute levels). Table 9.17, Table 9.18 and Table 9.19 show the results of the curve fitting process for respectively the frequency intervals 1, 2-3 and 4-and-more. Figure 9.16 shows the actual S-curve shapes of all S-curve intermediate activities for the relevant frequency intervals.

S-curve intermediate activity	Parameters & variables			
	α	β	V_{min}	V_{max}
Have lunch[1]	81.540	0.018	-2.850	2.890
Sport[2]	No valid data			

Table 9.17: Estimated values for the parameters and variables of function 5.3 for frequency interval 1.
[1] Only data observed for the time interval 11:00 - 14:00.
[2] The estimation process did not result in a true S-curve as expected; this activity is treated as a probabilistic intermediate activity in the context of the validation of USSU.

S-curve intermediate activity	Parameters & variables							
	First occurrence				Subsequent occurrences			
	α	β	V_{min}	V_{max}	α	β	V_{min}	V_{max}
Get a drink	76.940	0.039	-2.810	2.820	107.510	0.014	-2.920	3.610
Smoke[1]	No valid data				No valid data			
Have a break	85.000	0.019	-3.150	3.400	85.000	0.019	-3.260	3.520

Table 9.18: Estimated values for the parameters and variables of function 5.3 for frequency interval 2-3.

[1] The estimation process did not result in a true S-curve as expected; this activity is treated as a probabilistic intermediate activity in the context of the validation of USSU.

S-curve intermediate activity	Parameters & variables							
	First occurrence				Subsequent occurrences			
	α	β	V_{min}	V_{max}	α	β	V_{min}	V_{max}
Get a drink	-9.800	0.020	-3.920	4.300	131.000	0.025	-2.226	5.189
Have a break	35.100	0.040	-4.400	4.550	3.000	0.010	-4.400	5.850

Table 9.19: Estimated values for the parameters and variables of function 5.3 for frequency interval 4-and-more.
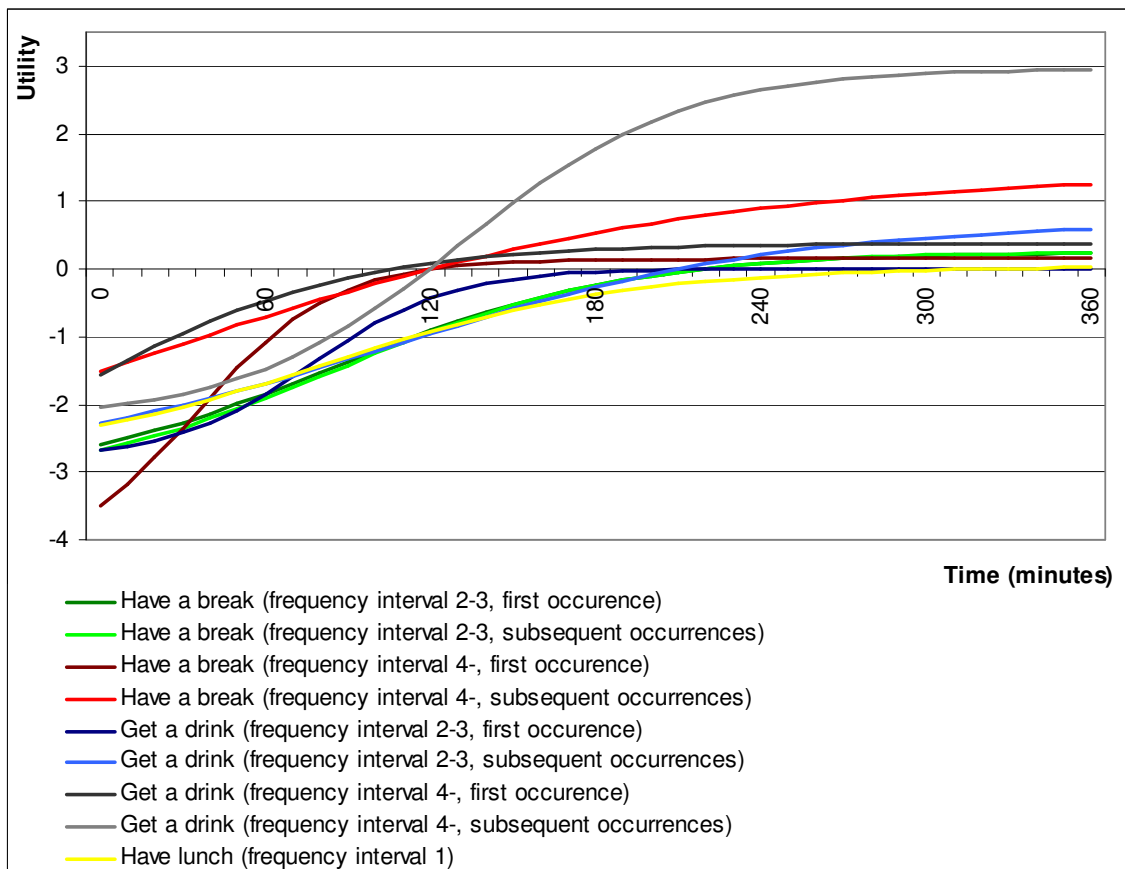
Figure 9.16: S-curves of all S-curve intermediate activities for relevant frequency intervals.

9.5　Conclusions

This chapter focussed on the calibration of the USSU prototype in relation to the chosen validation test case. For the calibration of the prototype an extensive data collection was performed with regard to the three input files, namely the organisation, building and configuration input file. The organisation input file contained all data related to the test case organisation; it specified the structure of this organisation. All data related to the building in which the test case organisation was housed was specified by the building input file. Except for the parameters used by the scheduler-modules (e.g. the time-interval and the mean walking speed) and the general set of activity-types, this file mainly consisted of parameters regarding the intermediate activities. These parameters were used by the intermediate scheduler to predict the intermediate activities. The calibration of the USSU prototype with respect to the first two input files was to a large extent based on existing data sources. However, for the configuration input file this was impossible as no relevant data source was available. The data required to estimate the parameters of the S-curve and probabilistic intermediate activities was collected using a web-based survey, mainly consisting of a stated choice experiment. Each of the steps with regard to estimating the parameters of the intermediate activities was discussed in detail. The calibration of the USSU prototype resulted in the three completely finalised input files (see appendix A2).

Chapter ten describes the two experiments which were performed to collect data about the actual human activity behaviour on the test case floor.

C10 Validation experiments

10.1 Introduction

Chapter nine focussed on the calibration of the USSU prototype in relation to the chosen validation test case. For the calibration of the prototype an extensive data collection was performed with regard to the three input files, namely the organisation, building and configuration input file. The calibration of the USSU prototype resulted in three completely finalised input files. Afterwards, these files were used for predicting the human activity behaviour in relation to the selected test case.

Finally, before the actual validation can be performed, the real space utilisation of the test case organisation on the test floor had to be observed. In order to execute a thorough validation of USSU two experiments were performed, namely a diary data collection and a RFID data collection. The two experiments resulted in two detailed,

large activity data sets, which made it possible to evaluate the predictive quality of the USSU system. Before both experiments are discussed in detail in this chapter, first a general introduction to the observation of human activity behaviour is given. This section explains why activity diaries and RFID technology were chosen for collecting the real human activity behaviour. This chapter ends with a section on conclusions regarding the validation experiments.

10.2   Observe the actual space utilisation

There are many possible ways of collecting data about the behaviour of people, such as through paper/digital activity diaries, by using technical equipment (e.g. video camera's or infrared sensors) or discreet shadowing of people (Teknomo et al., 2001; Kerridge et al., 2005, Tan, 2003, Arentze et al., 1997). Each method has its strong and weak points. Collecting data about human activity behaviour using paper/digital questionnaires is rather obtrusive and puts a relative high demand on the participants; they have to record all their activities by themselves. There is a realistic chance that people forget to enter activities, albeit not deliberate (Ettema, 1996). The use of technical systems (e.g. video cameras) to record the movements of people is expensive (e.g. it requires a lot of cameras to cover a whole floor). These systems also require a lot of post processing time (e.g. the data recorded using separate cameras have to be combined in order to track individuals across the whole floor). In addition, such systems, in particular video cameras, face strong issues of privacy. Furthermore, several sources in literature (Sundstrom, 1986; Martin and Bateson, 1993) suggest that the knowledge of being observed influences the behaviour of people (the so-called Hawthorne effect). The ideal situation for collecting data about human movement would be when the participants do not know that they are being observed (Fatah et al., 2006). However, in reality this is hardly feasible, not only for operational reasons (i.e. how to track individuals across a space if they are not 'equipped' with a certain traceable feature), but also because of privacy reasons.

A relative new technology called RFID (Radio Frequency IDentification) could be the key for a non-obtrusive way of collecting data about human movement and activity behaviour. Using this system, participants only have to carry a small device (so-called RFID tag), for example in their wallet, and the RFID system automatically registers their movements using so-called RFID readers (i.e. small radio receivers). During the observation period participants themselves do not have to perform any additional actions besides performing their normal behaviour. Due to the passive nature of this system the behaviour of people is only influenced in a limited manner and probably the most in the beginning of the experiment. This system results in observed data about the daily movement behaviour with a relative high degree of truth. However, a disadvantage of this system is that it only delivers data about the utilisation of spaces and the movement of employees between these spaces. It does not reveal the actual types of activities performed by the employees. For a thorough validation of USSU also detailed information about the activity behaviour of people (i.e. type, location and timing of activities) was required.

The optimal way of obtaining data about activities performed by individuals during a working day is by asking it directly to the people; there is simply no way of obtaining data about activity behaviour from for example video data. Due to the required level of detail of activity data the most logical method of obtaining of this data is through activity diaries, which are maintained by the participants themselves during a working day. Other methods, like questionnaires, do not reveal all the required data. By administering the activity diaries during the day instead of at the end of the day or the next day the chance of forgetting activities by respondents is small.

Next, an operational decision was made on the form of administering (i.e. paper or digital). Asking people to fill in activity diaries is an obtrusive and demanding way of collecting data. Each time an employee stands up from his chair at his workplace, he has to note down the current time, where he is going (i.e. activity location) and what he is going to do (i.e. activity type). When he gets back to his chair he again has to enter an activity. By using digital diaries it is possible to assist the respondent. A computerised form of activity diaries can automate tasks and can make the process of entering activities interactive. Furthermore, the activity data can directly be stored in a database. This does not only save lots of post processing time in comparison to paper activity diaries, but it also results in fewer errors.

None of the two observation methods on its own result in all data required for the full validation method as discussed in chapter eight. Therefore, the decision was made to apply both RFID technology and digital activity diaries for collecting data about the real human activity behaviour of the test case organisation. Both experiments were performed parallel to each other and had the same duration, namely 3 months. The first experiment (i.e. the RFID data collection) involved a large group of people, namely both groups comprising the test case organisation (i.e. Design Systems and Structural Design). For the latter experiment (i.e. the diary data collection) only direct colleagues (i.e. members of the Design Systems group) were asked to participate as it puts a relatively high demand on the respondents. The two experiments are discussed in the following two sections.

10.3   RFID data collection

An RFID system consists of readers and tags (see Figure 10.1). An RFID tag is a device which can be remotely accessed to retrieve data stored in its chip. Each tag is equipped with an antenna to receive and respond to radio-frequency queries from an RFID receiver. There are two types of RFID tags: passive and active tags. Passive tags do not have an internal power supply; the power required to transmit a response is induced through the incoming radio-frequency signal. These tags can only be read out from short distances (up to several meters). Active tags, on the other hand, can have a read distance of up to several hundreds of meters. These tags are equipped with an internal power source. An active RFID tag will send out a signal for example every 1.5 seconds. The battery of a tag lasts up to 5 years. In this experiment the active tags were applied in combination with a number of readers. Currently, RFID technology is used by some Dutch organisations for access control and as a means of working hours registration, but up to now never on the detailed level as was used in this experiment.
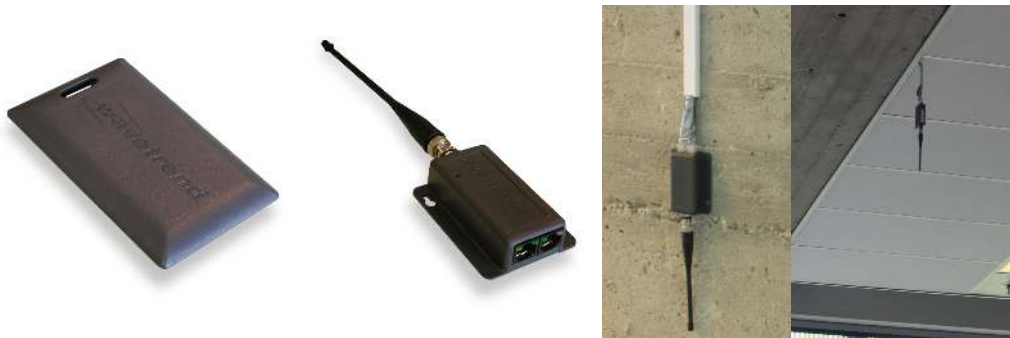
Figure 10.1: RFID tag (left) and readers.

10.3.1 The experiment

All employees belonging to the two chairs (i.e. Design Systems and Structural Design) housed on the test case floor were asked to participate in the RFID experiment. Roughly 50 employees are officially located on this floor. However, some employees are only rarely on this floor; they belong to one of the groups, but do not have a workplace on this floor. Others were not willing to participate. In the end 37 people accepted the request. Each person was requested to wear a RFID tag for a period of 3 months. The office floor was divided into zones; each zone was equipped with 1 or 2 readers to detect the presence of a tag (see Figure 10.2). In total 16 receivers where installed and setup (e.g. the threshold of the signal strength to detect a tag). Each reader registered all RFID tags that were within range. The placement of readers was such that the real movement behaviour of the employees could be tracked throughout the whole floor. The RFID tracking software stored a time-stamped event each time a respondent entered or left a zone (see Figure 10.3).

RFID reader   :: RFID reader on upper floor   ▢/▮ RFID zones
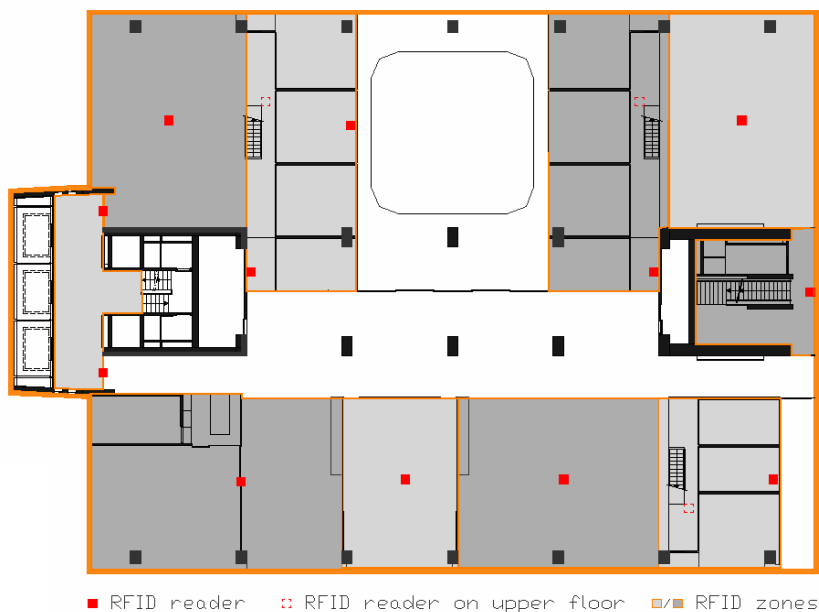
Figure 10.2: RFID zone layout.
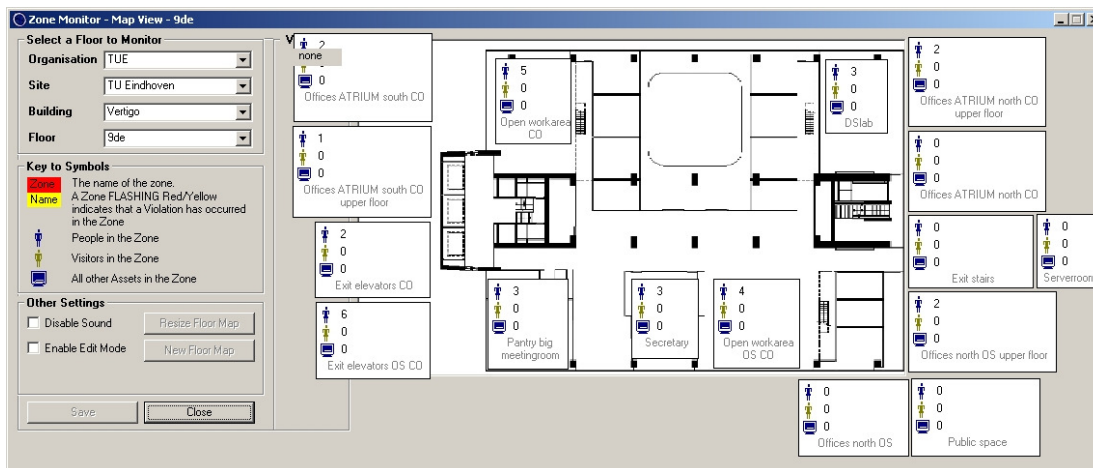
Figure 10.3: Screen dump of the RFID tracking software.

10.3.1.1 Post processing

When the data collected in the RFID experiment is compared with the predicted space utilisation, attention had to be paid to the way in which the activity behaviour is collected. Although the USSU system predicts space utilisation on the level of (parts of) building spaces, in the RFID experiment the space utilisation was observed on level of sets of spaces, called zones (see Table 4.1). Each zone was equipped with one or two readers. The main reason for this was that it proved to be too costly to equip each space with an RFID reader. To be able to compare the observed space utilisation with the predicted space utilisation, the predicted data had to be aggregated to allow for comparison and hence model validation. This was done using a purpose-built tool called analyseRFID (see Figure 10.4). Input for the tool is the time-stamped RFID data and a zone configuration file; this file is similar to the building input file used by the USSU prototype. Output is an excel file containing the zone utilisation and the movement behaviour of all employees.

Time	Zone entry
13-3-2006 8:25	Employee A Entered the Exit elevators OS CO zone
13-3-2006 8:25	Employee A Entered the Pantry big meetingroom zone
13-3-2006 8:25	Employee A Entered the Open workarea OS CO zone
13-3-2006 8:36	Employee A Entered the Offices ATRIUM north CO zone
13-3-2006 8:36	Employee A Entered the DSlab zone
13-3-2006 8:42	Employee A Entered the Offices ATRIUM north CO zone
13-3-2006 8:42	Employee A Entered the Open workarea OS CO zone
13-3-2006 8:50	Employee A Entered the Secretary zone
13-3-2006 8:50	Employee A Entered the Pantry big meetingroom zone
13-3-2006 8:51	Employee A Entered the Exit elevators OS CO zone
13-3-2006 8:51	Employee A Entered the Pantry big meetingroom zone
13-3-2006 8:52	Employee A Entered the Open workarea OS CO zone

Table 10.1: Zone entries for one employee (a PhD student).
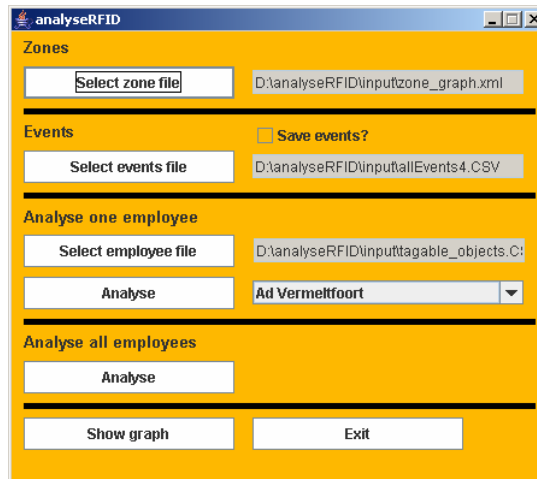
Figure 10.4: The analyseRFID tool.

10.3.1.2 Problems related to the RFID setup

A RFID reader uses a spherical radio field to detect tags. When two or more readers are nearby each other, the spherical fields of these readers can overlap; the distance at which this occurs depends on how the reader was set up (e.g. the detection range and the type of antenna equipped with the reader). This means that a tag can be in 2 or more zones at the same time. The tracking software selects the reader (and so the zone) which has the highest signal strength. However, as the signal strength of a tag recorded by the reader is influenced by distortions and reflections, the signal strength is constantly changing. During the experiment this caused tags to jump from one zone to another when in fact they were not moving. This was taken into account when validating USSU in relation to the data collected in the RFID experiment.

10.4   Diary data collection

Colleagues belonging to the Design Systems group were asked to maintain a diary of their daily activities. The purpose of a diary data collection is to obtain information about activities, their duration, sequence, and location from the observed people themselves. This experiment was performed parallel to the RFID experiment and had the same duration, namely 3 months. All colleagues were familiar with computers and were always connected to the internet. They were also familiar with a web-based time registration system as POPI. Therefore, the decision was made to implement the activity diaries as a web-based system. In this way they could easily enter an activity using their web browser. Considerable time was spent on making the web-based system user-friendly and intuitive such that entering data was as unobtrusive as possible, in terms of time and effort. This system was called POPI+, as an extended version of the time registration system formerly used by the faculty. The system was developed using the Ruby-on-Rails framework based on the class diagram depicted in Figure 10.5.
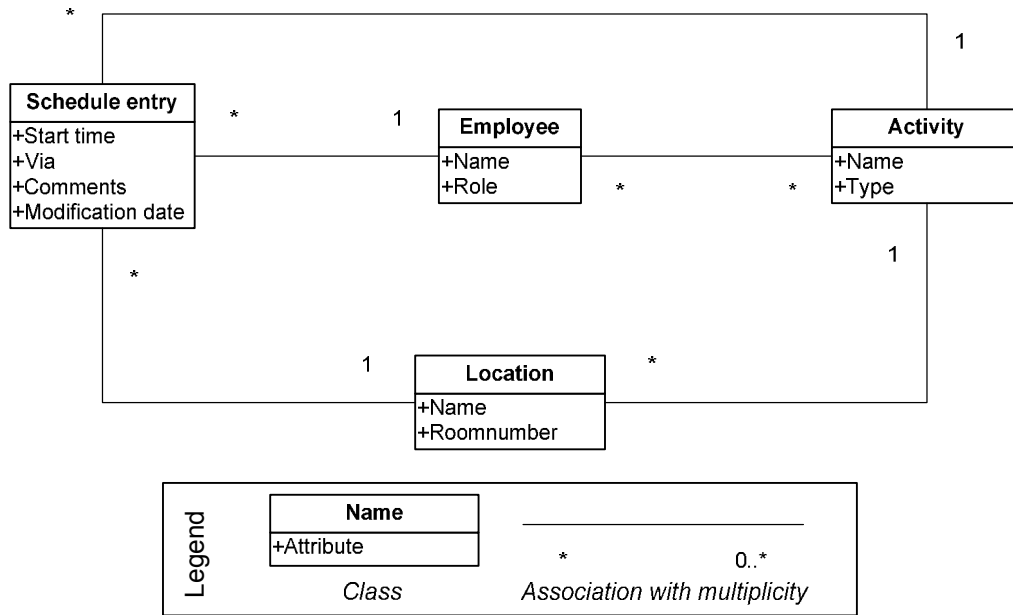
Figure 10.5: Class diagram of POPI+.

The webpage comprising the user section of POPI+ consisted of three parts (see Figure 10.6). In the top part the respondent could select the desired working day for which he was entering activities, by default the current working day. Below that there was a small form in which the respondent had to enter the properties of each activity he was about to perform. A respondent had to enter the start time, the type of activity and the location of the activity. Furthermore, when a respondent left the floor, he also had to enter how that was done (i.e. via the elevators or via the stairs). Finally, he had the ability to enter some comments. The lower half of the page showed all activities the respondent already had entered (i.e. his activity diary for the selected workday).

Although entering data in the survey system was made as simple, user-friendly and intuitive as possible, still some post processing was required. All activity diaries of the participants had to be checked for consistency (e.g. did they properly end all working days) and the locations of activities had to be made uniform (e.g. for a location different designations were used). In the end, this resulted in complete and consistent activity diaries of in total 9 employees of the Design Systems group.

Figure 10.6: Web-based activity diary (POPI+).

10.5 Conclusions

This chapter discussed how the real human activity behaviour was observed. RFID technology and digital activity diaries were applied for collecting data about the real human activity behaviour of the test case organisation. Both experiments were performed parallel to each other and had the same duration, namely 3 months. The first experiment (i.e. the RFID data collection) involved a large group of people, namely both groups comprising the test case organisation (i.e. Design Systems and Structural Design). For the latter experiment (i.e. the diary data collection) only direct colleagues (i.e. members of the Design Systems group) were asked to participate. The two experiments resulted in two detailed, large activity data sets, which made it possible to evaluate the predictive quality of the USSU system.

Chapter eleven discusses the results of the validation of USSU. It starts with discussing the results of the validation of USSU in relation to activity behaviour observed using the activity diaries (i.e. the POPI+ experiment). Then, the validation of USSU with regard to data collected in the RFID experiment is discussed.

C11 Validation results

11.1 Introduction

Chapters eight discussed the validation approach for USSU. Validation in the context of this research project related to determining the validity of the output of the USSU prototype. In other words, how accurately can the prototype predict the space utilisation of an organisation? Subsequently, chapter nine discussed the calibration of the USSU prototype based on an extensive data collection. Then, chapter ten described the two experiments which were performed to collect data about the real space utilisation with regard to the chosen test case.

After the USSU prototype was calibrated, it was possible to generate the movement patterns required for the validation of USSU. Each time USSU is run one movement pattern is created, specifying the activity behaviour of all (present) employees for one

working day. To improve the relevance and accuracy of the validation of USSU it proved better to use a set of movement patterns, instead of just one movement pattern. By doing so it was possible to analyse the predicted human activity behaviour over a number of working days. Infrequent activity behaviour that might arise from one of the movement patterns had less influence on the resulting mean human activity behaviour. The set of movement patterns were analysed using a purpose-built tool, called analyseUSSU (see Figure 11.1). This tool generated an excel file that contained the combined mean results of a set of movement patterns, as specified by the user. To (roughly) correspond with the duration of the validation experiments, in total 50 USSU movement patterns were generated and analysed.
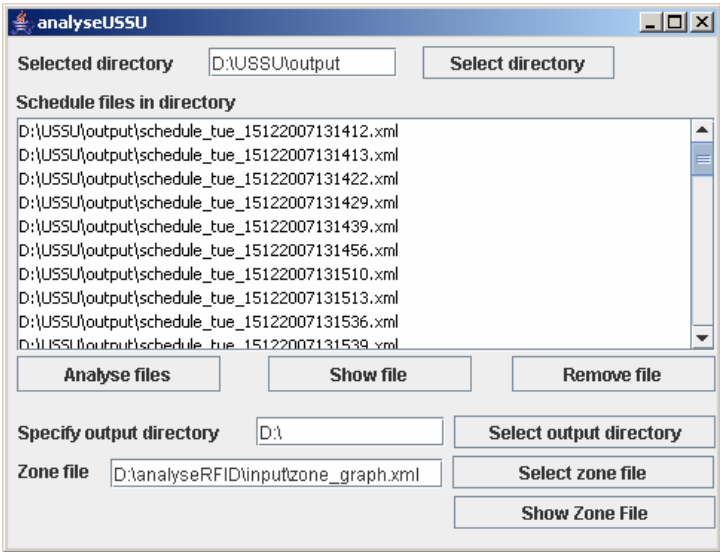
Figure 11.1: The analyseUSSU tool.

The two validation experiments resulted in two detailed, large activity data sets, which made it possible to evaluate the predictive quality of the USSU system. Table 11.1 shows an overview of details regarding both data sets. In 46 days the 9 participants of the POPI+ experiment (diary data collection) recorded roughly 6000 activities in the web-based system; the total duration of these activities was about 2400 hour. In the same time period the RFID system recorded about 360,000 events; each event relates to one of the 37 participants entering or leaving a RFID zone. These events had a total duration of more than 32,000 hour.

Property	Experiment	
	POPI+	**RFID**
Participants	9	37
Days	46	46
Number of entries	6,000 (667/person)	360,000 (9,370/person)
Hours accounted for	2,400 (267/person)	32,000 (865/person)

Table 11.1: Details regarding both experiments.

This chapter discusses the results of the validation of USSU. The validation approach was based on criterion variables. These criterion variables (e.g. the usage of facilities or

movement behaviour of employees) specify the aspects on which the observed and predicted movement patterns were compared. Each aspect system was tested according to the validation matrix as shown in Table 11.2. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees. The goodness-of-fit between the predicted activity behaviour (i.e. USSU) and observed activity behaviour (i.e. diary and RFID data collection) for each criterion variable was assessed using a combination of two statistical tests, namely: the student's *t*-test combined with a correlation coefficient determination and the variability test (see section 8.5).

Aspect	Experiment	Criterion variable			
		Time percentage	Mean duration	Mean frequency	Mean walking distance
Abstract-space	POPI+	x	x	x	-
Facility	POPI+	x	x	x	-
Intermediate activity	POPI+	x	x	x	-
Task-type	POPI+	x	x	x	-
Zone	RFID	x	-[1]	-[1]	-
Employee	RFID	-	-	-	x

Table 11.2: Validation matrix.
[1] Not possible due to problems with the RFID setup (see section 10.3.1.2).

This chapter starts with discussing the results of the validation of USSU in relation to activity behaviour observed in the POPI+ experiment. Then, the validation of USSU with regard to data collected in the RFID experiment is discussed. The chapter concludes with a discussion on the validation results.

11.2   Validation: USSU vs. POPI+

This section discusses the results of the validation of USSU in relation to activity behaviour observed using the activity diaries (i.e. the POPI+ experiment).

11.2.1 Abstract-spaces

Both the output of USSU and the output of POPI+ detail the activities on the level of abstract-spaces. The validation of USSU on the usage of abstract-spaces was divided in two parts, namely the usage of workplaces and the usage of meeting spaces. For both types of abstract-spaces the goodness-of-fit between USSU and POPI+ was determined using the following criterion variables: time percentage, mean duration and mean frequency.

11.2.1.1 Workplaces

The first step in determining the goodness-of-fit of the usage of workplaces was to determine the correlation coefficients for all criterion variables between the USSU and

POPI+ activity data (see Table 11.3). The correlation coefficients indicated low correlation and no statistical significance at 0.05 level for all three criterion variables ($P >$ 0.05). Due to the fact that all correlation coefficients were not significant the paired samples t-test could not be performed. Instead the independent samples t-test was applied, see Table 11.4 for the results.

Criterion variable	Correlation coefficient	
	r-**value**	P
Time percentage	0.38	0.31
Mean duration	0.14	0.71
Mean frequency	0.35	0.35

Table 11.3: Correlation coefficients USSU - POPI+ for the usage of workplaces.

Criterion variable	Levene's Test for Equality of Variances		Independent samples t-test	
	F	P	t-**value**	P
Time percentage	0.04	0.84	1.98	0.07
Mean duration	13.49	0.00	-3.44	0.01 [1]
Mean frequency	7.25	0.02	7.79	0.00 [1]

Table 11.4: Results of the independents samples t-test USSU - POPI+ for the usage of workplaces.
[1] Equal variances not assumed.

The results of the independent sample t-test indicated no significant differences between the results of POPI+ and USSU ($P >$ 0.05) for the first criterion variable regarding the usage of workplaces (i.e. time percentage). The results of the independent t-test for the two other criterion variables (i.e. mean duration and mean frequency) were significant ($P <$ 0.05). An explanation for this was that the skeleton activity behaviour of people who participated in POPI+ differed (too) much from the skeleton activity behaviour of their virtual counterparts in USSU. In USSU the time percentage for each task belonging to a role was based on output from the time registration system POPI. These time percentages are used by USSU to draw a set of skeleton activities for each employee per simulated working day. The higher the time percentage, the more time an employee spends on this task and the higher the probability that this skeleton activity will be selected. However, most employees who participated in the POPI+ experiment spent their time in a different way than the POPI data suggested. Table 11.5 shows the time percentages of task-types for both POPI+ and POPI for two POPI+ participants. For participant 1 the differences between the POPI and POPI+ time percentages were small. However, for participant 2 the differences were rather large.

Task-type	Participant 1		Participant 2	
	POPI+	POPI	POPI+	POPI
Give student coaching	0.01	0.01	0.03	0.22
Research (+ concentrated research)	0.93	0.94	0.69	0.34
Education (preparation + evaluation)	0.00	0.01	0.06	0.19
Teach	0.03	0.00	0.03	0.03
Follow course	0.00	0.01	0.00	0.03
External	0.02	0.01	0.18	0.13
Get PhD coaching	0.02	0.01	n/a	n/a
Give PhD coaching	n/a	n/a	0.01	0.07

Table 11.5: Time percentages of task-types for both POPI+ and POPI for two POPI+ participants.

Due to the differences between the POPI and POPI+ data sets, the skeleton activity behaviour predicted by USSU differed significantly from the skeleton activity behaviour of the POPI+ participants. This resulted in a different usage of workplaces in USSU than observed in the POPI+ experiment. The decision was made to apply another approach to validate the usage of workplaces, namely to consider only those POPI+ respondents whose observed skeleton activity behaviour in POPI+ matched with the skeleton activity behaviour given in the POPI data set. These POPI+ participants were selected based on the correlation coefficients between the POPI and POPI+ data sets for the time spent on task-types (see Table 11.6). The four participants with the highest correlation coefficient, 1, 3, 6 and 7 were selected ($P < 0.01$); participant 9 was ignored as the corresponding correlation coefficient could not be calculated due to limited number of associated tasks.

Participant	Correlation coefficient	
	r-value	*P*
1	1.00	0.00
2	0.80	0.03
3	1.00	0.00
4	0.84	0.02
5	0.36	0.48
6	0.96	0.00
7	1.00	0.00
8	0.79	0.03
9	n/a [1]	n/a [1]

Table 11.6: Correlation coefficients POPI - POPI+ for the time spent on task-types for all participants of POPI+.
[1] Correlation coefficient could not be determined due to limited number of tasks.

Next, the USSU and POPI+ data belonging to these four participants were used to validate the mean duration and mean frequency criterion variables for workplaces. As can be seen in Table 11.7, the correlation coefficients were not significant. Consequently, the paired *t*-test could not be performed. Table 11.8 shows the results of the independent samples *t*-test. The first criterion variable (i.e. mean duration) was not significant ($P > 0.05$) in contrast to the second criterion variable (i.e. mean frequency).

With regard to the mean duration of workspaces there were no significant differences between the predicted (USSU) and observed (POPI+) usage of workspaces.

Criterion variable	Correlation coefficient	
	r-value	*P*
Mean duration	0.80	0.20
Mean frequency	-0.17	0.83

Table 11.7: Correlation coefficients USSU - POPI+ for the usage of workplaces.

Criterion variable	Levene's Test for Equality of Variances		Independent samples *t*-test	
	F	*P*	*t*-value	*P*
Mean duration	3.33	0.12	-2.01	0.08
Mean frequency	4.58	0.07	3.99	0.01

Table 11.8: Results of the independent samples *t*-test USSU - POPI+ for the usage of workplaces.

Finally, Table 11.9 shows the results of the variability test for the three criterion variables. There was no strict criterion, like a confidence interval, to judge the validity of variability. As said in section 8.5.2: the smaller the variability is (i.e. the closer it gets to zero) the better the match between the two data sets. The variability of the first criterion variable (i.e. time percentage) was small and the associated standard deviation was also small. The same was true for the second criterion variable, the mean duration. However, the variability regarding the mean frequency was large and also the corresponding standard deviation was rather large. This proved that there were rather large differences between the POPI+ and USSU data sets with regard to the mean frequency of workplaces.

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.01	0.01
Mean duration	0.05	0.06
Mean frequency	29.17	15.90

Table 11.9: Results of the variability test USSU - POPI+ for the usage of workplaces.

11.2.1.2 Meeting spaces

This section discusses the goodness-of-fit between the USSU and POPI+ data sets for the second type of abstract-spaces, namely meeting spaces. First, the results of the Student's *t*-test in conjunction with the correlation coefficient determination for all criterion variables (i.e. time percentage, mean duration and mean frequency) are treated. Finally, the results of the variability test are discussed.

As the correlation coefficients were not significant at 0.05 level (Table 11.10), the independent samples *t*-test was applied instead of the paired samples *t*-test. Table 11.11 the results of the independent samples *t*-test. For all three criterion variables the

null hypothesis was not rejected. Therefore, there were no significant differences between the predicted (USSU) and observed (POPI+) usage of meeting places.

Criterion variable	Correlation coefficient	
	r-value	*P*
Time percentage	0.50	0.39
Mean duration	0.51	0.38
Mean frequency	-0.10	0.88

Table 11.10: Correlation coefficients USSU - POPI+ for the usage of meeting spaces.

Criterion variable	Levene's Test for Equality of Variances		Independent samples *t*-test	
	F	*P*	*t*-value	*P*
Time percentage	2.13	0.18	0.58	0.58
Mean duration	0.60	0.46	0.89	0.40
Mean frequency	5.11	0.05	-0.48	0.64

Table 11.11: Results of the independent samples *t*-test USSU - POPI+ for the usage of meeting spaces.

With regard to the variability test (see Table 11.12), the following observations can be made. The variability of the first criterion variable (i.e. time percentage) was very small, even negligible and also the associated standard deviation was negligible. In other words, there was no observable variability between the predicted and observed time percentages of meeting spaces. The other two criterion variables (i.e. mean duration and mean frequency) showed a slightly bigger variability, but were still negligible.

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.00	0.00
Mean duration	0.12	0.26
Mean frequency	0.05	0.10

Table 11.12: Results of the variability test USSU - POPI+ for the usage of meeting spaces.

11.2.2 Facilities

Not only did the USSU and POPI+ data sets detail the activities on the level of abstract-spaces, both data sets also revealed the usage of facilities.

The correlation coefficients of all criterion variables were not significant at 0.05 level (Table 11.13). Consequently, the independent samples *t*-test was applied instead of the paired samples *t*-test. The *t*-test resulted in *P*-values > 0.05 for all three criterion variables (Table 11.14). This meant that there were no significant differences between the predicted (USSU) and observed (POPI+) usage of facilities.

Criterion variable	Correlation coefficient	
	r-value	*P*
Time percentage	0.75	0.25
Mean duration	0.39	0.61
Mean frequency	0.83	0.17

Table 11.13: Correlation coefficients USSU - POPI+ for the usage of facilities.

Criterion variable	Levene's Test for Equality of Variances		Independent samples *t*-test	
	F	*P*	*t*-value	*P*
Time percentage	0.81	0.40	0.80	0.45
Mean duration	1.03	0.35	-0.81	0.45
Mean frequency	3.81	0.10	1.22	0.27

Table 11.14: Results of the independent samples *t*-test USSU - POPI+ for the usage of facilities.

Finally, the variability between the USSU and POPI+ data sets regarding the usage of facilities was determined; Table 11.15 shows the results. The first two criterion variables (i.e. time percentage and mean duration) suggested negligible differences between the observed (POPI+) and predicted (USSU) usage of facilities. The third and last criterion variable suggested slightly bigger differences between the observed and predicted activity data with regard to the mean frequency of facilities.

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.00	0.00
Mean duration	0.00	0.00
Mean frequency	1.55	1.74

Table 11.15: Results of the variability test USSU - POPI+ for the usage of facilities.

11.2.3 Intermediate activities types

The POPI+ experiment also collected data in relation to the types of activities performed by all participants. As a direct and qualitative comparison of predicted and observed activity behaviour on for example the order and timing of activities was not relevant (see section 8.4), the intermediate activity behaviour was analysed on a higher, more abstract level by applying the criterion variables time percentage, mean duration and mean frequency.

First, the results of the correlation coefficient determination are discussed (Table 11.16). The correlation coefficients indicated a very strong correlation between the observed and predicted intermediate activity behaviour which was significant at 0.05 level. The paired samples *t*-test (Table 11.17) indicated no significant differences between the predicted (USSU) and observed (POPI+) intermediate activity behaviour.

Criterion variable	Correlation coefficient	
	r-value	*P*
Time percentage	0.86	0.01
Mean duration	0.99	0.00
Mean frequency	0.82	0.02

Table 11.16: Correlation coefficients USSU - POPI+ for intermediate activities types.

Criterion variable	Paired-samples *t*-test	
	t-value	*P*
Time percentage	-0.12	0.91
Mean duration	-1.38	0.22
Mean frequency	1.35	0.23

Table 11.17: Results of the paired samples *t*-test USSU - POPI+ for intermediate activities types.

Finally, the results of the variability test are discussed (Table 11.18). The variability with respect to the first two criterion variables (i.e. time percentage and mean duration) was negligible. The variability of the third criterion variable was bigger and the standard deviation was in comparison to the variability value rather large. This suggested some differences between the USSU and POPI+ data sets with regard to the mean frequency of the intermediate activity types.

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.00	0.00
Mean duration	0.01	0.01
Mean frequency	0.86	1.29

Table 11.18: Results of the variability test USSU - POPI+ for intermediate activities types.

11.2.4 Task-types

Finally, this section focuses on the validation of USSU on the level of task-types. The skeleton activity behaviour, either predicted (USSU) or observed (POPI+), was based on a limited set of task-types. The goodness-of-fit between USSU and POPI+ regarding task-types was determined based on the same criterion variables as for the intermediate activity types, namely time percentage, mean duration and mean frequency.

The correlation coefficients between the USSU and POPI+ data sets on the level of task-types were significant and indicated a very strong correlation (Table 11.19). The results of the paired samples *t*-test (Table 11.20) were not significant ($P > 0.05$). Consequently, there were no statistical significant differences between the predicted (USSU) and observed (POPI+) on the level of task-types.

Criterion variable	Correlation coefficient	
	r-value	*P*
Time percentage	0.88	0.00
Mean duration	0.74	0.00
Mean frequency	0.99	0.00

Table 11.19: Correlation coefficients USSU - POPI+ for task-types.

Criterion variable	Paired-samples *t*-test	
	t-value	*P*
Time percentage	0.182	0.86
Mean duration	0.92	0.37
Mean frequency	-1.33	0.21

Table 11.20: Results of the paired samples *t*-test USSU - POPI+ for task-types.

The variability with respect to the first two criterion variables (i.e. time percentage and mean duration) was small (Table 11.21). The variability of the third criterion variable was slightly bigger and the standard deviation was in comparison to the variability value rather large. Apparently, some differences existed between the USSU and POPI+ data sets regarding the mean frequency of the task-types. This influenced the usage of workplaces and could explain why the validation of the mean frequency of workplaces resulted in significant differences between USSU and POPI+ (see section 11.2.1.1).

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.02	0.05
Mean duration	0.14	0.32
Mean frequency	0.59	1.96

Table 11.21: Results of the variability test USSU - POPI+ for task-types.

11.3   Validation: USSU vs. RFID

This section discusses the second part of the validation, namely the comparison of output from USSU with data collected in the RFID experiment.

11.3.1 Zones

In the RFID experiment human activity behaviour was observed on the level of sets of spaces, called zones (see section 10.3). The activity data stored by the RFID tracking system made it possible to analyse the utilisation of the zones. However, USSU predicts space utilisation on the level of abstract-spaces. Before the output of USSU could be compared with data collected in the RFID experiment, the abstract-spaces had to be merged in a set of zones comparable to the RFID zones. The problems with the RFID setup (see section 10.3.1.2) had only a minor influence on the time percentages of zones and were consequently disregarded with respect to this criterion variable. The

mean duration and mean frequency of zones, on the other hand, were strongly influenced by the RFID setup problems as tags frequently jumped from one zone to another without really moving. Therefore the goodness-of-fit between the USSU and RFID data sets regarding the zone usage was only assessed based on the time percentage.

Table 11.22 indicates a strong correlation between the predicted usage of zones (USSU) and the observed usage of zones (RFID); this result was significant at 0.05 level. The paired samples *t*-test for the zone utilisation shows a powerful outcome (Table 11.23); there were no significant differences between the predicted (USSU) and observed (RFID) usage of zones. This rather strong outcome of the *t*-test was further emphasised by the variability test. This test indicated negligible differences between the USSU and RFID data sets with regard to the utilisation of zones (Table 11.24).

Criterion variable	Correlation coefficient	
	r-value	*P*
Time percentage	0.77	0.01

Table 11.22: Correlation coefficient USSU - RFID for the usage of zones.

Criterion variable	Paired-samples *t*-test	
	t-value	*P*
Time percentage	0.00	1.00

Table 11.23: Results of the paired samples *t*-test USSU - RFID for the usages of zones.

Criterion variable	Variability	
	value	std. dev.
Time percentage	0.00	0.00

Table 11.24: Results of the variability test USSU - RFID for the usages of zones.

11.3.2 Employees

Not only did the RFID tracking system store the amount of time an individual was in a certain zone, it also stored the routes which were followed between the RFID zones. This meant that the data collected in the RFID experiment could also be used to validate USSU on the level of human movement behaviour. However, a large part of the stored activity data was not usable for this comparison due to the problems with the experiment setup in conjunction with the RFID technology (see section 10.3.1.2). A large number of RFID zones overlapped each other. As a result of the RFID setup problems tags in these zones jumped from one zone to another when they were not moving. This meant that the walking distances for individuals with a workplace in one of these zones were highly unreliable. Therefore these individuals were removed from the RFID data set and were not taken into account for the validation of USSU with regard to the movement behaviour of employees.

The validation of USSU in relation to human movement behaviour was based on one criterion variable, namely the mean walking distance. Table 11.25 shows the correlation

coefficient between the USSU and RFID data sets in relation to this criterion variable. The correlation coefficient was significant and indicated a strong correlation between the two data sets. The results of the paired samples *t*-test for the mean walking distance were not significant (Table 11.26). This meant that for this criterion variable the null hypothesis was not rejected. With regard to the mean walking distance there were no significant differences between the two data sets. Finally, the variability test suggested only minor differences between the two data sets with regard to movement behaviour (Table 11.27).

Criterion variable	Correlation coefficient	
	r-value	*P*
Mean walking distance	0.70	0.04

Table 11.25: Correlation coefficient USSU - RFID for the usage of zones.

Criterion variable	Paired-samples *t*-test	
	t-value	*P*
Mean walking distance	1.62	0.14

Table 11.26: Results of the paired samples *t*-test USSU - RFID for movement behaviour.

Criterion variable	Variability	
	value	std. dev.
Mean walking distance	0.05	0.08

Table 11.27: Results of the variability test USSU - RFID for movement behaviour.

11.4   Conclusions

This chapter discussed the results of the validation of USSU. With a single exception the validation of USSU throughout this chapter showed that there were no significant differences between the predicted and observed activity behaviour. This is further emphasised by the fact that all statistical tests supported each other and pointed in the same direction. As a consequence, the output of USSU is considered to be valid. In other words, USSU can be used to accurately predict the space utilisation of an organisation (at least when applied within the limitations set for this project).

The prototype of USSU was validated by comparing the predicted movement patterns for the test case organisation with the data collected for all participants of the POPI+ and RFID experiments. In other words, the validation focussed on the goodness-of-fit between the predicted and observed behaviour of the whole test organisation. So, although (almost) no significant differences were observed between the predicted and observed activity behaviour, this only holds true for the whole test case organisation and this does not rule out the possibility of large differences between the predicted and observed activity behaviour on an individual basis. Chapter four made clear that human activity behaviour in office buildings is very complex and differs per employee. A comparison of the predicted activity behaviour (USSU) with the observed activity behaviour (RFID/POPI+) per employee could result in considerable differences. For a

complete overview of the reliability of the predictions made by USSU a sensitivity analysis should be performed. This was not done for this thesis, but has been added to the recommendations for future research (see section 12.4).

The final chapter of this thesis will discuss the conclusions that can be drawn from this thesis. Furthermore, it will discuss the recommendations for future research.

C12 Conclusions & recommendations

12.1 Introduction

Activity and location schedules are input for building simulations (e.g. building performance simulation or evacuation simulation). These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Therefore, a more advanced scheduling method is needed that adequately represents real-life complexity of human activity and location schedules. The main objective of research project User Simulation of Space Utilisation (USSU) was to develop a system that can be applied for analysing and evaluating the space utilisation of a building for any given organisation. The system generates movement patterns that provide a representation of human activities that are executed in building spaces. A movement pattern not only describes which activities are performed and their

properties (e.g. location), but also the route that is followed between the locations of these activities. These movement patterns are a source of dynamic input data for building simulation tools. Reliable data on human movement is scarce. It is valuable input for several research areas. For instance, the relevance and performance of building simulation tools, like indoor climate simulations or working conditions assessments, will substantially improve when realistic input data is applied. If reliable human movement models can be created, then these models can not only be used to analyse existing situations, but also to simulate new building designs taking the digital design as input. This is also relevant for architects to evaluate the performance of a building design.

This project focussed on the simulation of human activity behaviour in office buildings. The lives of many people are affected by the design of office buildings. From the point of view of building simulation, an office building is also one of the key buildings types. Although research in the area of building simulation is not limited to office buildings, many research projects are focussed on offices. The same applies for the development and application of building simulation tools in practice. This all together makes office buildings an interesting and relevant building type for a system that evaluates space utilisation in relation to human activity behaviour. Buildings like an enterprise building or a university staff building are instances of the office building type; the latter was applied in this thesis to illustrate the theory behind this research project and to validate the developed system.

12.2   Summary

Building simulation is considered to be common practice in the building industry. It has undergone a substantial growth both in the academic world and the building industry since its emergence three decades ago. Research in this field of building simulation is also abundant, for instance with regard to modelling the behaviour of humans in egress situations. Moreover, much research effort has been made to resolve the shortcomings of the current available building simulation programs, except for incorporating realistic activity behaviour of building occupants. Research is still poor on the complexity of normal day-to-day, human activity and movement behaviour in buildings. Knowledge of real, dynamic behaviour of occupants of office buildings is limited. A system for (office) building simulation that produces data about the activity behaviour of the members of an organisation can improve the relevance and performance of building simulation tools.

The result of this research project is a system that can be used for analysing and evaluating the space utilisation of a building for a certain organisation. Most existing approaches for modelling activity schedules assume an individual-based decision making process. These models do not take into account the interaction between individuals. A special feature of the USSU system is the incorporation of interaction between skeleton activities (e.g. meetings). It plays an essential role in the USSU modelling approach. The proposed scheduling method is not producing schedules for planning purposes based on an optimisation method. Although the priority of an activity plays an important role in the scheduling process (e.g. for solving overlaps by the overlap-remover), the goal of the scheduling method is not to find the optimum activity

schedule with regard to the priority of its activities. In other words, the scheduling method does not try to optimise the sum of the priorities of the activities in an activity schedule. The USSU scheduling method is governed by the importance values of the eight scheduler-modules. Each scheduler-module uses a rule based algorithm to test the current activity schedule (and its activities) against a set of predefined criteria. If the criteria are satisfied then the scheduler-module returns its preset importance value, else it returns 0. The importance values are determined in such a way that USSU models the scheduling behaviour of employees following their heuristics. In other words, the scheduling method mimics the behaviour of real human beings when scheduling activities. This results in activity schedules that provide a realistic representation of human activities that are executed in building spaces. The scheduling method is partially based on a probabilistic model (i.e. the intermediate activities). Moreover the scheduler-modules work autonomously. The USSU system selects the scheduler-module with the highest importance; the user of the system does not have any control over the scheduling method. Therefore, the generated movement patterns will differ for each run, even when the same input files are used. The scheduling method can accommodate real-life complex organisational structures and maintain consistency between the activity schedules. The interaction between activities contributes significantly to the realism of the movement patterns.

USSU serves as a pre-processor for other simulation systems that need real-life data about the location of people at a specific time, such as indoor climate calculations, evacuation simulations and working condition assessment simulations. The underlying model integrates activity based modelling and workflow modelling constrained by the spatial conditions of a building. The combination of these two methods provides a solid basis that ensures process consistency, inclusion of individual (re)scheduling behaviour and allows execution in compressed time intervals. With this model, space utilisation can be simulated at a high level of realism instead of making assumptions as is usual in most building simulation programs. This is possible through the incorporation of human activities as they are executed in real life, split up into skeleton activities (i.e. workflow dependent activities) and intermediate activities (i.e. social and/or physiological activities). Scheduling of activities is executed under bounded rationality. People are only aware of their own agenda which evolves in compressed time. Consequently building simulation can be executed with much more reliable data, reflecting the actual use of a building. Not only existing situations can be analysed, but also new buildings can be investigated using the digital design as input.

For the validation of USSU two approaches were followed, namely comparison with activity diaries and with tracking movement in space. Both experiments were performed on the ninth floor of the building of the Faculty of Architecture, Building, and Planning. A group of 9 people was asked to maintain a diary of the daily activities and the location where these activities were executed (the so-called POPI+ experiment). For a larger group of 37 people, including the previous group, the real space utilisation was captured using RFID (Radio Frequency IDentification) technology. Each person was requested to wear a RFID tag for a period of 3 months. The office floor was divided into zones; each zone was equipped with 1 or 2 readers to detect the presence of a tag. In total 16 receivers where installed and setup (e.g. the signal strength threshold to detect a RFID tag). The placement of readers was such that the real movement behaviour of the employees could be tracked throughout the whole floor.

The two validation experiments resulted in two detailed, large activity data sets, which made it possible to evaluate the predictive quality of the USSU system. The validation of USSU was based on criterion variables. The four categories of criterion variables were:

- Time percentage of use/occurrence of abstract-spaces, zones, facilities, tasks-types and intermediate activity types.
- Mean duration of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean frequency of use/occurrence of abstract-spaces, facilities, tasks-types and intermediate activity types.
- Mean walking distance of employees.

These criterion variables specified the aspects on which the observed and predicted movement patterns were compared. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees.

The validation of USSU on the usage of abstract-spaces was subdivided into two parts, namely the usage of workplaces and the usage of meeting spaces. The validation resulted in a reasonable goodness-of-fit between the predicted (USSU) and observed (POPI+) usage of both types of abstract-spaces. Except for the criterion variable *mean frequency* in relation to workplaces (i.e. the number of times a workspace is used during a working day) there were no significant differences between the observed and predicted human activity behaviour with regard to usage of abstract-spaces. The assessment of the goodness-of-fit between USSU and POPI+ also made clear that there were no significant differences between the predicted and observed usage of facilities. The same applied for the validation of USSU with respect to intermediate activities types and task-types. For both types of activities the validation resulted in a very strong correlation coefficient between the observed and predicted (POPI+) activity behaviour. This was confirmed by the Student's t-test as well as the variability test, which suggested only minor differences between the USSU and POPI+ data sets for both types of activities. The Student's t-test for the usage of zones showed an even more powerful outcome. There were no significant differences between the predicted (USSU) and observed (RFID) usage of zones. This was further emphasised by the variability test which also indicated negligible differences between the USSU and RFID data sets with regard to the usage of zones. Finally, the validation of USSU in relation to human movement behaviour indicated no significant differences between the USSU and RFID data sets. The results of the paired samples t-test were significant. The variability test suggested only minor differences between the two data sets.

12.3 Conclusions

According to Achten (2007):
"The strength of the USSU approach lies in person-based model which make simulations for office building designs more precise and accurate. The consequence for creating a more elaborate model obviously lies in the extensive data-collection that is necessary beforehand and the restricted use to office buildings".

The scheduling method has been developed for office buildings. It can also be applied to other building types and organisations provided that the following conditions are met. A building must be represented as a network of (abstract) spaces. This representation is not appropriate in case of large spaces with an undefined functionality (e.g. halls); in most situations the network construction is straightforward. The organisation must be represented by people that execute skeleton activities and intermediate activities. A prerequisite is that the organisation can be described through well defined and quantified job specifications. Although intermediate activities are organisation independent, the S-curve function of the S-curve intermediate activities (e.g. *get a drink*) can only be estimated in the context of skeleton activities. Thus, new experiments are necessary to determine the parameters and variables of the S-curve intermediate activities.

In chapter two the SHOCC and the Lightswitch-2002 model were introduced. SHOCC provides a platform for the integration of advanced behavioural models for a whole building energy simulation using ESP-r, a building energy simulation program. The main shortcoming and limitation of SHOCC is the underlying model for predicting the presence of buildings occupants, an adapted version of the Lightswitch-2002 model. This model can not accurately predict the occupancy profiles for buildings housing large and rather complex organisations, like office buildings. Hoes (2007) combined the SHOCC model with the USSU model. Output from USSU (i.e. movement patterns) was converted into input for the SHOCC model. This makes it possible to simulate the influence of occupants on a building (e.g. the interaction with environmental controls) based on dynamic human behaviour instead of static presence profiles. Hoes showed that the combination of SHOCC with USSU can realistically simulate situations in which short-term variations in occupancy play an important role, for instance when simulating a lighting system based on automatic occupancy-sensors and assessing associated energy savings in comparison with a manual control lighting system. His research clearly revealed the added value of USSU with respect to building performance simulation.

RFID technology allows for a non-obtrusive way of collecting data about human movement. Participants of the experiment only had to carry a small RFID tag, for instance in their wallet, and the RFID system automatically registered their movements using a number of strategically placed readers. The RFID system made it possible to track the movements of all participants across the floor and thereby to collect data about the real movement behaviour of the participants. To improve the accuracy of the collected data (e.g. to 'filter' out infrequent behaviour) the human movement behaviour had to be collected for a relative long continuous period. Therefore, and as the RFID system did not put a high demand on the participants, it was decided to collect the data for a considerable period of time, namely 3 months. As a result, the observed human activity behaviour was averaged over a long time interval. In spite of problems related to the RFID setup (i.e. overlapping zones which caused tags to jump for one location to another) the experiment resulted in realistic data about the daily movement behaviour.

A disadvantage of the RFID experiment is that it only delivers data about the utilisation of zones and the movement of employees between these zones. In order to thoroughly validate USSU data was needed on the level of types of activities performed by participants. Due to the required level of detail of activity data the most logical method of

obtaining of these data was through activity diaries, which are maintained by the participants themselves during a working day. As the second experiment (so-called POPI+ experiment) was more obtrusive and demanding than the first experiment only direct colleagues belonging to the Design Systems group were asked to maintain a diary of their daily activities. To limit the load on the participants, this experiment was performed parallel to the RFID experiment and had the same duration, namely 3 months. Entering data with regard to the daily activity diaries was made as simple, user-friendly and intuitive as possible by applying a purpose-built survey system. However, data entry was still rather obtrusive (i.e. it asked considerable effort from the respondents) and some post processing was also required. Despite these issues the experiment resulted in reliable and detailed observed data about the human activity behaviour of the participants.

With a single exception, the mean frequency of workplaces, the validation of USSU showed that there were no significant differences between the predicted and observed activity behaviour. This is further emphasised by that fact that both statistical tests (i.e. Student's t-test combined with a correlation coefficient determination and the variability test) supported each other and pointed in the same direction. As a consequence, the output of USSU is considered to be valid. In other words, USSU can be used to accurately predict the space utilisation of an organisation (at least when applied within the limitations set for this project).

The prototype of USSU was validated by comparing the predicted movement patterns for the test case organisation with the data collected for all participants of the POPI+ and RFID experiments. In other words, the validation focussed on the goodness-of-fit between the predicted and observed behaviour of the whole test organisation. So, although (almost) no significant differences were observed between the predicted and observed activity behaviour, this only holds true for the whole test case organisation and this does not rule out the possibility of large differences between the predicted and observed activity behaviour on an individual basis. Human activity behaviour in office buildings is very complex and differs per employee. A comparison of the predicted activity behaviour (USSU) with the observed activity behaviour (RFID/POPI+) per employee could result in considerable differences. For a complete overview of the reliability of the USSU predictions (i.e. movement patterns) a sensitivity analysis should be performed. This was not done for this thesis, but has been added to the recommendations for future research (see below).

12.4 Recommendations for future research

This section will discuss a few possible directions of future research to improve the performance and relevance of the USSU system.

Many of the skeleton activities require interaction between employees. It is the responsibility of the interaction-scheduler to determine which skeleton activities require interaction and how to solve this. However, in the scheduling process there is no schedule adjustment because of accidental interaction between people (e.g. encounters while walking to an activity location, or at a coffee machine), or interaction between a person and his physical environment (e.g. queuing in the corridor, blocked door).

Interaction between people can be included through an iterative process in which after each scheduling cycle the presence of two or more people at a location at the same time is checked. If this is the case (e.g. several people are queuing at the coffee machine), then the system has to decide if interaction between the concerned individuals should occur. An encounter between two or more people does not (always) have to result into interaction (e.g. someone might ignore other people when he is under time pressure). Further research should reveal which factors influence the chance of people engaging into interaction with regard to intermediate activities. The capacity of an abstract-space (i.e. activity location) is taken into account in the current system, but not the capacity of the paths between the locations. Similar to the case of person interaction, an additional test is needed to calculate how many people move along the same path at the time same.

The validation of USSU showed that the system can accurately predict the space utilisation of an organisation. However, it also revealed a shortcoming in the framework of USSU with regard to the usage of workplaces. The validation made clear that there are significant differences between the observed and predicted human activity behaviour with regard to the number of times a workplace is used during a working day. USSU resulted in a considerable higher value of the mean frequency of a workplace than the POPI+ data set indicated. The mean frequency of a workplace is a result of the combined effect of skeleton and intermediate activity behaviour. Some of the skeleton activities (e.g. *attend presentation* or *attend external meeting*) and all of the intermediate activities performed by an individual require an abstract-space other than his own workplace. These two categories of activities basically interrupt the usage of a workplace and increase its mean frequency. Without both types of activities an individual would spend 100% of his time at a workplace and the mean frequency would be (close to) 1. However, the validation revealed that there were no significant differences between the predicted and observed activity behaviour in relation to the occurrence of intermediate activity types and task-types.

Nevertheless, there is an issue with the intermediate and skeleton activity behaviour. In the real world an individual will combine certain activities in one action. Combining activities not only reduces time (and energy) spent on walking back and forth between the locations of activities, but also lowers the number of times an individual has to leave his workplace.

Example
In the real world an employee is likely to combine the intermediate activities *get a drink* and *go to toilet*, when the toilet is in close vicinity to the pantry and when he thinks that he has to perform the activity *go to toilet* in the near future anyway. Combining an intermediate with a skeleton activity is also not uncommon in the real world. Very often an individual will perform the intermediate activity *get a drink* just before he is going to perform a skeleton activity, like *attend meeting*.

In USSU skeleton and intermediate activities are scheduled independent from each other. Although the USSU system prevents overlaps and time-gaps between two activities, it does not verify the order of the different types of activities. For instance, it does not check whether two intermediate activities belonging to two different intermediate activity-types are performed consecutively or not. By adding the

functionality of combining skeleton and intermediate activities to USSU, its performance should increase; at least combining activities should reduce the mean frequency of workplaces. This could be done by adding a ninth scheduler-module to the USSU framework, namely the combination-finder with as main task to search for combinations of activities. Future research should make clear which activities can be combined with each other as not all possible combinations will occur in the real world.

For producing reliable data about the human activity behaviour in a building, USSU relies on detailed data about the organisation and the building in which this organisation is housed. The required data collection to calibrate the three input files (i.e. organisation, building and configuration input files) can in some cases be a real challenge. This especially applies to cases where USSU is applied to analyse the performance of a building when the organisation that will occupy this building is not (yet) known, for example in the case of property development. To overcome this drawback to the application of USSU, templates for different types of organisations could be developed. Each template relates to a different type of organisation (e.g. an insurance company or a university) and describes the average composition of an organisation belonging to such an organisation type. By applying these templates, USSU can be used to analyse a building based on the average activity behaviour of this organisation type. By applying different templates USSU can quickly analyse the performance of a building for various organisation types.

Finally, as mentioned above for a complete overview of the reliability of the predictions made by USSU a sensitivity analysis should be performed. A sensitivity analysis can also reveal if it is possible to simplify the USSU model and its input by removing those input parameters which do not have a significant influence on the (variability of the) created movement patterns.

Bibliography

van der Aalst, W.M.P. and K.M. van Hee, 1996, "Business process redesign: A Petri-Net-based approach", *Computers in Industry*, 29, p. 15-26.

van der Aalst, W.M.P. and K.M. van Hee, 2002, *Workflow management: models, methods, and systems*, MIT Press, London.

van der Aalst W.M.P. and A.H.M. ter Hofstede, 2003, "YAWL: Yet another Workflow Language", *Information Systems*, 30 (4), p. 245-275.

van der Aalst, W.M.P., ter Hofstede, A.H.M., Kiepuszewski, B. and A.P. Barros, 2003, "Workflow patterns", *Distributed and parallel databases*, 14 (1), p. 5-51, Springer , The Netherlands.

Abushakra, B., Sreshthaputra, A., Haberl, J. and D. Claridge, 2001, *Compilation of diversity factors and schedules for energy and cooling load calculations*, ASHRAE research project 1093-RP, Texas, USA.

Achten, H.H., 2007, *Design computing: principles of computer aided architectural design*, Nakladatelství ČVUT, Fakulta Architektury, Praha, Czech Republic.

Anggraini, R., Arentze, T.A. and H.J.P Timmermans, 2006, "A model of within-households travel- activity decisions capturing interactions between household heads", *Progress in Design & Decision Support Systems in architecture and urban planning*, p. 19-34, Eindhoven University of Technology, Eindhoven, The Netherlands.

Arentze, T.A, Hofman F., Kalfs, N. and H. J. P.Timmermans, 1997, "Data needs, data collection and data quality requirements of activity-based transport demand models", *International Conference on Transport Survey Quality and Innovation,* Grainau, Germany.

Arentze, T.A. and H.J.P. Timmermans, 2000, *ALBATROSS*, EIRASS, Eindhoven, The Netherlands.

Arentze, T.A. and H.J.P. Timmermans, 2006, "New theory of dynamic activity generation", TRB 85th Annual Meeting Compendium of Papers CD-ROM, Washington DC, USA.

Arentze, T.A. and H.J.P. Timmermans, 2008, "A need-based model of multi-day, multi-person activity generation", *Transportation Research Part B* (Articles in Press).

ASID, 1999, *Recruiting and retaining qualified employees by design*, American Society of Interior Designers.

Augenbroe, G., 2001, "Building simulation trends going into the new millennium", *Proceedings of the seventh international IBPSA conference*, p. 15-27.

Averill, J., Mileti, D., Peacock. R., Kuligowski, E., Groner, N., Proulx, G., Reneke, P and H. Nelson, 2007, "Federal investigation of the evacuation of the World Trade Center on September 11", *Pedestrian and Evacuation Dynamics*, p. 1-12, Springer, Berlin, Germany.

Bartak, M., Beausoleil-Morrison, I., Clarke, J. A., Denev, J., Drkal, F., Lain, M., Macdonald, I. A., Melikov, A., Popiolek, Z. and P. Stankov, 2002, "Integrating CFD and building simulation", *Building and environment*, 37 (8-9), p. 865-871.

Beddoe, G.R. and S. Petrovic, 2006, "Selecting and weighting features using a genetic algorithm in a case-based reasoning approach to personnel rostering", *European Journal of Operational Research*, 175, p. 649-671.

Bengtson, S., Holmstedt, G., Kecklund, L., Lorin, H. and P. Widlundh, 2001, "The behaviour of young people in a fire at a dance party in Gothenburg in 1998", *Proceedings of the Second International Symposium on Human Behavior in Fire*, p. 209-220, Interscience Communications, London, UK.

Blue, V.J. and J.L. Adler, 2000, "Cellular automata microsimulation of bidirectional pedestrian flows", *Transportation Research Board*, 1678, p. 135-141.

Boer, L. C. and D. W. Veldhuijzen van Zanten, 2005, "Behaviour on tunnel fire", *Pedestrian and Evacuation Dynamics 2005*, p. 89-98, Springer, Berlin, Germany.

Bonnes, M. and G. Secchiaroli, 1995, *Environmental psychology: A psycho-social introduction*, Sage, Thousand Oaks, USA.

Bourgeois, D., 2005, *Detailed occupancy prediction, occupancy-sensing control and advanced behavioural modelling within whole-building energy simulation*, Université Laval, Quebec, Canada.

Bouwbesluit 2003, 2006, VNG Uitgeverij, Den Haag, The Netherlands (in Dutch).

Brennan, P., 1997, "Timing human response in real fires", *Proceedings of the fifth international symposium on fire safety science*, p. 807-818.

Brennan, P. and I.R. Thomas, 2001, "Victims of Fire? Predicting outcomes in residential fires', *Proceedings of the second international symposium on human behavior in fire*, p. 123-134, Interscience Communications, London, UK.

BSI, 1997, *Draft British Standard BS DD240 fire safety engineering in buildings, Part 1: Guide to the application of fire safety engineering principles*, British Standards Institution, UK.

Bryan, J.L., 1999, "Human behaviour in fire: the development and maturity of a scholarly study area", *Proceedings of the First International Symposium,* p. 3-12.

Bryan, J.L., 2002, "A selected historical review of human behavior in fire", *Fire protection engineering*, 16, p. 4-10.

Chan, C.-M. and J.K.L. Chui, 2006, "Wind-induced response and serviceability design optimization of tall steel buildings", *Engineering structures*, 28 (4), p. 503-513, Elsevier Ltd.

Chu, G.Q., Chen, T., Sun, Z.H. and J.H. Sun, 2007, "Probabilistic risk assessment for evacuees in building fires", *Building and environment*, 42 (3), p. 1283-1290.

Citherlet, S. and J. Hand, 2002, "Assessing energy, lighting, room acoustics, occupant comfort and environmental impacts performance of building with a single simulation program", *Building and environment*, 37 (8-9), p. 845-856.

Çokcan, B., Brell-Çokcan, S. and K. Tavoussi Tafreshi, 2007, "Earthquake - the importance of earthquake-resistant design in case of emergency evacuations", *Pedestrian and Evacuation Dynamics 2005*, p. 99-108, Springer, Berlin, Germany.

Corgnati, S.P., Fabrizio, E. and M. Filippi, 2008, "The impact of indoor thermal conditions, system controls and building types on the building energy demand", *Energy and Buildings*, 40 (4), p. 627-636.

Crawley, D. B, Lawrie, L.K., Winkelmann, F.C., Buhl, W. F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J. and J. Glazer, 2001, "EnergyPlus: creating a new-generation building energy simulation program", *Energy and buildings*, 33 (4), p. 319-331.

Crawley, D. B, 2003, presentation at ASHRAE meeting, Chicago, USA.

Daamen, W., 2004, *Modelling passenger flows in public transport facilities*, DUP Science, Delft, The Netherlands.

Daniel, D.C., Glaser, C., Feng, O., Voung, J. and L. Xiao, 2004, "Towards an algebra for lighting simulation", *Building and environment*, 39 (8), p. 895-903.

Davis, T.R.V, 1984, "The influence of the physical environment in offices", *The academy of management review*, 9 (2), p. 271-283

Deru, M., and P. Torcellini, 2004, "Improving sustainability of buildings through a performance-based design approach", *World renewable energy congress VIII*.

Dijkstra, E.W., 1959, "Note on two problems in connection with graphs (spanning tree, shortest path)", *Numerical Mathematics*, 1, p. 269-271

Dijkstra, J. and H.J.P. Timmermans, 1999, "Towards a multi-agent model for visualizing simulated user behavior to support the assessment of design performance", *Media and design process - ACADIA'99*, p. 226-237.

Dijkstra, J., Timmermans, H.J.P. and B. de Vries, 2000, "Towards a multi-agent system for visualising simulated behavior within the built environment", *Design & Decision Support Systems in urban planning - Proceedings on the 5th international conference*, p. 101-117.

Dijkstra, J., Jessurun, J., de Vries, B. and H. Timmermans, 2006, "Agent architecture for simulating pedestrians in the built environment", *Fourth international workshop on agents in traffic and transportation at AAMAS-06*. p. 8-16. ACM.

Djunaedy, E., Hensen, J.L.M., and M. Loomans, 2005, "External coupling between CFD and energy simulation: implementation and validation", *ASHRAE transactions*, 109, p. 612-624.

Eastman, C. M., 1999, *Building product models: computer environments supporting design and construction*, CRC Press.

Eiselt, H.A. and C.L. Sandblom, 2004, D*ecision analysis, location models and scheduling problems*, Springer, New York, USA.

Ellingwood, B.R., 2001, "Earthquake risk assessment of building structures, *Reliability engineering & system s*afety, 74 (3), p. 251-262, Elsevier Science Ltd.

Ettema, D.F., 1996, *Activity-based travel demand modelling*, Eindhoven University of Technology, Eindhoven, The Netherlands.

Fahy, R., and G. Proulx, 2001, "Toward creating a database on delay times to start evacuation and walking speeds for use in evacuation modeling", *Proceedings of the second international symposium on human behavior in fire*, p. 175-179, Interscience Communications, London, UK.

Fatah gen. Schieck, Penn, A., Kostakos, V., O'Neill, E., Kindberg, T., Stanton Fraser, D. and T. Jones, 2006, "Design tools for pervasive computing in urban environments", *8th International conference on design and decision support systems in architecture and urban planning*, p. 467-486, Springer, Dordrecht, The Netherlands.

Fowler, M. and K. Scott, 2000, *UML Distilled, a brief guide to the standard object modeling language,* Addison-Wesley, Amsterdam, The Netherlands.

Fritsch, R., Kohler, A., Nygard-Ferguson, M. and J.-L. Scartezzini, 1990, "A stochastic model of user behaviour regarding ventilation", *Building and Environment*, 25 (2), p. 173-181.

Fruin, J.J., 1971, *Pedestrian planning and design*, Metropolitan Association of Urban Designers and Environmental Planners, New York, USA.

Galea, E.R., Finney, K.M., Dixon, A.J.P, Siddiqui, A. and D.P. Cooney, 2003, "An analysis of human behaviour during aircraft evacuation situations using the AASK v3.0 database", *Aeronautical journal*, 107 (1070), p. 219-231.

Galea, E.R., Lawrence, P., Blake, S., Dixon, A. J. P. and H. Westeng, 2007, "The 2001 World Trade Centre evacuation", *Pedestrian and Evacuation Dynamics 2005*, p. 225-238, Springer, Berlin, Germany.

Gelernter, M., 1995, *Sources of architectural form: a critical history of western design theory*, Manchester University Press, Manchester, UK.

Golob, T.F. and M.G. McNally, 1997, "A Model of Activity Participation between household heads", *Transportation research part B*, 31 (3), p. 177-194.

Guilford, J.P. and B. Fruchter, 1978, *Fundamental statistics in psychology and education*, McGraw-Hill, London, UK.

Gwynne, S., Galea, E. R., Lawrence, P. and L. Filippidis, 2001, "Modelling occupant interaction with fire conditions using the buildingExodus evacuation model", *Fire safety journal*, 36 (4), p. 327-357.

Han, C., Kunz, J. and K. Law, 1997, "Making automated building code checking a reality", *Facility management journal*, p. 22-28.

Helbing, D. and P. Molnar, 1995, "Social force model for pedestrian dynamics", *Physical review E*, 51, p. 4282-4286.

Hensen, J.L.M., 2004, "Towards more effective use of building performance simulation in design", *Developments in Design & Decision Support Systems in Architecture and Urban Planning*, p. 291-306, Eindhoven, The Netherlands.

Herzberg, F., 1972, *Work and the nature of man*, Staples Press, London, UK.

Hien. W.N., Poh. L.K. and H. Feriadi, 2000, "The use of performance-based simulation tools for building design and evaluation - a Singapore Perspective", *Building and environment*, 35, p. 709-736,

Hoes, P., 2007, *Gebruikersgedrag in gebouwsimulaties - van eenvoudig tot geavanceerd gebruikersgedragmodel: een gevoeligheidsanalyse voor het gebruikersgedrag en een onderzoek naar de robuustheid van een gebouw voor de gebruiker* , Eindhoven University of Technology, Eindhoven, The Netherlands (in Dutch, with English summary).

Hoogendoorn, S.P., Bovy, P.H.L., and W. Daamen, 2002, "Microscopic pedestrian wayfinding and dynamics modelling", *Pedestrian and evacuation dynamics*", p. 123-154, Springer-Verlag, Berlin, Germany.

Hoogendoorn, S. P. and P. H. L. Bovy, 2004, "Pedestrian route-choice and activity scheduling theory and models", *Transportation research part B*, 38 (2), p.169-190.

Hopfe, C.J. and J. Hensen, 2006, "An approach to use building performance simulation to support design optimization", *Proceedings of the forum bauinformatik*.

Hopfe, C.J., Hensen, J., and W. Plokker, W, 2007, "Uncertainty and sensitivity analysis for detailed design support", *Proceedings of the 10th IBPSA building simulation conference*, p. 1799-1804.

Howard, R. and B-C. Bjork, 2007, Building information models – experts' views on BIM/IFC developments, *24th W78 Conference*, p. 47-54.

Hunt, D., 1979, "The use of artificial lighting in relation to daylight levels and occupancy", *Building and environment*, 14, p. 21-33.

Ingolfsson, A., Haque, Nd. A. and A. Umnikov, 2002, "Accounting for time-varying queueing effects in workforce scheduling", *European journal of operational research*, 139, p. 585-597.

Japee, S. and M. Schiler, M., 1995, "A method of post occupancy glare analysis for building energy performance analysis", *Proceedings of the American solar energy conference*.

Jensen, K., 1992, *Coloured Petri Nets*, Springer-Verlag, Berlin, Germany.

Joh, C-H., 2004, *Measuring and Predicting Adaptation in Multidimensional Activity-Travel Patterns,* Eindhoven University of Technology, Eindhoven, The Netherlands.

Kerridge, J., Hine, J. and M. Wigan, 2001, "Agent-based modelling of pedestrian movements: the questions that need to be asked and answered", *Environment and planning B*, 28, p. 327-341.

Kerridge, J., Keller, T., Chamberlain, T. and N. Sumpter, 2005, "Collecting pedestrian trajectory data in real-time", *Pedestrian and Evacuation Dynamics 2005*, p. 27-39, Springer, Berlin, Germany.

Kima, S-Y. and J-J. Kimb, 2007, Influence of light fluctuation on occupant visual perception, *Building and environment*, 42, p. 2888-2899.

Kitamura, R., Yamamoto, T. and S. Fujii, 1996, "A discrete-continuous analysis of time allocation to two types of discretionary activities which accounts for unobserved heterogeneity", T*ransportation and traffic theory*, Elsevier, Oxford, UK, p. 431-453.

Kleijnen, J.P.C., 1995, "Verification and validation of simulation models", *European journal of operational research,* 82 (1), p. 145-162.

Klüpfel, H., Meyer-König, T., Wahle, J. and M. Schreckenberg, 2000, "Microscopic simulation of evacuation processes on passenger ships", *Proceedings of the fourth international conference on cellular automata for research and industry: theoretical and practical issues on cellular automata*, p. 63-71, Springer-Verlag, London, UK.

Klüpfel, H. and T. Meyer-König, 2003, "Characteristics of the PedGo software for crowd movement and egress simulation", *Pedestrian and evacuation dynamics 2003*, p. 331-340, CMS Press, University of Greenwich, London, UK.

Klüpfel, H. and T. Meyer-König, 2005, "Simulation of the evacuation of a football stadium using the ca model pedGo", *Traffic and granular flow '03*, p. 423-428, Springer, Berlin, Germany.

Kobes, M., Oberijé, N., Rosmuller, N., Helsloot, I., and B. de Vries, 2007, "Fire response performance. Behavioural research in virtual reality", *Conference proceedings AOFS 7th Asia-Oceania symposium on fire science and technology*

Kristensen, L.M., Christensen, S., and K. Jensen, 1998, "The practitioner's guide to coloured Petri Nets", *International journal on software tools for technology transfer*, 2, p. 98-132.

Langdon, F. J., 1966, "Modern Offices: A User Survey", *National Building Studies Research Paper*, 41, Her Majesty's Stationery Office, London, UK.

Law, A.M. and W.D. Kelton, 2000, *Simulation modeling and analysis*, McGraw-Hill, New York. USA.

Leather, P., Beale, D. and L. Sullivan, 2003, "Noise, psychosocial stress and their interaction in the workplace", *Journal of environmental psychology*, 23 (2), p. 213-222.

van Leeuwen, J.P., Jessurun, A.J. and E. de Wit, E, 2004. "The digital dormer - applying for building permits online, *Proceedings of the European Conference on Product and Process Modelling 2004*, p. 355-361, Balkema Publishers, Rotterdam, The Netherlands.

Liu, J., Aizawa, H. and H. Yoshino, 2004, "CFD prediction of surface condensation on walls and its experimental validation", *Building and environment*, 39 (8), p. 905-911.

Maat, C. and T.A. Arentze, 2003. "Variation of activity patterns with features of the spatial context", *Proceedings of the 82nd annual meeting of the Transportation Research Board meeting*, Washington D.C, USA.

MacLennan, H.A., Regan, M.A., and R. Ware, 1999, "An engineering model for the estimation of occupant pre-movement and or response times and the probability of their occurrence", *Fire and materials*, 23(6), p. 255-63.

Mahdavi, A., Mohammadi A., Kabir, E., and L. Lambeva, 2008, "Occupants' operation of lighting and shading systems in office buildings", *Journal of building performance simulation*, 1(1), p. 57-65.

Martin, P. and P. Bateson, 1993, *Measuring behaviour: An introductory guide*, Cambridge University Press, Cambridge, UK.

Maslow, A. H., 1943, "A Theory of Human Motivation", *Psychological review*, 50, p. 370-396.

van Meel, J., 2000, *The European office: office design and national context*, 010 Publishers, Rotterdam, The Netherlands.

Melhado, M.A., Beyer, P.O., Hensen, J.M. and L.F.G. Siqueira, 2005, "The thermal comfort, the indoor environment control, and the energy consumption in three types of operating rooms", *Proceedings of the Ninth International IBPSA Conference*, p. 747-753.

Meyer-König, T., Klüpfel, H. and M. Schreckenberg, 2002, "Assessment and analysis of evacuation processes on passenger ships by microscopic simulation", *Pedestrian and evacuation dynamics*, p. 297-302, Springer, Berlin, Germany.

Moldovan, H., Gilman, M., Knoblauch, P. and S. Woloj, 2007, "Football stadium simulation - a microscopic simulation of the pedestrian access, *Pedestrian and evacuation dynamics*, p. 315-320, Springer, Berlin, Germany.

Newsham, G. R., 1995. "Lightswitch: A stochastic model for predicting office lighting energy consumption", *Proceedings of right light three, 3rd European conference on energy efficient lighting*, Newcastle, UK , p. 59-66.

Nicol, J.F., 2001, "Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds heaters and fans", *Proceedings of the seventh international IBPSA conference*, p. 1073-1078.

Nijland, L, Arentze, T.A. and H.J.P. Timmermans, 2008, "Multi-day activity scheduling reactions to future events in a dynamic agent-based model of activity-travel behaviour", *Proceedings of the ninth international conference on design & decision support systems in architecture and urban planning*, Eindhoven, Netherlands (CD-ROM).

O'Connor, D.J., 2005, "Integrating human behavior factors into design", *Fire protection engineering*, 28, p. 8-20.

O'Grady, W. and M. Keane, 2005, "Specification of an IFC based software application to support CFD simulation", *IBPSA building simulation*.

Olsson, P. A. and M. A. Regan, 2001, "A comparison between actual and predicted evacuation times", *Safety science*, 38 (2), p. 139-145.

Oswald, M., Lebeda, C., Schneider, U. and H. Kirchberger, 2007, "Full-scale evacuation experiments in a smoke filled rail carriage - a detailed study of passenger behaviour under reduced visibility", Pedestrian and evacuation dynamics 2005, p. 41-55, Springer, Berlin, Germany.

Page, J., 2007, *Simulating occupant presence and behaviour in buildings*, École polytechnique fédérale de Lausanne, Lausanne, Switzerland.

Papamichael, K., LaPorta, J. and H. Chauvet, 1997, "Building design advisor: automated integration of multiple simulation tools", *Automation in construction*, 6 (4), p. 341-352.

Proshansky, H.M., Ittelson, W.H. and L.G. Rivlin, 1970, *Environmental psychology: man and his physical setting*, Holt, Rinehart & Winston, New York, USA.

Proulx, G., 2000, "Why building occupants ignore fire alarms", *Construction technology Update*, 42. IRC-NRCC, Ottawa, Canada.

Proulx, G., 2001, "Occupant Behaviour and Evacuation", *Proceedings of the 9th international fire protection symposium*, p. 219-232.

Raymond, S. and R. Cunliffe, 1997, *Tomorrow's office: creating effective and humane interiors*, Spon, London, UK.

Reinhart, C.F., 2004, "Lightswitch–2002: A model for manual control of electric lighting and blinds", *Solar energy*, 77 (1), p. 15–28.

Renwick, P, and E. Lawler, 1978, "What you really want from your job", *Psychology today*, 12 (5), p. 53-66.

Robinson, R., 2006, "Some trends and research needs in energy and comfort prediction", *Proceedings of comfort and energy use in building*, Windsor, UK.

Sahlin, P., Eriksson, L., Grozman, P., Johnsson, H., Shapovalov, A. and M. Vuolle, 2004, "Whole-building simulation with symbolic DAE equations and general purpose solvers", *Building and* environment, 39 (8), p. 949-958.

Sargent, R.G., 1998, "A tutorial on validation and verification of simulation models", *Proceedings of the 20th conference on winter simulation*, p. 33-39, San Diego, USA.

Schelhorn, T., O'Sullivan, D., Haklay, M. and M. Thurstain-Goodwin, 1999, *Streets an agent-based pedestrian model*, Centre for Advanced Spatial Analysis UCL, London, UK.

Schmidt, D., 2005, "Designing low-exergy' buildings"', *Proceedings of the 7th Nordic symposium on building physics in the Nordic countries*, Reykjavik, Iceland.

Scott, M. and P.S. Kanaroglou, 2002, "An activity-episode generation model that captures interactions between household heads: development and empirical analysis", *Transportation research part B*, 36 (10), p. 875-896, Elsevier Science Publishers.

SFPE, 2003, *Engineering guide to human behavior in fire*, Society of Fire Protection Engineers, USA.

Shen, J., 2005. "A review of stated choice method", *Discussion papers in economics and business (05-27)*, Osaka University, Osaka, Japan.

Soebarto, V.I. and T.J. Williamson, 2002, "Multi-criteria assessment of building performance: theory and implementation", *Building and environment, 36*, p. 681-690

Struck, C., Kotek, P., and J. Hensen, 2007, "On incorporating uncertainty analysis in abstract building performance simulation tools", *Proceedings of the 12th symposium for building physics*, p. 193-205.

Sun, C.Y. and B. de Vries, 2006, "An Architecture-Based Model for Underground Space Evacuation", *Proceedings of the 20-th European conference on modelling and simulation ECMS 2006*, p. 578-583, ECMS, Bonn, Germany.

Sundstrom, E., 1986, *Work places: the psychology of the physical environment in offices and factories*, Cambridge University Press, Cambridge, UK.

Sundstrom, E., Town, J.P., Rice, R.W., Osborn, D.P. and M. Brill, 1994, "Office noise, satisfaction", *Environment and behavior*, 26 (2), p. 195-222. Sage Publications.

Tan, A.A.W., 2003, *The reliability and validity of interactive virtual reality computer experiments*, Eindhoven University of Technology, Eindhoven, The Netherlands.

Teknomo, K., Takeyama, Y. and H. Inamura, 2001 "Tracking system to automate data collection of microscopic pedestrian traffic flow", *Proceeding of The 4th Eastern Asia society For transportation studies*, 3 (1), p. 11-25, Hanoi, Vietnam.

Tian, K. and R.W. Belk, 2005, "Extended self and possessions in the workplace", *Journal of consumer research*, 32, p. 297-310.

Tianzhen Hong, S. K. Chou and T. Y. Bong, 2000, "Building simulation: an overview of developments and information sources", *Building and environment*, 35 (4), p. 347-361.

Vovsha, P., Petersen, E. and R. Donelly, 2003, "Explicit modeling of joint travel by household members: statistical evidence and applied approach", *82rd annual conference of the Transportation Research Board*, Washington, D.C., USA.

Vovsha, P, Petersen, E. and R. Donelly, 2004, "Impact of intra-household interaction of individual daily activity-travel patterns", *83rd annual conference of the Transportation Research Board*, Washington, D.C., USA.

Wang, D., Federspiel, C. C., and F Rubinstein, 2005, "Modeling occupancy in single person offices", *Energy and buildings*, 37(2), p. 121-126.

Ward, G.J, 1994, "The RADIANCE lighting simulation and rendering system", *Proceedings of the 21st annual conference on computer graphics and interactive techniques*, p. 459-472.

Wells, M. and L. Thelen, 2002, "What does your workspace say about you? The influence of personality, status, and workspace on personalization", *Environment and behavior*, 34 (3), p. 300-321, Sage Publications.

Wells, M.M., Thelen, L. and J. Ruark, 2007, "Workspace personalization and organizational culture: does your workspace reflect you or your company?", *Environment and behavior*, 39, p. 616-634.

Wen, Y. K., 2001, "Reliability and performance-based design", *Structural safety*, 23(4), p. 407-428.

de Wilde, J., 2004, *Computational support for the selection of energy saving building components*, DUP Science, Delft, The Netherlands.

Willis, A., Kukla, R., Hine, J. and J. M. Kerridge, 2000, "Developing the behavioural rules for an agent-based model of pedestrian movement", *Proceedings of the European transport conference*, p. 69-80.

Wohlwill, J. F., 1975, "Behavioral response and adaptation to environmental stimulation", *Physiological anthropology*, p. 295-334, Harvard University Press, Cambridge, USA.

Working Conditions Act (Arbeidsomstandighedenwet), 1999, Ministerie van SZW (in Dutch).

Yang, Q.Z. and X. Li, 2001, "Representation and execution of building codes for automated code checking", *Proceedings of the Ninth international conference on computer aided architectural design futures*, p. 315-329.

Yamaguchi, Y., Shimoda, Y. and M. Mizuno, 2003, "Development of district energy system simulation model based on detailed energy demand model", *Proceedings of the seventh international IBPSA conference*, p. 1443-1450.

Yung, D., Proulx, G. and N Benichou, 2001, "Comparison of model predictions and actual experience of occupant response and evacuation in two highrise apartment building fires" *Proceedings of the second international symposium on human behavior in fire*, p. 77-87, Interscience Communications, London, UK.

Zhai, Z., 2006, "Application of computational fluid dynamics in building design: aspects and trends", *Indoor and built environment*, 15 (4), p. 305-313.

Zhang, J., Timmermans, H.J.P. and A. Borgers, 2002, "Utility-maximizing model of household time use for independent, shared, and allocated activities incorporating group decision mechanisms", *Transportation research record*, 1807 (1).

Zimmermann, G., 2003, "Modeling the building as a system", *8th International IBPSA Conference*, p. 1483 - 1490.

Zimmermann, G., 2006, "Modeling and simulation of dynamic user behavior in buildings - a lighting control case study", *eWork and eBusiness in architecture, engineering and*

construction: Proceedings of the 6th European conference on product and process modelling, p. 309-316, Taylor & Francis Group.

Appendices

A1 Intermediate activity survey data

Analysis design

Dummy variable	Activity occurrence		Description
	First Table A1.2	**Subsequent** Table A1.3	
DX$_1$	0/1		1 = Working mainly meetings [x_1]; 0 = else
DY	0/1		1 = Activity type is concentrated work [y_1]; 0 = else
DY$_2$	0/1		1 = Activity type is meeting, **not** initiator [y_2]; 0 = else
DY$_3$	0/1		1 = Activity type is meeting, initiator [y_3]; 0 = else
DZb1	0		1 = Second longest elapsed time [z_1]; 0 = else
DZb2	0	0/1	1 = Third longest elapsed time [z_2]; 0 = else
DZb3	0		1 = Shortest elapsed time [z_3]; 0 = else
DZa1		0	1 = Second longest elapsed time [z_1]; 0 = else
DZa2	0/1	0	1 = Third longest elapsed time [z_2]; 0 = else
DZa3		0	1 = Shortest elapsed time [z_3]; 0 = else
DU	1	1	1 = Execute activity; 0 = not execute activity
RespID	-	-	Respondent ID
Chance	-	-	Probability entered by respondent in stated choice experiment

Table A1.1: Explanation of dummy variables used in coding schemes.

RespID	SitID	DX1	DY1	DY2	DY3	DZb1	DZb2	DZb3	DZa1	DZa2	DZa3	DU	CHANCE
1	1	1	0	1	0	0	0	0	0	0	1	1	
	1	0	0	0	0	0	0	0	0	0	0	0	
	2	1	0	0	1	0	0	0	0	0	1	1	
	2	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	1	1	
	3	0	1	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	1	
	4	0	0	1	0	0	0	0	0	1	0	0	
	5	0	0	0	0	0	0	0	0	0	0	1	
	5	0	0	0	0	0	0	0	0	1	0	0	
	6	0	0	0	0	0	0	0	1	0	0	1	
	6	0	0	0	1	0	0	0	0	1	0	0	
	7	1	0	0	0	0	0	0	1	0	0	1	
	7	0	0	0	0	0	0	0	0	0	0	0	
	8	1	1	0	0	0	0	0	1	0	0	1	
	8	0	0	0	0	0	0	0	0	0	0	0	
	9	0	0	1	0	0	0	0	1	0	0	1	
	9	0	0	0	0	0	0	0	0	0	0	0	
	10	0	0	0	1	0	0	0	0	0	0	1	
	10	0	0	0	0	0	0	0	0	0	0	0	
	11	1	0	0	0	0	0	0	0	0	0	1	
	11	0	1	0	0	0	0	0	0	0	0	0	
	12	0	0	0	0	0	0	0	0	0	0	1	
	12	1	0	1	0	0	0	0	0	0	0	0	
	13	0	0	0	0	0	0	0	0	0	0	1	
	13	1	0	0	1	0	0	0	0	0	0	0	
	14	0	0	0	0	0	0	0	0	0	0	1	
	14	1	0	0	0	0	0	0	0	0	0	0	
	15	0	0	0	0	0	0	0	0	0	0	1	
	15	0	1	0	0	0	0	0	0	0	0	0	
	16	0	0	0	0	0	0	0	0	0	0	1	
	16	0	0	0	0	0	0	0	0	0	0	0	

Table A1.2: Dummy coding scheme for first activity occurrence.

RespID	SitID	DX1	DY1	DY2	DY3	DZb1	DZb2	DZb3	DZa1	DZa2	DZa3	DU	CHANCE
	1	1	0	1	0	0	0	1	0	0	0	1	
	1	0	0	0	0	0	0	0	0	0	0	0	
	2	1	0	0	1	0	0	1	0	0	0	1	
	2	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	1	0	0	0	1	
	3	0	1	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	1	0	0	0	1	
	4	0	0	1	0	0	0	0	0	0	0	0	
	5	0	0	0	0	0	1	0	0	0	0	1	
	5	0	0	1	0	0	0	0	0	0	0	0	
	6	0	0	0	1	0	1	0	0	0	0	1	
	6	1	0	0	0	0	0	0	0	0	0	0	
	7	1	0	0	0	0	1	0	0	0	0	1	
	7	0	1	0	0	0	0	0	0	0	0	0	
	8	1	0	0	0	0	1	0	0	0	0	1	
	8	0	0	1	0	0	0	0	0	0	0	0	
	9	0	0	0	0	1	0	0	0	0	0	1	
	9	0	0	0	1	0	0	0	0	0	0	0	
	10	0	0	0	0	1	0	0	0	0	0	1	
	10	0	0	0	0	0	0	0	0	0	0	0	
	11	1	0	0	0	1	0	0	0	0	0	1	
	11	0	1	0	0	0	0	0	0	0	0	0	
	12	1	0	0	0	1	0	0	0	0	0	1	
	12	0	0	1	0	0	0	0	0	0	0	0	
	13	1	0	0	0	0	0	0	0	0	0	1	
	13	0	0	0	1	0	0	0	0	0	0	0	
	14	1	0	0	0	0	0	0	0	0	0	1	
	14	0	0	0	0	0	0	0	0	0	0	0	
	15	0	0	0	0	0	0	0	0	0	0	1	
	15	0	1	0	0	0	0	0	0	0	0	0	
	16	0	0	1	0	0	0	0	0	0	0	1	
	16	0	0	0	0	0	0	0	0	0	0	0	

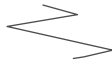**Table A1.3: Dummy coding scheme for subsequent activity occurrences.**

A2 USSU input files

Organisation input file (short version)

```
<organisation name="tue" type="university" workdaystarttime="07:00:00" workdaystarvariance="2000000"
workdayendtime="19:00:00" workdayaveragelength="540" workdaylengthvariance="50" numberofholidays="45"
numberofworkingdays="200">
    <roles>
        <role type="Chair OS" avarageguest="0">
            <task tasktype="Chair meeting OS" timepercentage="0.63" priority="99" averageduration="60"
            minduration="30" unit="OS" maintask="false"/>
        </role>
        <role type="Chair Beton" avarageguest="0">
            <task tasktype="Chair meeting Hout" timepercentage="0" priority="98" averageduration="60"
            minduration="30" unit="Stapelbouw" maintask="false"/>
        </role>

        <role type="Chair Board SDCT" avarageguest="0">
            <task tasktype="Chair board meeting SDCT (bestuursvergadering)" timepercentage="2.5"
            priority="99" averageduration="60" minduration="30" unit="Board SDCT" maintask="false"/>
        </role>
        <role type="UHD" avarageguest="0">
            <task tasktype="External" timepercentage="2.51" priority="92" averageduration="120" minduration="60"
            unit="TUE" maintask="false"/>
            <task tasktype="Concentrated research" timepercentage="2" priority="96" averageduration="60"
            minduration="15" unit="TUE" maintask="false"/>
            <task tasktype="Education (preparation + evaluation)" timepercentage="27.9" priority="95"
            averageduration="60" minduration="15" unit="TUE" maintask="false"/>
            <task tasktype="Follow course" timepercentage="1.27" priority="91" averageduration="240"
            minduration="120" unit="TUE" maintask="false"/>
            <task tasktype="Give PHD coaching" timepercentage="4.31" priority="97" averageduration="60"
            minduration="30" unit="TUE" maintask="false"/>
            <task tasktype="Give student coaching" timepercentage="15.78" priority="94" averageduration="60"
            minduration="30" unit="TUE" maintask="false"/>
            <task tasktype="Research" timepercentage="37.99" priority="97" averageduration="60" minduration="15"
            unit="TUE" maintask="true"/>
            <task tasktype="Teach" timepercentage="4.92" priority="96" averageduration="120" minduration="60"
            unit="TUE" maintask="false"/>
            <task tasktype="Management" timepercentage="3.49" priority="96" averageduration="60" minduration="15"
            unit="TUE" maintask="false"/>
        </role>
        <role type="PROF" avarageguest="0">
            <task tasktype="External" timepercentage="12.63" priority="96" averageduration="120" minduration="60"
            unit="TUE" maintask="false"/>
            <task tasktype="Concentrated research" timepercentage="1.32" priority="95" averageduration="60"
            minduration="15" unit="TUE" maintask="false"/>
            <task tasktype="Education (preparation + evaluation)" timepercentage="18.66" priority="95"
            averageduration="60" minduration="15" unit="TUE" maintask="false"/>
            <task tasktype="Follow course" timepercentage="2.64" priority="91" averageduration="240"
            minduration="120" unit="TUE" maintask="false"/>
            <task tasktype="Give PHD coaching" timepercentage="6.7" priority="96" averageduration="60"
            minduration="15" unit="TUE" maintask="false"/>
            <task tasktype="Give student coaching" timepercentage="21.64" priority="96" averageduration="60"
            minduration="30" unit="TUE" maintask="false"/>
            <task tasktype="Research" timepercentage="25.15" priority="94" averageduration="60" minduration="15"
            unit="TUE" maintask="true"/>
            <task tasktype="Teach" timepercentage="3.29" priority="97" averageduration="120" minduration="60"
            unit="TUE" maintask="false"/>
            <task tasktype="Management" timepercentage="7.97" priority="93" averageduration="60" minduration="15"
            unit="TUE" maintask="false"/>
        </role>
        <role type="SEC" avarageguest="0">
            <task tasktype="Administrative work" timepercentage="98.91" priority="99" averageduration="60"
            minduration="15" unit="TUE" maintask="true"/>
            <task tasktype="Follow course" timepercentage="1.09" priority="98" averageduration="240"
            minduration="120" unit="TUE" maintask="false"/>
        </role>
```

```
<role type="PHD" avarageguest="0">
    <task tasktype="External" timepercentage="1.29" priority="96" averageduration="120" minduration="60"
    unit="TUE" maintask="false"/>
    <task tasktype="Concentrated research" timepercentage="4.66" priority="97" averageduration="60"
    minduration="15" unit="TUE" maintask="false"/>
    <task tasktype="Education (preparation + evaluation)" timepercentage="1.21" priority="96"
    averageduration="60" minduration="15" unit="TUE" maintask="false"/>
    <task tasktype="Follow course" timepercentage="1.24" priority="95" averageduration="240"
    minduration="120" unit="TUE" maintask="false"/>
    <task tasktype="Get PHD coaching" timepercentage="1.12" priority="96" averageduration="60"
    minduration="15" unit="TUE" maintask="false"/>
    <task tasktype="Give student coaching" timepercentage="0.74" priority="95" averageduration="60"
    minduration="30" unit="TUE" maintask="false"/>
    <task tasktype="Research" timepercentage="88.6" priority="98" averageduration="60" minduration="15"
    unit="TUE" maintask="true"/>
    <task tasktype="Teach" timepercentage="0.21" priority="95" averageduration="120" minduration="60"
    unit="TUE" maintask="false"/>
    <task tasktype="Management" timepercentage="0.92" priority="93" averageduration="60" minduration="15"
    unit="TUE" maintask="false"/>
</role>
</roles>
<tasktypes>
    <tasktype name="Attend meeting CO" activitytype="meeting"/>
    <tasktype name="Chair meeting CO" activitytype="meeting"/>
    <tasktype name="Take minutes board meeting SDCT (bestuursvergadering)" activitytype="meeting"/>
    <tasktype name="Attend meeting DDSS" activitytype="meeting"/>
    <tasktype name="Chair meeting DDSS" activitytype="meeting"/>



    <tasktype name="External" activitytype="external"/>
    <tasktype name="Management" activitytype="work"/>
    <tasktype name="Attend presentation DDSS" activitytype="meeting"/>
    <tasktype name="Give presentation DDSS" activitytype="meeting"/>
    <tasktype name="Get student coaching" activitytype="meeting"/>
    <tasktype name="Give student coaching" activitytype="meeting"/>
    <tasktype name="Get PHD coaching" activitytype="meeting"/>
    <tasktype name="Give PHD coaching" activitytype="meeting"/>
    <tasktype name="Teach" activitytype="meeting"/>
    <tasktype name="Education (preparation + evaluation)" activitytype="work"/>
    <tasktype name="Concentrated education (preparation + evaluation)" activitytype="work_concentrated"/>
    <tasktype name="Get education" activitytype="meeting"/>
    <tasktype name="Research" activitytype="work"/>
    <tasktype name="Concentrated research" activitytype="work_concentrated"/>
    <tasktype name="Concentrated administrative work" activitytype="work_concentrated"/>
    <tasktype name="Administrative work" activitytype="work"/>
    <tasktype name="System management" activitytype="work"/>
    <tasktype name="Concentrated system management" activitytype="work_concentrated"/>
</tasktypes>
<organisationalunits>
    <unit name="TUE" root="true">
        <unit name="OPTUE">
            <task tasktype="Attend meeting OPTUE" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="UD" maintask="false"/>
            <task tasktype="Attend meeting OPTUE" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="UHD" maintask="false"/>
            <task tasktype="Attend meeting OPTUE" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="PROF" maintask="false"/>
            <task tasktype="Attend meeting OPTUE" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="SEC" maintask="false"/>
        </unit>
        <unit name="BWK">
            <unit name="UMDS">
                <unit name="OS">
                    <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
                    minduration="30" role="PHD" maintask="false"/>
                    <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
                    minduration="30" role="UD" maintask="false"/>
```

```xml
            <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="UHD" maintask="false"/>
            <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="PROF" maintask="false"/>
            <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="SEC" maintask="false"/>
            <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="SD" maintask="false"/>
            <task tasktype="Attend meeting OS" timepercentage="0.63" priority="100" averageduration="60"
            minduration="30" role="SA" maintask="false"/>
            <unit name="DB OS">
                <task tasktype="Attend meeting DB OS" timepercentage="0.63" priority="100"
                averageduration="60" minduration="30" role="UD" maintask="false"/>
                <task tasktype="Attend meeting DB OS" timepercentage="0.63" priority="100"
                averageduration="60" minduration="30" role="UHD" maintask="false"/>
                <task tasktype="Attend meeting DB OS" timepercentage="0.63" priority="100"
                averageduration="60" minduration="30" role="PROF" maintask="false"/>
                <task tasktype="Attend meeting DB OS" timepercentage="0.63" priority="100"
                averageduration="60" minduration="30" role="SEC" maintask="false"/>
            </unit>
        </unit>
        <unit name="URB"/>
    </unit>



    <unit name="DDSS">
        <task tasktype="Attend meeting DDSS" timepercentage="0.06" priority="99" averageduration="60"
        minduration="30" role="UD" maintask="false"/>
        <task tasktype="Attend meeting DDSS" timepercentage="0.06" priority="100" averageduration="60"
        minduration="30" role="UHD" maintask="false"/>
        <task tasktype="Attend meeting DDSS" timepercentage="0.06" priority="100" averageduration="60"
        minduration="30" role="PROF" maintask="false"/>
        <task tasktype="Attend meeting DDSS" timepercentage="0.06" priority="98" averageduration="60"
        minduration="30" role="PHD" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="100"
        averageduration="60" minduration="30" role="PHD" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="100"
        averageduration="60" minduration="30" role="UD" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="99"
        averageduration="60" minduration="30" role="UHD" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="99"
        averageduration="60" minduration="30" role="PROF" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="100"
        averageduration="60" minduration="30" role="SA" maintask="false"/>
        <task tasktype="Attend presentation DDSS" timepercentage="0.63" priority="100"
        averageduration="60" minduration="30" role="SD" maintask="false"/>
        <task tasktype="Give presentation DDSS" timepercentage="0.63" priority="99" averageduration="60"
        minduration="30" role="PHD" maintask="false"/>
    </unit>
        </unit>
    </unit>
</organisationalunits>
<employees>
    <employee name="Employee1" age="-1" gender="male" smokes="false" fte="1" sports="false">
        <role type="PROF"/>
        <role type="Chair OS"/>
        <role type="Chair DB OS"/>
        <unit name="DDSS"/>
        <unit name="DB OS"/>
    </employee>
    <employee name=" Employee2" age="-1" gender="male" smokes="false" fte="1" sports="false">
        <role type="UD"/>
        <unit name="OS"/>
        <unit name="OPTUE"/>
        <unit name="DDSS"/>
    </employee>
    <employee name=" Employee3" age="-1" gender="male" smokes="false" fte="1" sports="false">
```

```xml
                    <role type="PHD"/>
                    <unit name="OS"/>
                    <unit name="DDSS"/>
                </employee>
                <employee name=" Employee4" age="-1" gender="male" smokes="true" fte="1" sports="false">
                    <role type="SA"/>
                    <role type="OnderzoekOnderwijsMedewerker"/>
                    <unit name="OS"/>
                    <unit name="DDSS"/>
                </employee>
                <employee name=" Employee5" age="-1" gender="male" smokes="false" fte="1" sports="false">
                    <role type="UD"/>
                    <unit name="Stapelbouw"/>
                </employee>



                <employee name=" Employee37" age="-1" gender="male" smokes="false" fte="1" sports="false">
                    <role type="UHD"/>
                    <unit name="Architectuur en integratie"/>
                </employee>
                <employee name=" Employee38" age="-1" gender="male" smokes="false" fte="1" sports="false">
                    <role type="UD"/>
                    <unit name="Architectuur en integratie"/>
                </employee>
            </employees>
            <taskgroups>
                <taskgroup name="student coaching">
                    <taskgroupconfiguration iniator="false" minamount="1" maxamount="3" tasktype="Get student coaching"
                    resourcetype="external"/>
                    <taskgroupconfiguration iniator="true" minamount="1" maxamount="1" tasktype="Give student coaching"
                    resourcetype="internal"/>
                </taskgroup>
                <taskgroup name="PHD coaching">
                    <taskgroupconfiguration iniator="true" minamount="1" maxamount="1" tasktype="Get PHD coaching"
                    resourcetype="internal"/>
                    <taskgroupconfiguration iniator="false" minamount="1" maxamount="2" tasktype="Give PHD coaching"
                    resourcetype="internal"/>
                </taskgroup>



                <taskgroup name="meeting - OS">
                    <taskgroupconfiguration iniator="true" minamount="1" maxamount="1" tasktype="Chair meeting OS"
                    resourcetype="internal"/>
                    <taskgroupconfiguration iniator="false" minamount="2" maxamount="4" tasktype="Attend meeting OS"
                    resourcetype="internal"/>
                </taskgroup>
                <taskgroup name="presentation - ddss">
                    <taskgroupconfiguration iniator="true" minamount="1" maxamount="1" tasktype="Give presentation DDSS"
                    resourcetype="internal"/>
                    <taskgroupconfiguration iniator="false" minamount="1" maxamount="8" tasktype="Attend presentation
                    DDSS"  resourcetype="internal"/>
                    <taskgroupconfiguration iniator="false" minamount="1" maxamount="2" tasktype="Attend presentation
                    DDSS"  resourcetype="external"/>
                </taskgroup>
                <taskgroup name="student education">
                    <taskgroupconfiguration iniator="true" minamount="1" maxamount="1" tasktype="Teach"
                    resourcetype="internal"/>
                    <taskgroupconfiguration iniator="false" minamount="10" maxamount="20" tasktype="Get education"
                    resourcetype="external" />
                </taskgroup>
            </taskgroups>
        </organisation>
```

Building input file (short version)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<building name="Vertigo" type="traditional office" state="built">
    <abstractspaces>
        <abstractspace type="space" name="floor 9" capacity="-1" root="true">
            <abstractspace type="abstractspace" name="9.00a: hallway" capacity="-1">
              <node xcoordinate="0" ycoordinate="-4.79" ID="109"/>
              <node xcoordinate="7.35" ycoordinate="-4.79" ID="118"/>
              <node xcoordinate="7.35" ycoordinate="-7.14" ID="119"/>
            </abstractspace>
            <abstractspace type="abstractspace" name="9.00c: hallway" capacity="-1">
              <node xcoordinate="34.24" ycoordinate="-8.89" ID="9"/>
              <node xcoordinate="34.24" ycoordinate="-14.21" ID="11"/>
              <node xcoordinate="34.24" ycoordinate="-9.94" ID="330"/>
              <node xcoordinate="35.13" ycoordinate="-8.89" ID="331"/>
              <node xcoordinate="36.03" ycoordinate="-8.89" ID="332"/>
              <node xcoordinate="36.03" ycoordinate="-11.28" ID="333"/>
              <node xcoordinate="36.03" ycoordinate="-12.35" ID="334"/>
              <node xcoordinate="34.24" ycoordinate="-12.35" ID="2011"/>
              <node xcoordinate="35.13" ycoordinate="-9.39" ID="2020"/>
            </abstractspace>
            <abstractspace type="abstractspace" name="9.00d: hallway" capacity="-1">
              <node xcoordinate="33.24" ycoordinate="2.66" ID="18"/>
              <node xcoordinate="33.24" ycoordinate="4.39" ID="6"/>
              <node xcoordinate="33.24" ycoordinate="6.9" ID="125"/>
              <node xcoordinate="33.24" ycoordinate="11.28" ID="126"/>
              <node xcoordinate="33.24" ycoordinate="12.28" ID="140"/>
              <node xcoordinate="33.74" ycoordinate="6.9" ID="460"/>
              <node xcoordinate="33.74" ycoordinate="7.4" ID="2100"/>
            </abstractspace>


            <abstractspace type="abstractspace" name="Elevator side" capacity="-1">
              <node xcoordinate="7.5" ycoordinate="0" ID="114"/>
              <node xcoordinate="-7.5" ycoordinate="0" ID="570"/>
              <abstractspace type="space" name="Elevator side" capacity="-1" >
                <abstractspace type="abstractspace" name="toilet_male" capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="7.5" ycoordinate="3.7" ID="115"/>
                    <facility type="toilet_male" name="Toilet"/>
                </abstractspace>
                <abstractspace type="abstractspace" name="toilet_female" capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="7.5" ycoordinate="-3.7" ID="116"/>
                    <facility type="toilet_female" name="Toilet"/>
                </abstractspace>
                <abstractspace type="abstractspace" name="toilet_male"  capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="-7.5" ycoordinate="3.7" ID="571"/>
                    <facility type="toilet_male" name="Toilet"/>
                </abstractspace>
                <abstractspace type="abstractspace" name="toilet_female"  capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="-7.5" ycoordinate="-3.7" ID="572"/>
                    <facility type="toilet_female" name="Toilet"/>
                </abstractspace>
              </abstractspace>
            </abstractspace>
            <abstractspace type="abstractspace" name="stairs_side" capacity="-1">
              <node xcoordinate="42.56" ycoordinate="1.44" ID="452"/>
              <node xcoordinate="42.56" ycoordinate="-4.79" ID="111"/>
              <abstractspace type="space" name="Stairs_side" capacity="-1">
                <abstractspace type="abstractspace" name="toilet_female"  capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="37.6" ycoordinate="1.44" ID="117"/>
```

```xml
                    <facility type="toilet_female" name="Toilet"/>
                    <facility type="toilet_female" name="Toilet"/>
                </abstractspace>
                <abstractspace type="abstractspace" name="serverroom"  capacity="-1">
                    <activitytype type="work"/>
                    <node xcoordinate="62.4" ycoordinate="0" ID="453"/>
                </abstractspace>
                <abstractspace type="abstractspace" name="toilet_male"  capacity="-1">
                    <activitytype type="toilet"/>
                    <node xcoordinate="34.15" ycoordinate="0" ID="454"/>
                    <facility type="toilet_male" name="Toilet"/>
                    <facility type="toilet_male" name="Toilet"/>
                </abstractspace>
            </abstractspace>
        </abstractspace>
        <abstractspace type="abstractspace" name="9.09: open office space" capacity="-1">
            <node xcoordinate="28.12" ycoordinate="-15.11" ID="30"/>
            <node xcoordinate="28.12" ycoordinate="-14.21" ID="2010"/>
            <abstractspace type="abstractspace" name="workplace_?" capacity="1" employee="Vincent Tabak">
                <activitytype type="work"/>
                <activitytype type="work_concentrated"/>
                <activitytype type="break"/>
                <node xcoordinate="30.35" ycoordinate="-14.21" ID="31"/>
            </abstractspace>



            <abstractspace type="abstractspace" name="workplace_?" capacity="1" employee="?">
                <activitytype type="work"/>
                <activitytype type="work_concentrated"/>
                <activitytype type="break"/>
                <node xcoordinate="30.35" ycoordinate="-7.56" ID="350"/>
            </abstractspace>
        </abstractspace>
        <abstractspace type="abstractspace" name="printercorner"  capacity="-1">
            <activitytype type="printer"/>
            <activitytype type="break"/>
            <node xcoordinate="17.43" ycoordinate="-3.23" ID="4"/>
            <facility type="printer" name="LaserPrinterSomething"/>
        </abstractspace>
        <abstractspace type="abstractspace" name="coffee corner" capacity="-1">
            <activitytype type="coffee corner"/>
            <activitytype type="break"/>
            <node xcoordinate="7.85" ycoordinate="-7.14" ID="315"/>
            <facility type="coffee machine" name="AwfulCoffeeMachine"/>
        </abstractspace>
        <abstractspace type="space" name="9.08: secretary" capacity="-1">
            <node xcoordinate="21.7" ycoordinate="-7.3" ID="1"/>
            <node xcoordinate="16.11" ycoordinate="-7.3" ID="181"/>
            <node xcoordinate="16.11" ycoordinate="-9.8" ID="182"/>
            <node xcoordinate="21.7" ycoordinate="-9.8" ID="0"/>
            <node xcoordinate="21.7" ycoordinate="-15" ID="190"/>
            <node xcoordinate="16.11" ycoordinate="-15" ID="191"/>
            <node xcoordinate="16.11" ycoordinate="-13" ID="192"/>
            <node xcoordinate="21.7" ycoordinate="-13" ID="193"/>
            <facility type="beamer" name="Loud beamer"/>
            <abstractspace type="abstractspace" name="workplace_?" capacity="1" employee="?">
                <activitytype type="work"/>
                <activitytype type="work_concentrated"/>
                <activitytype type="secretary"/>
                <activitytype type="break"/>
                <node xcoordinate="20" ycoordinate="-9.8" ID="194"/>
            </abstractspace>



        </abstractspace>
        <abstractspace type="space" name="9.06: big meeting room" capacity="-1">
```

```
<node xcoordinate="7.35" ycoordinate="-10" ID="66"/>
<node xcoordinate="6.35" ycoordinate="-10" ID="271"/>
<node xcoordinate="5.35" ycoordinate="-10" ID="272"/>
<node xcoordinate="4.35" ycoordinate="-10" ID="273"/>
<node xcoordinate="3.35" ycoordinate="-10" ID="274"/>
<node xcoordinate="2.35" ycoordinate="-10" ID="275"/>
<node xcoordinate="7.35" ycoordinate="-15" ID="281"/>
<node xcoordinate="6.35" ycoordinate="-15" ID="282"/>
<node xcoordinate="5.35" ycoordinate="-15" ID="283"/>
<node xcoordinate="4.35" ycoordinate="-15" ID="284"/>
<node xcoordinate="3.35" ycoordinate="-15" ID="285"/>
<node xcoordinate="2.35" ycoordinate="-15" ID="286"/>
<node xcoordinate="1.35" ycoordinate="-10" ID="260"/>
<node xcoordinate="1.35" ycoordinate="-11" ID="261"/>
<node xcoordinate="1.35" ycoordinate="-12" ID="2003"/>
<node xcoordinate="1.35" ycoordinate="-13" ID="2004"/>
<node xcoordinate="1.35" ycoordinate="-14" ID="262"/>
<node xcoordinate="1.35" ycoordinate="-15" ID="263"/>
<node xcoordinate="8.35" ycoordinate="-10" ID="250"/>
<node xcoordinate="8.35" ycoordinate="-11" ID="251"/>
<node xcoordinate="8.35" ycoordinate="-12" ID="2001"/>
<node xcoordinate="8.35" ycoordinate="-13" ID="2002"/>
<node xcoordinate="8.35" ycoordinate="-14" ID="252"/>
<node xcoordinate="8.35" ycoordinate="-15" ID="253"/>
<abstractspace type="abstractspace" name="meetingspace" capacity="20"  public="true">
  <activitytype type="meeting"/>
    <node xcoordinate="7.35" ycoordinate="-10.5" ID="291"/>
    <node xcoordinate="6.35" ycoordinate="-10.5" ID="292"/>
    <node xcoordinate="5.35" ycoordinate="-10.5" ID="293"/>
    <node xcoordinate="4.35" ycoordinate="-10.5" ID="294"/>
    <node xcoordinate="3.35" ycoordinate="-10.5" ID="295"/>
    <node xcoordinate="2.35" ycoordinate="-10.5" ID="296"/>
    <node xcoordinate="7.35" ycoordinate="-14.5" ID="301"/>
    <node xcoordinate="6.35" ycoordinate="-14.5" ID="302"/>
    <node xcoordinate="5.35" ycoordinate="-14.5" ID="303"/>
    <node xcoordinate="4.35" ycoordinate="-14.5" ID="304"/>
    <node xcoordinate="3.35" ycoordinate="-14.5" ID="305"/>
    <node xcoordinate="2.35" ycoordinate="-14.5" ID="306"/>
    <node xcoordinate="1.85" ycoordinate="-11" ID="310"/>
    <node xcoordinate="1.85" ycoordinate="-12" ID="2007"/>
    <node xcoordinate="1.85" ycoordinate="-13" ID="2008"/>
    <node xcoordinate="1.85" ycoordinate="-14" ID="311"/>
    <node xcoordinate="7.85" ycoordinate="-11" ID="312"/>
    <node xcoordinate="7.85" ycoordinate="-12" ID="2005"/>
    <node xcoordinate="7.85" ycoordinate="-13" ID="2006"/>
    <node xcoordinate="7.85" ycoordinate="-14" ID="313"/>
  </abstractspace>
</abstractspace>
<abstractspace type="space" name="9.10: office room" capacity="-1" >
  <node xcoordinate="37.2" ycoordinate="-12.35" ID="62"/>
  <node xcoordinate="39.2" ycoordinate="-12.35" ID="340"/>
  <node xcoordinate="37.2" ycoordinate="-14.61" ID="341"/>
  <node xcoordinate="37.2" ycoordinate="-15.61" ID="342"/>
  <node xcoordinate="39.2" ycoordinate="-14.61" ID="343"/>
  <node xcoordinate="39.2" ycoordinate="-15.61" ID="344"/>
  <abstractspace type="abstractspace" name="workplace_?" capacity="1" employee="?">
    <activitytype type="work"/>
    <activitytype type="work_concentrated"/>
    <activitytype type="break"/>
    <node xcoordinate="40.01" ycoordinate="-12.35" ID="14"/>
  </abstractspace>
  <abstractspace type="abstractspace" name="meetingspace" capacity="4" public="false">
    <activitytype type="meeting"/>
    <node xcoordinate="37.5" ycoordinate="-14.61" ID="48"/>
    <node xcoordinate="37.5" ycoordinate="-15.61" ID="49"/>
    <node xcoordinate="38.8" ycoordinate="-14.61" ID="50"/>
    <node xcoordinate="38.8" ycoordinate="-15.61" ID="51"/>
  </abstractspace>
```

```xml
        </abstractspace>
        <abstractspace type="space" name="9.13: office room" capacity="-1">
          <node xcoordinate="43.63" ycoordinate="-9.39" ID="141"/>
          <node xcoordinate="43.63" ycoordinate="-10.39" ID="360"/>
          <node xcoordinate="45.13" ycoordinate="-10.39" ID="361"/>
          <node xcoordinate="43.63" ycoordinate="-9.89" ID="364"/>
          <abstractspace type="abstractspace" name="workplace_?" capacity="1" employee="?">
            <activitytype type="work"/>
            <activitytype type="work_concentrated"/>
            <activitytype type="break"/>
            <node xcoordinate="45.13" ycoordinate="-11.89" ID="20"/>
          </abstractspace>
          <abstractspace type="abstractspace"  name="workplace_?" capacity="1" employee="?">
            <activitytype type="work"/>
            <activitytype type="work_concentrated"/>
            <activitytype type="break"/>
            <node xcoordinate="45.13" ycoordinate="-9.39" ID="21"/>
          </abstractspace>
          <abstractspace type="abstractspace" name="meetingspace" capacity="2" public="false">
            <activitytype type="meeting"/>
            <node xcoordinate="42.93" ycoordinate="-9.89" ID="362"/>
            <node xcoordinate="43.39" ycoordinate="-10.39" ID="363"/>
          </abstractspace>
        </abstractspace>

        <abstractspace type="externalabstractspace" name="faculteit" capacity="-1" traveltime="2.5">
          <activitytype type="external"/>
          <activitytype type="smoke"/>
          <node xcoordinate="-20" ycoordinate="10" ID="24"/>
        </abstractspace>
        <abstractspace type="externalabstractspace"  name="campus tu/e" capacity="50" traveltime="10">
          <activitytype type="external"/>
          <activitytype type="canteen"/>
          <activitytype type="sportcentre"/>
          <activitytype type="meeting"/>
          <node xcoordinate="-20" ycoordinate="12" ID="25"/>
        </abstractspace>
        <abstractspace type="externalabstractspace"  name="eindhoven" capacity="-1" traveltime="20">
          <activitytype type="external"/>
          <node xcoordinate="-20" ycoordinate="14" ID="26"/>
        </abstractspace>
        <abstractspace type="externalabstractspace" name="national" capacity="-1" traveltime="90">
          <activitytype type="external"/>
          <node xcoordinate="-20" ycoordinate="16" ID="27"/>
        </abstractspace>
        <abstractspace type="entrance"  name="elevators" capacity="-1" traveltime="0">
          <node xcoordinate="0" ycoordinate="0" ID="112"/>
        </abstractspace>
        <abstractspace type="entrance" name="stairs" capacity="-1" traveltime="2">
          <node xcoordinate="42.56" ycoordinate="0" ID="4080"/>
        </abstractspace>
    </abstractspaces>
    <edges>
        <edge node1="0" node2="1"/>
        <edge node1="1" node2="2"/>
        <edge node1="2" node2="3"/>

        <edge node1="215" node2="241"/>
        <edge node1="216" node2="242"/>
        <edge node1="217" node2="243"/>
        <edge node1="218" node2="244"/>
        <edge node1="219" node2="245"/>
    </edges>
</building>
```

Configuration input file (full version)

```xml
<config timeinterval="30" maxoverlapinterval="5" meanwalkingspeed="1.3">
    <activitytypes>
        <activitytype type="meeting"/>
        <activitytype type="work"/>
        <activitytype type="work_concentrated"/>
        <activitytype type="external"/>
        <activitytype type="canteen"/>
        <activitytype type="toilet"/>
        <activitytype type="coffee corner"/>
        <activitytype type="printer"/>
        <activitytype type="mailbox"/>
        <activitytype type="sportcentre"/>
        <activitytype type="break"/>
        <activitytype type="smoke"/>
        <activitytype type="secretary"/>
    </activitytypes>
    <intermediateactivitytypes>
        <intermediateactivitytype name="Get a drink" priority="100" activitytype="coffee corner" type="scurve"/>
        <intermediateactivitytype name="Have lunch" priority="100" activitytype="canteen" type="scurve"/>
        <intermediateactivitytype name="Have a break" priority="100" activitytype="break" type="scurve"/>
        <intermediateactivitytype name="Go to toilet" priority="100" activitytype="toilet" type="probabilistic"/>
        <intermediateactivitytype name="Walk to printer"  priority="100" activitytype="printer" type="probabilistic"/>
        <intermediateactivitytype name="Sport" priority="100" activitytype="sportcentre" type="probabilistic"/>
        <intermediateactivitytype name="Smoke" priority="100" activitytype="smoke" type="probabilistic"/>
    </intermediateactivitytypes>
    <intermediateactivities>
        <intermediateactivity name="Go to toilet" averagefrequence="2.78" frequenceVariance="1.14"
        averageduration="2" mindistance="60">
            <facility type="toilet"/>
        </intermediateactivity>
        <intermediateactivity name="Walk to printer" averagefrequence="3.96"  frequenceVariance="1.76"
        averageduration="1" mindistance="5">
            <facility type="printer"/>
        </intermediateactivity>
        <intermediateactivity name="Sport" averagefrequence="0.82"  frequenceVariance="0.39" averageduration="45"
        mindistance="240"/>
        <intermediateactivity name="Smoke" averagefrequence="2.22"  frequenceVariance="1.64" averageduration="6"
        mindistance="60"/>
        <intermediateactivity name="Get a drink"  interval="0"  maxfrequence="0" noofrespondents="2.6" />
        <intermediateactivity name="Get a drink"  averageduration="3" interval="2" slope="0.014" displacement="107.51"
            maxutility="3.61" minutility="-2.92" slopeNo="0.039" displacementNo="76.94" maxutilityNo="2.82"
            minutilityNo="-2.81" maxfrequence="3"  noofrespondents="40.5"  constantUtility="0.688">
            <typeoftask type="work" offset="0" />
            <typeoftask type="work_concentrated" offset="-0.54" />
            <typeoftask type="meeting" offset="-1.13" />
            <typeoftask type="meeting_initiator" offset="-0.66" />
            <typeofday type="work" offset="0" />
            <typeofday type="meeting" offset="0.062" />
            <facility type="coffee machine"/>
        </intermediateactivity>
        <intermediateactivity name="Get a drink" averageduration="3"  interval="3" slope="0.025" displacement="131.00"
            maxutility="5.189" minutility="-2.226" slopeNo="0.020" displacementNo="-9.8" maxutilityNo="4.3"
            minutilityNo="-3.92" maxfrequence="8" afternooneffect="1.5"  noofrespondents="56.9" constantUtility="0.7">
            <typeoftask type="work" offset="0" />
            <typeoftask type="work_concentrated" offset="-1.08" />
            <typeoftask type="meeting" offset="-1.04" />
            <typeoftask type="meeting_initiator" offset="-1.08" />
            <typeofday type="work" offset="0" />
            <typeofday type="meeting" offset="0.33" />
            <facility type="coffee machine"/>
        </intermediateactivity>
        <intermediateactivity name="Have lunch"  interval="0"  maxfrequence="0" noofrespondents="9.5" />
        <intermediateactivity name="Have lunch"  averageduration="28" interval="1" timeframestart="11:00:00"
            timeframeend="14:00:00" slopeNo="0.018" displacementNo="81.540" maxutilityNo="2.890" minutilityNo="-
            2.850" maxfrequence="1" noofrespondents="90.5" constantUtility="0.702">
```

```xml
                    <typeoftask type="work" offset="0" />
                    <typeoftask type="work_concentrated" offset="-0.74" />
                    <typeoftask type="meeting" offset="-1.44" />
                    <typeoftask type="meeting_initiator" offset="-1.24" />
                    <typeofday type="work" offset="0" />
                    <typeofday type="meeting" offset="0.13" />
                    <facility type="coffee machine"/>
                </intermediateactivity>
                <intermediateactivity name="Have a break"  interval="0"  maxfrequence="0" noofrespondents="13.75" />
                <intermediateactivity name="Have a break"  averageduration="8" interval="2" slope="0.019" displacement="85.0"
                    maxutility="3.52" minutility="-3.260" slopeNo="0.09" displacementNo="85" maxutilityNo="3.4" minutilityNo="-
                    3.15" maxfrequence="3"  noofrespondents="66.35" constantUtility="0.735">
                    <typeoftask type="work" offset="0" />
                    <typeoftask type="work_concentrated" offset="-0.57" />
                    <typeoftask type="meeting" offset="-1.16" />
                    <typeoftask type="meeting_initiator" offset="-0.94" />
                    <typeofday type="work" offset="0" />
                    <typeofday type="meeting" offset="0.05" />
                    <facility type="coffee machine"/>
                </intermediateactivity>
                <intermediateactivity name="Have a break" averageduration="8" interval="3" slope="0.0095" displacement="3.0"
                    maxutility="5.85" minutility="-4.4" slopeNo="0.04" displacementNo="35.100" maxutilityNo="4.55" minutilityNo="-
                    4.4" maxfrequence="8" afternooneffect="1.80"  noofrespondents="19.8" constantUtility="0.404">
                    <typeoftask type="work" offset="0" />
                    <typeoftask type="work_concentrated" offset="-0.84" />
                    <typeoftask type="meeting" offset="-1.32" />
                    <typeoftask type="meeting_initiator" offset="-0.91" />
                    <typeofday type="work" offset="0" />
                    <typeofday type="meeting" offset="0.20" />
                    <facility type="coffee machine"/>
                </intermediateactivity>
            </intermediateactivities>
        </config>
```

A3 USSU movement pattern

Activity	Start time	End time	Location	Activity-type
Research	7:46:43	7:53:24	workplace_employeeA (floor 9)	work
Walk to printer	7:53:24	7:55:30	printercorner (floor 9)	printer
Research	7:55:30	8:00:00	workplace_employeeA (floor 9)	work
Education (preparation + evaluation	8:00:00	9:00:00	workplace_employeeA (floor 9)	work
Research	9:00:00	9:16:49	workplace_employeeA (floor 9)	work
Have a break	9:16:49	9:25:11	workplace_employeeB (floor 9)	break
Research	9:25:11	9:33:28	workplace_employeeA (floor 9)	work
Get a drink	9:33:28	9:37:32	coffee corner (floor 9)	coffee corner
Research	9:37:32	9:59:39	workplace_employeeA (floor 9)	work
Give student coaching	9:59:39	10:55:35	meetingspace (9.27: small meeting room)	meeting
Go to toilet	10:55:35	10:58:39	toilet_male (Elevator side)	toilet
Research	10:58:39	11:40:38	workplace_employeeA (floor 9)	work
Have a break	11:40:38	11:49:22	workplace_employeeA (floor 9)	break
Research	11:49:22	11:58:28	workplace_employeeA (floor 9)	work
Get a drink	11:58:28	12:02:32	coffee corner (floor 9)	coffee corner
Research	12:02:32	12:29:06	workplace_employeeA (floor 9)	work
Have a break	12:29:06	12:38:54	workplace_employeeC (floor 9)	break
Research	12:38:54	12:39:33	workplace_employeeA (floor 9)	work
Go to toilet	12:39:33	12:42:37	toilet_male (Elevator side)	toilet
Research	12:42:37	13:13:43	workplace_employeeA (floor 9)	work
Have lunch	13:13:43	14:02:17	campus tu/e (externalabstractspace)	canteen
Management	14:02:17	14:21:28	workplace_employeeA (floor 9)	work
Get a drink	14:21:28	14:25:32	coffee corner (floor 9)	coffee corner
Research	14:25:32	14:45:54	workplace_employeeA (floor 9)	work
Go to toilet	14:45:54	14:48:58	toilet_male (Elevator side)	toilet
Research	14:48:58	14:59:39	workplace_employeeA (floor 9)	work
Give student coaching	14:59:39	15:48:39	meetingspace (9.27: small meeting room) resources: 4 x guest	meeting
Walk to printer	15:48:39	15:50:45	printercorner (floor 9)	printer
Research	15:50:45	16:46:53	workplace_employeeA (floor 9)	work

Table A3.1: Movement pattern of one example employee.

Complete XML based movement pattern

```xml
<employee age="1" fte="1.0" gender="male" name="? Linder" smokes="false" sports="false" workdaylength="32410" workspace="workplace_? (floor 9)">
    <roles>
        <role type="UD" />
    </roles>
    <schedule endtime="16:46:53" originalendtime="16:46:36" originalstarttime="07:47:00" starttime="07:46:43">
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="401" endtime="7:53:24" name="Research" nodeID="564" priority="96" starttime="7:46:43" traveltime_to_entranceend="0" traveltime_to_entrancestart="17" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="printercorner (floor 9)" activitytype="printer" duration="126" endtime="7:55:30" name="Walk to printer" nodeID="4" priority="100" starttime="7:53:24" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="33" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="270" endtime="8:00:00" name="Research" nodeID="564" priority="96" starttime="7:55:30" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="3600" endtime="9:00:00" name="Education (preparation + evaluation)" nodeID="564" priority="97" starttime="8:00:00" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity"/>
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1009" endtime="9:16:49" name="Research" nodeID="564" priority="96" starttime="9:00:00" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="break" duration="502" endtime="9:25:11" name="Have a break" nodeID="566" priority="100" starttime="9:16:49" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="11" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="497" endtime="9:33:28" name="Research" nodeID="564" priority="96" starttime="9:25:11" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="244" endtime="9:37:32" name="Get a drink" nodeID="315" priority="100" starttime="9:33:28" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1327" endtime="9:59:39" name="Research" nodeID="564" priority="96" starttime="9:37:32" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="meetingspace (9.27: small meeting room)" activitytype="meeting" duration="3356" endtime="10:55:35" name="Give student coaching" nodeID="529" priority="97" resources="Guest;Guest" starttime="9:59:39" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="21" type="SkeletonActivity" />
        <activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="184" endtime="10:58:39" name="Go to toilet" nodeID="115" priority="100" starttime="10:55:35" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="2519" endtime="11:40:38" name="Research" nodeID="564" priority="96" starttime="10:58:39" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="workplace_? (9.28: office room)" activitytype="break" duration="524" endtime="11:49:22" name="Have a break" nodeID="532" priority="100" starttime="11:40:38" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="22" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="546" endtime="11:58:28" name="Research" nodeID="564" priority="96" starttime="11:49:22" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="244" endtime="12:02:32" name="Get a drink" nodeID="315" priority="100" starttime="11:58:28" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1594" endtime="12:29:06" name="Research" nodeID="564" priority="96" starttime="12:02:32" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="break" duration="588" endtime="12:38:54" name="Have a break" nodeID="325" priority="100" starttime="12:29:06" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="54" type="IntermediateActivity" />
        <activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="39" endtime="12:39:33" name="Research" nodeID="564" priority="96" starttime="12:38:54" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
```

<activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="184" endtime="12:42:37" name="Go to toilet" nodeID="115" priority="100" starttime="12:39:33" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1866" endtime="13:13:43" name="Research" nodeID="564" priority="96" starttime="12:42:37" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
<activity abstractspace="campus tu/e (externalabstractspace)" activitytype="canteen" duration="2914" endtime="14:02:17" name="Have lunch" nodeID="25" priority="100" starttime="13:13:43" traveltime_to_entranceend="17" traveltime_to_entrancestart="17" traveltime_to_location="600" type="IntermediateActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1151" endtime="14:21:28" name="Management" nodeID="564" priority="92" starttime="14:02:17" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
<activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="244" endtime="14:25:32" name="Get a drink" nodeID="315" priority="100" starttime="14:21:28" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1222" endtime="14:45:54" name="Research" nodeID="564" priority="96" starttime="14:25:32" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
<activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="184" endtime="14:48:58" name="Go to toilet" nodeID="115" priority="100" starttime="14:45:54" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="32" type="IntermediateActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="641" endtime="14:59:39" name="Research" nodeID="564" priority="96" starttime="14:48:58" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
<activity abstractspace="meetingspace (9.27: small meeting room)" activitytype="meeting" duration="2940" endtime="15:48:39" name="Give student coaching" nodeID="527" priority="97" resources="Guest;Guest;Guest;Guest" starttime="14:59:39" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="21" type="SkeletonActivity" />
<activity abstractspace="printercorner (floor 9)" activitytype="printer" duration="126" endtime="15:50:45" name="Walk to printer" nodeID="4" priority="100" starttime="15:48:39" traveltime_to_entranceend="0" traveltime_to_entrancestart="0" traveltime_to_location="33" type="IntermediateActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="3368" endtime="16:46:53" name="Research" nodeID="564" priority="96" starttime="15:50:45" traveltime_to_entranceend="17" traveltime_to_entrancestart="0" traveltime_to_location="0" type="SkeletonActivity" />
</schedule>
<movementpattern>
<travel duration="17.0" endtime="7:47:00" node_from="112" node_to="564" route="[112 (0.0, 0.0), 110 (0.0, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 13.059999999999999" starttime="7:46:43" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="384.0" endtime="7:53:24" name="Research" nodeID="564" starttime="7:47:00" type="SkeletonActivity" />
<travel duration="33.0" endtime="7:53:57" node_from="564" node_to="4" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 64 (18.2, 1.5), 317 (18.2, 3.23), 4 (17.43, 3.23)] 24.82" starttime="7:53:24" />
<activity abstractspace="printercorner (floor 9)" activitytype="printer" duration="60.0" endtime="7:54:57" name="Walk to printer" nodeID="4" starttime="7:53:57" type="IntermediateActivity" />
<travel duration="33.0" endtime="7:55:30" node_from="4" node_to="564" route="[4 (17.43, 3.23), 317 (18.2, 3.23), 64 (18.2, 1.5), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.82" starttime="7:54:57" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="270.0" endtime="8:00:00" name="Research" nodeID="564" starttime="7:55:30" type="SkeletonActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="3600.0" endtime="9:00:00" name="Education (preparation + evaluation)" nodeID="564" starttime="8:00:00" type="SkeletonActivity" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1009.0" endtime="9:16:49" name="Research" nodeID="564" starttime="9:00:00" type="SkeletonActivity" />
<travel duration="11.0" endtime="9:17:00" node_from="564" node_to="566" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 561 (5.22, 12.28), 183 (5.22, 14.23), 566 (5.72, 14.23)] 7.890000000000001" starttime="9:16:49" />
<activity abstractspace="workplace_? (floor 9)" activitytype="break" duration="480.0" endtime="9:25:00" name="Have a break" nodeID="566" starttime="9:17:00" type="IntermediateActivity" />
<travel duration="11.0" endtime="9:25:11" node_from="566" node_to="564" route="[566 (5.72, 14.23), 183 (5.22, 14.23), 561 (5.22, 12.28), 562 (5.22, 7.34), 564 (5.72, 7.34)] 7.890000000000001" starttime="9:25:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="497.0" endtime="9:33:28" name="Research" nodeID="564" starttime="9:25:11" type="SkeletonActivity" />
<travel duration="32.0" endtime="9:34:00" node_from="564" node_to="315" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 15 (10.75, 4.79), 118 (7.35, 4.79), 119 (7.35, 7.14), 315 (7.85, 7.14)] 24.410000000000004" starttime="9:33:28" />
<activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="180.0" endtime="9:37:00" name="Get a drink" nodeID="315" starttime="9:34:00" type="IntermediateActivity" />
</movementpattern>

<travel duration="32.0" endtime="9:37:32" node_from="315" node_to="564" route="[315 (7.85, 7.14), 119 (7.35, 7.14), 118 (7.35, 4.79), 15 (10.75, 4.79), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.41" starttime="9:37:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1327.0" endtime="9:59:39" name="Research" nodeID="564" starttime="9:37:32" type="SkeletonActivity" />
<travel duration="21.0" endtime="10:00:00" node_from="564" node_to="527" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 510 (12.04, 2.66), 511 (13.04, 2.66), 512 (14.04, 2.66), 513 (15.04, 2.66), 524 (15.04, 2.16)] 15.5" starttime="9:59:39" />
<activity abstractspace="meetingspace (9.27: small meeting room)" activitytype="meeting" duration="3314.0" endtime="10:55:14" name="Give student coaching" nodeID="527" starttime="10:00:00" type="SkeletonActivity" />
<travel duration="21.0" endtime="10:55:35" node_from="527" node_to="564" route="[524 (15.04, 2.16), 513 (15.04, 2.66), 512 (14.04, 2.66), 511 (13.04, 2.66), 510 (12.04, 2.66), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 15.5" starttime="10:55:14" />
<travel duration="32.0" endtime="10:56:07" node_from="564" node_to="115" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 110 (0.0, 4.79), 112 (0.0, 0.0), 114 (7.5, 0.0), 115 (7.5, 3.7)] 24.259999999999998" starttime="10:55:35" />
<activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="120.0" endtime="10:58:07" name="Go to toilet" nodeID="115" starttime="10:56:07" type="IntermediateActivity" />
<travel duration="32.0" endtime="10:58:39" node_from="115" node_to="564" route="[115 (7.5, 3.7), 114 (7.5, 0.0), 112 (0.0, 0.0), 110 (0.0, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.259999999999998" starttime="10:58:07" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="2519.0" endtime="11:40:38" name="Research" nodeID="564" starttime="10:58:39" type="SkeletonActivity" />
<travel duration="22.0" endtime="11:41:00" node_from="564" node_to="533" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 144 (10.75, 6.9), 143 (12.04, 6.9), 530 (12.04, 4.85), 532 (14.29, 4.85)] 16.28" starttime="11:40:38" />
<activity abstractspace="workplace_? (9.28: office room)" activitytype="break" duration="480.0" endtime="11:49:00" name="Have a break" nodeID="533" starttime="11:41:00" type="IntermediateActivity" />
<travel duration="22.0" endtime="11:49:22" node_from="533" node_to="564" route="[532 (14.29, 4.85), 530 (12.04, 4.85), 143 (12.04, 6.9), 144 (10.75, 6.9), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 16.28" starttime="11:49:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="546.0" endtime="11:58:28" name="Research" nodeID="564" starttime="11:49:22" type="SkeletonActivity" />
<travel duration="32.0" endtime="11:59:00" node_from="564" node_to="315" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 15 (10.75, 4.79), 118 (7.35, 4.79), 119 (7.35, 7.14), 315 (7.85, 7.14)] 24.410000000000004" starttime="11:58:28" />
<activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="180.0" endtime="12:02:00" name="Get a drink" nodeID="315" starttime="11:59:00" type="IntermediateActivity" />
<travel duration="32.0" endtime="12:02:32" node_from="315" node_to="564" route="[315 (7.85, 7.14), 119 (7.35, 7.14), 118 (7.35, 4.79), 15 (10.75, 4.79), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.41" starttime="12:02:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1594.0" endtime="12:29:06" name="Research" nodeID="564" starttime="12:02:32" type="SkeletonActivity" />
<travel duration="54.0" endtime="12:30:00" node_from="564" node_to="325" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 64 (18.2, 1.5), 318 (23.13, 1.5), 3 (23.13, 4.79), 321 (23.13, 12.83), 322 (23.13, 15.11), 325 (23.55, 15.11)] 41.28" starttime="12:29:06" />
<activity abstractspace="workplace_? (floor 9)" activitytype="break" duration="480.0" endtime="12:38:00" name="Have a break" nodeID="325" starttime="12:30:00" type="IntermediateActivity" />
<travel duration="54.0" endtime="12:38:54" node_from="325" node_to="564" route="[325 (23.55, 15.11), 322 (23.13, 15.11), 321 (23.13, 12.83), 3 (23.13, 4.79), 2 (21.7, 4.79), 316 (18.2, 4.79), 180 (16.11, 4.79), 120 (14.57, 4.79), 15 (10.75, 4.79), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 41.279999999999994" starttime="12:38:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="39.0" endtime="12:39:33" name="Research" nodeID="564" starttime="12:38:54" type="SkeletonActivity" />
<travel duration="32.0" endtime="12:40:05" node_from="564" node_to="115" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 110 (0.0, 4.79), 112 (0.0, 0.0), 114 (7.5, 0.0), 115 (7.5, 3.7)] 24.259999999999998" starttime="12:39:33" />
<activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="120.0" endtime="12:42:05" name="Go to toilet" nodeID="115" starttime="12:40:05" type="IntermediateActivity" />
<travel duration="32.0" endtime="12:42:37" node_from="115" node_to="564" route="[115 (7.5, 3.7), 114 (7.5, 0.0), 112 (0.0, 0.0), 110 (0.0, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.259999999999998" starttime="12:42:05" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1866.0" endtime="13:13:43" name="Research" nodeID="564" starttime="12:42:37" type="SkeletonActivity" />
<travel duration="17.0" endtime="13:14:00" node_from="564" node_to="112" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 110 (0.0, 4.79), 112 (0.0, 0.0)] 13.059999999999999" starttime="13:13:43" />
<travel duration="600.0" endtime="13:24:00" node_from="112" node_to="25" route="[112 (0.0, 0.0), 25 (20.0, 12.0)] 23.323807579381203" starttime="13:14:00" />

<activity abstractspace="campus tu/e (externalabstractspace)" activitytype="canteen" duration="1680.0" endtime="13:52:00" name="Have lunch" nodeID="25" starttime="13:24:00" type="IntermediateActivity" />
<travel duration="600.0" endtime="14:02:00" node_from="25" node_tonode_from="112" route="[25 (20.0, 12.0), 112 (0.0, 0.0)] 23.323807579381203" starttime="13:52:00" />
<travel duration="17.0" endtime="14:02:17" node_from="112" node_to="564" route="[112 (0.0, 0.0), 110 (0.0, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 13.059999999999999" starttime="14:02:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1151.0" endtime="14:21:28" name="Management" nodeID="564" starttime="14:02:17" type="SkeletonActivity" />
<travel duration="32.0" endtime="14:22:00" node_from="564" node_to="315" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 15 (10.75, 4.79), 118 (7.35, 4.79), 119 (7.35, 7.14), 315 (7.85, 7.14)] 24.410000000000004" starttime="14:21:28" />
<activity abstractspace="coffee corner (floor 9)" activitytype="coffee corner" duration="180.0" endtime="14:25:00" name="Get a drink" nodeID="315" starttime="14:22:00" type="IntermediateActivity" />
<travel duration="32.0" endtime="14:25:32" node_from="315" node_to="564" route="[315 (7.85, 7.14), 119 (7.35, 7.14), 118 (7.35, 4.79), 15 (10.75, 4.79), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.41" starttime="14:25:00" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="1222.0" endtime="14:45:54" name="Research" nodeID="564" starttime="14:25:32" type="SkeletonActivity" />
<travel duration="32.0" endtime="14:46:26" node_from="564" node_to="115" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 110 (0.0, 4.79), 112 (0.0, 0.0), 114 (7.5, 0.0), 115 (7.5, 3.7)] 24.259999999999998" starttime="14:45:54" />
<activity abstractspace="toilet_male (Elevator side)" activitytype="toilet" duration="120.0" endtime="14:48:26" name="Go to toilet" nodeID="115" starttime="14:46:26" type="IntermediateActivity" />
<travel duration="32.0" endtime="14:48:58" node_from="115" node_to="564" route="[115 (7.5, 3.7), 114 (7.5, 0.0), 112 (0.0, 0.0), 110 (0.0, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.259999999999998" starttime="14:48:26" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="641.0" endtime="14:59:39" name="Research" nodeID="564" starttime="14:48:58" type="SkeletonActivity" />
<travel duration="21.0" endtime="15:00:00" node_from="564" node_to="527" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 510 (12.04, 2.66), 511 (13.04, 2.66), 512 (14.04, 2.66), 513 (15.04, 2.66), 524 (15.04, 2.16)] 15.5" starttime="14:59:39" />
<activity abstractspace="meetingspace (9.27: small meeting room)" activitytype="meeting" duration="2898.0" endtime="15:48:18" name="Give student coaching" nodeID="527" starttime="15:00:00" type="SkeletonActivity" />
<travel duration="21.0" endtime="15:48:39" node_from="527" node_to="564" route="[524 (15.04, 2.16), 513 (15.04, 2.66), 512 (14.04, 2.66), 511 (13.04, 2.66), 510 (12.04, 2.66), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 15.5" starttime="15:48:18" />
<travel duration="33.0" endtime="15:49:12" node_from="564" node_to="4" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 113 (10.75, 4.79), 166 (10.75, 2.66), 63 (10.75, 1.5), 64 (18.2, 1.5), 317 (18.2, 3.23), 4 (17.43, 3.23)] 24.82" starttime="15:48:39" />
<activity abstractspace="printercorner (floor 9)" activitytype="printer" duration="60.0" endtime="15:50:12" name="Walk to printer" nodeID="4" starttime="15:49:12" type="IntermediateActivity" />
<travel duration="33.0" endtime="15:50:45" node_from="4" node_to="564" route="[4 (17.43, 3.23), 317 (18.2, 3.23), 64 (18.2, 1.5), 63 (10.75, 1.5), 166 (10.75, 2.66), 113 (10.75, 4.79), 560 (5.22, 4.79), 562 (5.22, 7.34), 564 (5.72, 7.34)] 24.82" starttime="15:50:12" />
<activity abstractspace="workplace_? (floor 9)" activitytype="work" duration="3351.0" endtime="16:46:36" name="Research" nodeID="564" starttime="15:50:45" type="SkeletonActivity" />
<travel duration="17.0" endtime="16:46:53" node_from="564" node_to="112" route="[564 (5.72, 7.34), 562 (5.22, 7.34), 560 (5.22, 4.79), 110 (0.0, 4.79), 112 (0.0, 0.0)] 13.059999999999999" starttime="16:46:36" />
    </movementpattern>
</employee>

Samenvatting (Dutch summary)

Betrouwbare data over menselijke bewegingen in (kantoor)gebouwen is schaars. Terwijl zulke gegevens erg relevant kunnen zijn. Denk bijvoorbeeld aan het toetsen van de veiligheid van gebouwen. Gebouwsimulatie is tegenwoordig een integraal onderdeel van het ontwerpproces. Eén van de belangrijkste tekortkomingen is het feit dat je met de bestaande systemen niet goed het gebruik van het gebouw door de bewoners kunt simuleren. Simulaties zijn tot nu toe voornamelijk gebaseerd op aannames over menselijk gedrag in de gebouwde omgeving. Kennis over het normale, dagelijkse patroon van activiteiten en bewegingen van mensen in (kantoor) gebouwen is beperkt Dit was de aanleiding voor de ontwikkeling van een systeem waarmee met behulp van waarheidsgetrouwe gegevens over de desbetreffende organisatie het ruimtegebruik van een kantoorgebouw voorspeld kan worden: de User Simulation of Space Utilisation (USSU).

Het leven van veel mensen wordt beïnvloed door kantoorgebouwen, aangezien men er vaak een flink deel van zijn tijd doorbrengt. Het systeem (en het onderzoek naar de werking van het systeem) richtte zich op de invloed van het gebouwontwerp op het menselijke gedrag. Met het systeem kunnen niet alleen bestaande situaties worden geanalyseerd, maar ook nieuwe gebouwen worden getoetst met het digitale ontwerp als

invoer. Relevant voor architecten, als middel om het functioneren van een gebouwontwerp te toetsen.

Om het menselijke gedrag in kantoorgebouwen realistisch te kunnen voorspellen, zijn er twee typen van activiteiten gedefinieerd: werkgerelateerde activiteiten en tussentijdse, meer sociale of persoonlijke activiteiten. De werkgerelateerde activiteiten zijn de zogenaamde kernactiviteiten: activiteiten gekoppeld aan de workflow van de organisatie, bijvoorbeeld het verrichten van onderzoek of het begeleiden van studenten. Veel werkgerelateerde activiteiten vereisen interactie. Eén van de nieuwe aspecten van USSU is de mogelijkheid om de interactie tussen gebruikers bij het uitvoeren van kernactiviteiten mee te nemen in de analyse. Wat het realisme van de simulatie sterk vergroot. Het tweede type activiteiten houdt geen direct verband met de organisatie en het soort werk dat de medewerkers verrichten, maar is voornamelijk afhankelijk van hun psychologische en sociale behoeftes. Dit zijn de zogenaamde tussentijdse activiteiten, bijvoorbeeld het halen van een kop koffie, roken of het maken van een praatje. De meeste tussentijdse activiteiten hebben een beperkte duur van tien tot twintig minuten. Ofschoon een medewerker het merendeel van zijn tijd besteedt aan de kernactiviteiten, zijn het de tussentijdse activiteiten die verantwoordelijk zijn voor het meeste bewegingsgedrag van mensen in kantooromgevingen.

Om de verzameling van activiteiten te benoemen, is in deze context het woord "agenda" gebruikt (zie Tabel 1). Voor het genereren van de agenda's heeft USSU gedetailleerde gegevens nodig over de organisatie (zoals functie-indeling en organisatiestructuur) en het te analyseren gebouwontwerp (zoals werkruimte-indeling en locaties van faciliteiten). Bovendien heeft USSU gegevens nodig over de tussentijdse activiteiten. Die activiteiten worden voorspeld aan de hand van parameters als de gemiddelde frequentie en duur. Deze gegevens staan los van de specifieke organisatie en het gebouw en kunnen in principe hergebruikt worden voor de analyse van een ander gebouw. Op basis van deze gegevens kan USSU de agenda's genereren en het ruimtegebruik voor de desbetreffende organisatie voorspellen. De kracht van USSU is dat het systeem geen gebruik maakt van theoretische aannames, maar van waarheidsgetrouwe gegevens die al beschikbaar zijn in de organisatie, bijvoorbeeld bij personeelszaken.

Activiteit	Starttijd	Eindtijd	Locatie
Programmeren	09:29:06	09:35:36	Werkplek 9.13 (kantoor)
Thee halen	09:35:36	09:38:24	Pantry
Programmeren	09:38:24	09:41:06	Werkplek 9.13 (kantoor)
Lesgeven	09:41:06	12:18:54	Collegezaal hall 2
Programmeren	12:18:54	13:02:31	Werkplek 9.13 (kantoor)
Lunchen	13:02:31	13:27:31	Kantine
Programmeren	13:27:31	13:58:50	Werkplek 9.13 (kantoor)
Bijwonen van een vergadering	13:58:50	17:00:00	Vergaderruimte 9.20

Tabel 1: Voorbeeld van een agenda.

USSU genereert voor iedere medewerker in de te analyseren organisatie een activiteitenagenda die het gedrag van het individu beschrijft (zie Figuur 1). Na het laden van de gewenste invoergegevens heeft de gebruiker van USSU geen invloed op het

genereren van deze agenda's. USSU bepaalt zelf hoe de diverse activiteiten gepland worden en bijvoorbeeld hoe de eerder genoemde interactie tussen de kernactiviteiten plaatsvindt. Iedere keer dat USSU wordt gebruikt om een gebouw te simuleren, resulteert dat in een verzameling agenda's voor alle medewerkers van de organisatie. Deze agenda's zullen echter per keer dat USSU wordt gestart, verschillen. Door een zekere variatie (onder meer bij het plannen van de tussentijdse activiteiten) zal de voorspelling van USSU steeds enigszins verschillen, zelfs wanneer dezelfde invoergegevens worden gebruikt. Net als in de werkelijkheid zal de agenda van een medewerker dus van dag tot dag variëren.
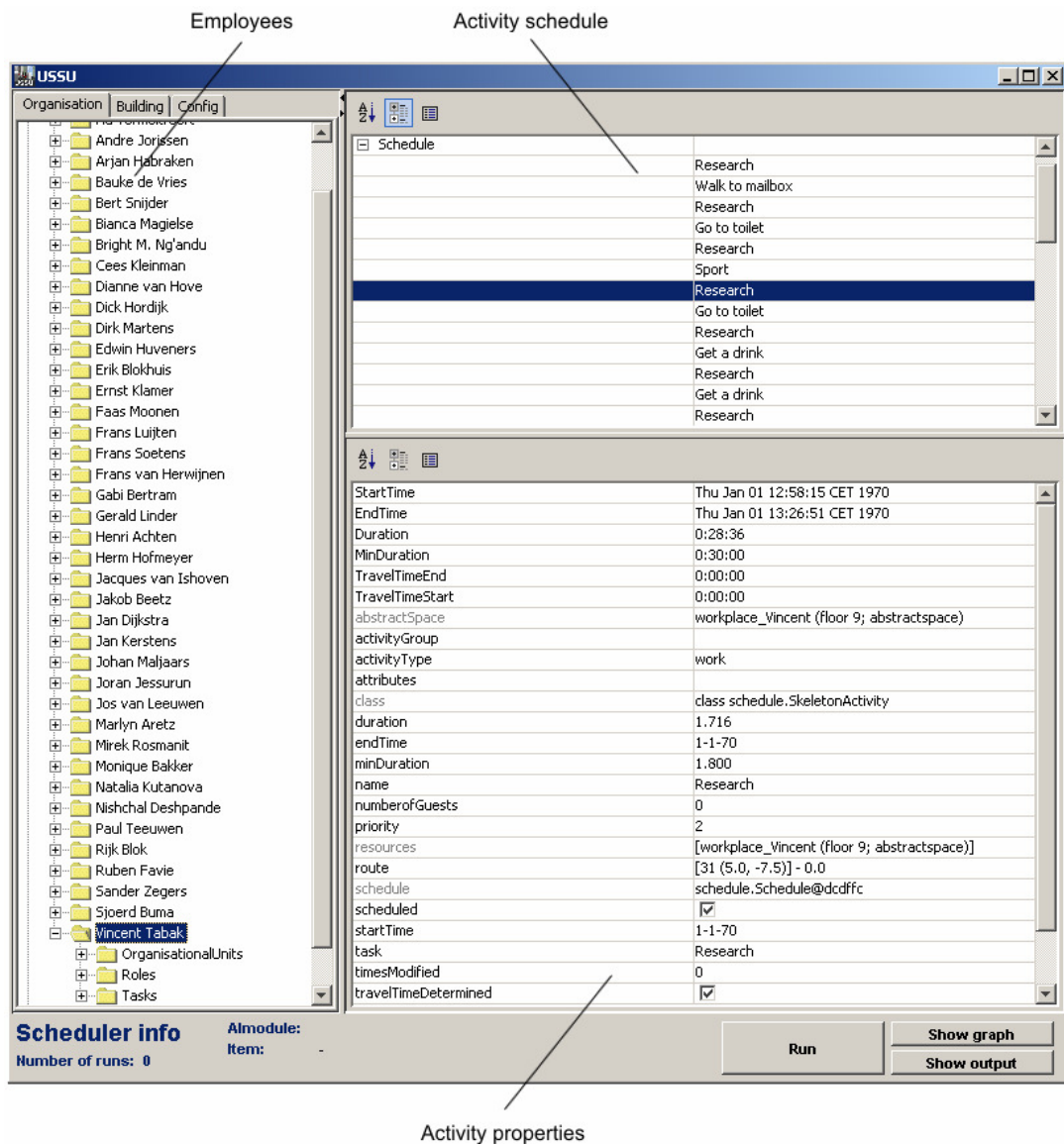
Figuur 1: Prototype van USSU inclusief gegeneerde agenda voor een medewerker.

Een belangrijk deel van het onderzoek richtte zich op het valideren van USSU. Het doel van de validatie was te bepalen hoe precies USSU het ruimtegebruik van een organisatie kan voorspellen. De nauwkeurigheid werd bepaald door agenda's, gegenereerd met USSU, te vergelijken met agenda's geobserveerd in de echte wereld.

Een letterlijke vergelijking van voorspelde en geobserveerde agenda's was echter niet zinvol, omdat zowel de voorspelde als de geobserveerde agenda's per dag zullen verschillen, ondermeer in volgorde en duur van de diverse activiteiten. Wanneer echter wordt gekeken naar de gemiddelde tijd die een medewerker besteedt aan een bepaald type activiteit, dan zullen die gegevens overeen moeten komen. De voorspelde en waargenomen agenda's werden daarom onder meer vergeleken op basis van de gemiddelde tijdsbesteding per activiteit. Verder zijn beide typen agenda's op basis van een beperkt aantal criteria vergeleken: gebruik van werk- en vergaderruimtes, de loopafstanden en het gebruik van faciliteiten.

Om de validatie uit te kunnen voeren, waren gegevens nodig over het daadwerkelijk gedrag van mensen in een kantooromgeving. De negende vloer van Vertigo werd gekozen als context voor de validatie van USSU (zie Figuur 2). Twee experimenten zijn uitgevoerd op de vloer om zoveel mogelijk gegevens te verzamelen over het activiteitengedrag van onze collega's. In het eerste, kleinschalige experiment werd aan de directe collega's van Ontwerpsystemen gevraagd om een agenda bij te houden van hun dagelijkse activiteiten en de locaties daarvan. Daarvoor is een web-based agendasysteem ontwikkeld. Uiteindelijk resulteerde dit experiment in gedetailleerde agenda's van negen medewerkers.

Figuur 2: Gesimuleerde kantoor omgeving.

Met een tweede, grootschaliger experiment werd het bewegingsgedrag van mensen middels RFID (Radio Frequency Identification)-technologie bestudeerd (zie Figuur 3). Dit experiment maakte aanzienlijk minder inbreuk op het gedrag van de deelnemers. De deelnemers hoefden alleen een kleine, zogenaamde RFID-tag (een mini radiozender) bij zich te dragen. De signalen van de RFID-tags werden automatisch geregistreerd door 16 ontvangers, geïnstalleerd op vloer negen. Het systeem van zenders en ontvangers maakte het mogelijk om het (bewegings)gedrag van onze collega's op de hele vloer te bestuderen, zonder dat het gedrag (teveel) beïnvloed werd door het systeem. Aan dit experiment deden in totaal 37 collega's mee. Beide experimenten werden gelijktijdig uitgevoerd voor een duur van drie maanden en resulteerden in twee grote, gedetailleerde dataverzamelingen over het ruimtegebruik en bewegingsgedrag van mensen op vloer negen.
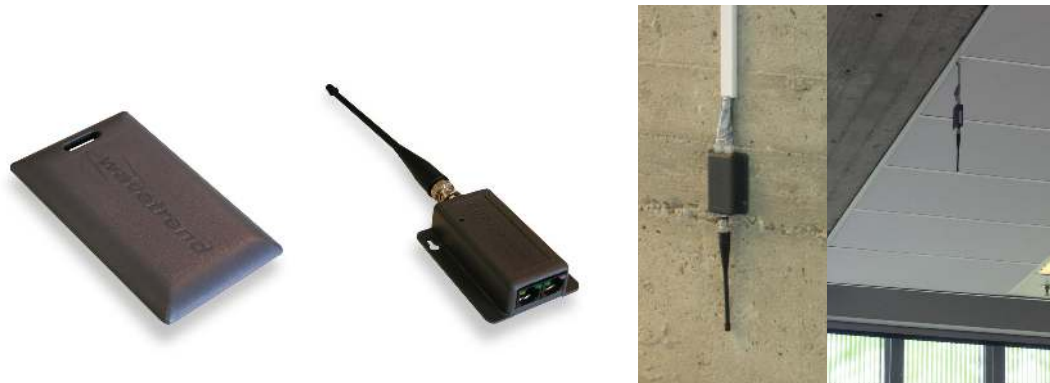
Figuur 3: RFID zenders (tags) en ontvangers (receivers)

In totaal werd het ruimtegebruik van de vloer voor vijftig werkdagen gesimuleerd. Op die manier konden extremiteiten in het (bewegings)gedrag ondervangen worden en werd een dataverzameling verkregen die het gemiddelde gedrag op de vloer voorspelt. Vervolgens zijn beide dataverzamelingen met elkaar vergeleken om de nauwkeurigheid van USSU vast te stellen. Om de goodness-of-fit te bepalen, is een combinatie van twee statistische testen gebruikt, namelijk de student's *t*-test in combinatie met de correlatie-coëfficiënt en de variabiliteit-test.

Uit de validatie bleek dat er geen significante verschillen bestonden tussen het voorspelde en waargenomen (bewegings)gedrag. Enige uitzondering was de gemiddelde gebruiksfrequentie van werkplekken. De bevindingen werden versterkt door het feit dat de resultaten van de twee statistische testen elkaar ondersteunden en allemaal in dezelfde richting wezen. Conclusie: USSU kan worden gebruikt voor het correct voorspellen van het ruimtegebruik door medewerkers in een kantoorgebouw. Daarnaast toont de validatie van USSU aan dat RFID-technologie goed geschikt is om op een niet opdringerige wijze gegevens te verzamelen over menselijk (bewegings)gedrag in de gebouwde omgeving.

Curriculum Vitae

Vincent Tabak was born in 1978 in Veghel, village in the neighbourhood of Eindhoven, the Netherlands. In 1996 he started his study at the faculty of Architecture, Building, and Planning at the Eindhoven University of Technology. He graduated in 2003 from the group Design Systems, which is part of the research school Design & Decision Support Systems obtaining the degree of Master of Science. In his graduation project he developed an interactive urban design tool in conjunction with the municipality of Tilburg to improve the interaction between urban planning and urban design. In the same year Vincent joined the Design Systems group as PhD student. His PhD project "User Simulation of Space Utilisation" focussed on developing a system for the simulation of human movement and utilisation of space capacity in office buildings.

Since September 2007 Vincent is a people flow analyst in SMART, Buro Happold's advanced analysis and simulation team, in Bath, UK. Buro Happold is an international multi-disciplinary engineering consultancy. He has delivered various people flow projects, ranging from schools to airports. He also leads the further development of SMART Move, a dynamic network simulation tool to model complex scenarios of people movement through a 3D network.