Lauri Koskela

An exploration towards a production theory and its application to construction

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Lauri Koskela

VTT Building Technology

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puh. vaihde (09) 4561, faksi (09) 456 4374

Statens tekniska forskningscentral (VTT), Bergsmansvägen 5, PB 2000, 02044 VTT
tel. växel (09) 4561, fax (09) 456 4374

Technical Research Centre of Finland (VTT), Vuorimiehentie 5, P.O.Box 2000, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 4374

VTT Rakennustekniikka, Rakentaminen ja kiinteistönhallinta, Kivimiehentie 4, PL 1801, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 6251

VTT Byggnadsteknik, Byggande och fastighetsförvaltning, Stenkarlsvägen 4, PB 1801, 02044 VTT
tel. växel (09) 4561, fax (09) 456 6251

VTT Building Technology, Construction and Facility Management,
Kivimiehentie 4, P.O.Box 1801, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 6251

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Abstract

This thesis endeavors to answer to two specific questions. Is it possible to formulate a theory of production? Does such a theory add to our understanding and lead to improved performance when applied to construction?

The answer to the first question is sought by reviewing the history of production thinking both from the scientific and the industrial points of view. Historical analysis reveals that three different conceptualizations of production have been used in practice and conceptually advanced in the 20th century. In the first conceptualization, production is viewed as a transformation of inputs to outputs. Production management equates to decomposing the total transformation into elementary transformations, tasks, and carrying out the tasks as efficiently as possible. The second conceptualization views production as a flow, where, in addition to transformation, there are waiting, inspection and moving stages. Production management equates to minimizing the share of non-transformation stages of the production flow, especially by reducing variability. The third conceptualization views production as a means for the fulfillment of the customer needs. Production management equates to translating these needs accurately into a design solution and then producing products that conform to the specified design.

It is argued that all these conceptualizations are necessary, and they should be utilized simultaneously. The resulting transformation-flow-value generation model of production is called the TFV theory of production. It is noteworthy that this same new conceptualization also applies to product design and development, as revealed by a historical analysis of this field.

But does this explicit theory help us with regard to construction? In various countries, construction has long since suffered from productivity and quality problems. A case study and the results of prior research on contemporary construction show that there are endemic management problems associated with both client decision-making, design management and construction management. An interpretation based on the TFV theory reveals that a significant part of these problems are self-inflicted, caused by the prevailing, limited view on production. Thus, the TFV theory largely explains the origins of construction problems.

When initial implementation by pioneering companies of the construction industry is studied it is also clear that methods based on the TFV theory bring manifest benefits. Thus, the TFV theory of production should be applied to construction. The theory explains the problems in contemporary construction, and suggests vastly improved efficiency.

The answer to the research questions can thus be summarized shortly. It is possible to formulate a theory of production, which also provides a new theoretical foundation for construction. The resultant TFV theory, even in its emergent state, already provides direction for experimentation and creation of new understanding and capabilities, both regarding construction research and practice.

Preface

The starting point for the research effort described in this dissertation was my stay at the Center for Integrated Facility Engineering (CIFE), Stanford University, in 1991–92. During this stay, I became convinced that many, if not most, problems of construction are due to deficiencies of theory. Since then, I have had the opportunity of further developing these ideas both in my work at VTT and, during the winter 1993–94, at CSIRO, Melbourne. Invaluable motivation has been provided by the International Group for Lean Construction (IGLC), formed in 1993. This group has organized an annual seminar, providing a forum for exchange of ideas and experiences. Of all the people associated with IGLC, I want to particularly mention the initiatives and contributions of Professors Glenn Ballard and Greg Howell.

At VTT Building Technology many present and former colleagues have participated in projects and discussions relating to new construction management methods, and have thus directly and indirectly contributed to the formation of ideas in this dissertation. I want especially mention Messr. Pekka Huovila, Mika Lautanala, Kalle Kähkönen, Matti Hannus and Petri Laurikka. The contributions of Dr. Pertti Lahdenperä and Mr. Veli-Pekka Tanhuanpää have been indispensable: the former for creating conditions for this project in the STAR research program of VTT Building Technology, and the latter for his invaluable field work and data analysis for a case study.

My supervisor, Professor Eero Eloranta, from Helsinki University of Technology, has directed my research wisely at critical moments. I have frequently had useful discussions with Professor Ari Vepsäläinen, from the Business School of Helsinki, and architect Esa Vepsäläinen regarding problems of research in general and methodology in particular.

A draft of this thesis has been commented on by Messr. Glenn Ballard, Greg Howell, Pekka Huovila, Abdul Samad Kazi, Hannu Kurki, Jarkko Leinonen and Esa Vepsäläinen. I want to thank them for their valuable criticism. I would like to thank Mrs. Eryl Howard for making valuable linguistic corrections to the thesis.

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Jorma Kivimaa (NCC Puolimatka, Unit for Western Finland) for providing the opportunity to carry out in-depth case research on a construction project. Regarding implementation of new production principles in construction, information has been provided by Messr. Matthew Bacon (BAA), Jan-Eric Johnson (Arcona), Sezar Robinson (Goldsztein), Yoshiyuki Suzuki (Sekisui) and Jim Teston (TDIndustries).

The preparation of the dissertation has been funded by VTT Building Technology. I am most grateful for this opportunity to carry out research requiring a long time of maturation.

Finally, I would like to thank my wife Karoliina and my son Mikael for their love and support during this effort.

I dedicate this work to the memory of my parents.

Espoo, March 2000

Lauri Koskela

Contents

1. Introduction

1.1 Background

The problems of construction are well known (Tucker 1986, Chemillier 1993, WS Atkins... 1993). Construction productivity lags behind that of manufacturing. Occupational safety is notoriously worse than in other industries. The quality of construction is considered to be insufficient.

A number of solutions or visions have been offered to relieve the chronic problems in construction. Industrialization (i.e. prefabrication and modularization) has for a long time been viewed as one direction of progress. Currently, computer integrated construction is seen as an important way to reduce fragmentation in construction, which is considered to be a major cause of existing problems. Robotized and automated construction, closely associated with computer integrated construction, is another solution promoted by researchers. However, at least up till now, there have been no signs of major improvements resulting from these envisioned solutions.

Several scholars of construction have pointed out the lack of a theoretical foundation in construction as a barrier to progress. Halpin (1993) claims that "we have not gone far enough in seeking a basic framework for the construction of facilities". Fenves (1996) calls for a science base for the application of information technologies in civil and structural engineering. One component of this science base would deal with the understanding of the processes of planning, design and management that engineers use.

However, this lack of theoretical foundation is also shared by the discipline of production and operations management in general. It has even been argued that there is presently no science of manufacturing (Heim & Compton 1992, p. 16). Rather, production has been seen as the task of applying existing technology in a systematic way.

Obviously, the creation of theories of production in general or of particular types of production, like construction, is rather a research frontier than a research task for an individual researcher. However, it must be started somewhere. It can be argued that the development of theories should start from the most foundational and generic aspects of production. If these are not conceptualized in an appropriate manner, the more practical principles and methods will systematically inherit the resultant deficiencies.

1.2 Research problem

In view of the discussion above, the research problem in this study is formulated as follows. *Is it possible to point out or to formulate a theory of production that would add to our understanding of a specific production situation, such as occurs in construction, both from a scientific and a practical point of view?*

1.3 Research strategy

The broad research problem, presented above, is composed of two, interrelated questions:

1 *Is there a justified theory of production or is it possible to formulate such a theory?*
2 *Does the theory of production add to our understanding and lead to improved performance when applied to the specific production context of construction?*

The first question is focused on the existence and possibility of a general theory of production. What are the concepts for describing production? What principles for controlling production exist?

To answer the first question, the study considers theories as defined by scientists as well as the major industrial models of the 20th century. What theories have researchers promoted? Which existing theories can be regarded as acceptable from the point of view of empirical validation? Which theories, even if implicit, have actually been used?

The second question addresses the benefits and implications of applying the best theory of production, as found in the former part of the study, in a specific production context, namely in the construction industry. Does the theory add to our understanding of construction? Does it bring about improvement in construction? Does the application of the theory of production to construction add to the validity of the theory?

Methodologically, the second question is approached by means of a case study on a construction project, where the observations are explained by using the theoretical framework created. Furthermore, through short case studies of actual implementation of novel methods of construction management, it is ascertained whether the prescriptions resulting from the theory lead to improved performance.

1.4 Focus and scope

The research problem is approached as an operations management problem. Due to the intrinsic nature of construction, both design and production operations have to be considered. Thus, the research draws on the state of the art in various disciplines focusing on design and production.

The research is mainly focused on building construction. However, the issues raised are directly relevant for other complex assembly-type of construction, like bridges, industrial plants, and to some extent also for other delivery projects of large one-of-a-kind products, like in ship and paper-machine industries.

1.5 Evolution of the research

It would be pretentious to claim that this research progressed systematically as planned. Rather, it evolved rather haphazardly in a series of unexpected discoveries. Given the outcome of this research, which can be understood as suggesting a new theoretical foundation for production management, it is appropriate to describe the evolution of ideas, separately from their systematic presentation and justification.

The original research theme was the application of the new production philosophy to construction – or lean construction, as it has been called by a group of collaborating researchers since 1993. The trigger to selecting this research theme was frustration with the slow maturing of practicable results from research on construction computing and construction automation, with which the author had been involved since 1982. On the other hand, big productivity gains, due to deceptively simple-looking organizational and managerial methods, called first as just-in-time production (JIT) and later as lean production, had been reported from manufacturing since the end of the 1970's. There was a need to learn whether the same methods were applicable in construction, too.

The first discovery concerned the discrepancy between the doctrine of operations management, viewing production as a *transformation*, and the framework forwarded by advocates of JIT, viewing production as a *flow*. On closer analysis, this discrepancy turned out to provide a theoretical explanation for both the conventional and the new production models. Thus, in effect, the rise of JIT meant an all-encompassing change in the way production was viewed.

The report “Application of the New Production Philosophy to Construction” (Koskela 1992) was the first outcome of this research. In it, consideration was mainly focused on the physical production phase. The next task was to investigate the design phase. Somewhat unexpectedly, it turned out that the approach of concurrent engineering was largely based on the same theoretical foundation as lean construction. Further experimentation in modeling and managing design gave greater insight into specific features of design. In particular, it turned out that there is a need for a third, independent conceptualization, addressing the *generation of value*.

Gradually, the view strengthened that it is not only important to understand the theory of lean production, but the theory of production in general. Lean production had augmented the earlier theoretical basis of production, rather than substituted for it. In several instances, the observation was made that not even the prescriptions of the earlier theory were followed, resulting in problems. Thus, the theme of the study shifted from lean construction to production theory and its application to construction.

1.6 Contents

The thesis consists of two main parts (besides introductory and concluding chapters). The first part, addressing theories of production in general, comprises Chapters 2–7. In Chapter 2, it is clarified what a theory of production means and whether such a theory already exists. In Chapter 3, the transformation-oriented concept of production, as applied in manufacturing for the major part of the 20th century, is presented. Chapter 4 presents an overview on the flow-oriented concept of production, the underlying theory in lean production. Chapter 5 presents the value-oriented concept of production, originating in the quality movement. Chapter 6 consolidates the partial concepts into an integrated view on production, called the TFV concept of production. Chapter 7 analyzes product design and development from the point of view of the TFV concept.

The second part of the thesis, comprising Chapters 8–11, focuses on the application of the theory of production, as defined in the first part, to construction. Chapter 8 analyzes the theory and practice of contemporary construction as described in the literature. The causes of chronic performance problems of construction are investigated, based on a case study and prior research, in Chapter 9. Chapter 10 analyzes the characteristics of production systems in construction. In Chapter 11, an investigation into what can be learned from construction implementation of approaches containing elements from the TFV concept is carried out.

Finally, in Chapter 12, the results of this study and their implications for construction management are discussed. In Chapter 13, the findings of this research are summarized.

2. In search of a theory of production

Why do we need a theory of production? Is there a theory of production? These questions are the subject of this chapter. We first discuss the notion of scientific theory in general and the specific notion of "theory of production" and then proceed to set the requirements for a theory of production as applied in this thesis. Finally, we investigate whether a theory of production already exists.

2.1 What is a scientific theory?

2.1.1 About terms

At the outset it is necessary to note that the term *theory* is used in several different ways, and that also other terms are commonly used for conveying the meaning of theory as it is used in this study. The terms *theory* or *theoretical* are actually used in three different, although partially overlapping, ways[i]:

- Opposition to practice, non-practical
- Hypothetical speculation and "not dealing with facts as presented by experience"
- General principles of any science or field.

In this presentation, the terms *theory* or *theoretical* are used primarily in the last sense indicated above. However, the usage of terminology is not coherent. Often, terms like *foundation*, *philosophy, paradigm, first principles*[ii]*, system* and *model* are used instead of the term theory. The term *doctrine*[iii] refers especially to such a theory that is taught by a scientific discipline.

2.1.2 Functions of theory

The common view is that theories address to two goals of science: explanation (or understanding) and prediction (Dubin 1978, Deutsch 1997*)*. Prediction refers to the capability of a theory to foretell the behavior of the system considered. The validity of a theory is usually tested by investigating its capability to predict. Understanding (or explanation) is more difficult to define. Dubin holds that understanding is knowledge about the interaction of units in the system considered. Similarly, Deutsch characterizes explanations that lead to understanding as being about "why" rather than "what" and about the inner workings of things. Whether theories should always include an explanation (in addition to prediction) is a disputed topic in the philosophy of science. Deutsch argues that explanation also plays a role in the growth of scientific knowledge: theories are – and should be – rejected because they contain poor explanation, not only because they fail in experimental tests on their prediction capability. This position is accepted in this study.

2.1.3 Elements of a scientific theory

Whetten (1989) argues that when introduced, a theory, for being complete, must contain four essential elements:

- What. Which factors (variables, constructs, and concepts) logically should be considered as part of the explanation of the phenomena of interest?
- How. How are factors related? Here, causality is introduced.
- Why. What is the rationale that justifies the selection of factors and the proposed causal relationships? An explanation[iv] is required.
- Who, Where, When. The boundaries of generalizability and thus the range of the theory have to be set.

Whetten comments that the last element, the boundaries of the theory, is often the least developed area.

2.1.4 Evolution of theories

How do theories develop? An appropriate starting point for the discussion of this issue is provided by the influential views of Kuhn on scientific paradigms and their development. The concept of paradigm is broader than the concept of theory: in addition to theory, it includes implicit rules of carrying out research.

According to Kuhn (1970), the progress of science is characterized by two distinct modes of inquiry. *Normal science* consists of research firmly based on past scientific achievements, acknowledged by a particular scientific community as supplying the foundation for further practice. These achievements share two characteristics: they were sufficiently unprecedented, and they were open-ended to leave unsolved problems. One aspect of a paradigm is that it defines a criterion for choosing problems that can be assumed to have solutions. Kuhn compares this to puzzle solving. Thus, normal science is highly cumulative and successful. It consists of three classes of problems: determination of significant facts, matching of facts with theory (testing), and articulation of theory.

Kuhn calls the other mode of inquiry scientific revolution or *paradigm change*. It is initiated by *anomalies*, the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science. It continues with an exploration of the area of inquiry and closes when the paradigm theory has been adjusted. However, novelty emerges only with difficulty and resistance, and this period can be characterized as science in crisis.

The situation after paradigm change is described by Kuhn as follows:

> ...[I]t is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications. [...] When the transition is complete, the profession will have changed its view of the field, its methods, and its goals.

From another angle, Deutsch (1997) has interestingly discussed development of theories. The growth of science has led to specialization, resulting from the emergence of a great number of theories on any subject. This leads easily to the view that it is more and more difficult for an individual to understand all what is known. However, Deutsch argues that there is a countercurrent to specialization, namely unification through fewer, deeper and more general (broader) theories. By "deeper" he means that each of them explains more than its predecessors did. By "more general" he means that each of them says more, about a wider range of situations, than several distinct theories did previously. Indeed, at least in the natural sciences, some great advances in understanding have come about through unification.

2.2 Production: theory and practice

Next, the specific features of a theory of production are discussed.

2.2.1 Theory of production is prescriptive

We have to note the essential difference between natural and behavioral sciences, as discussed above, and the disciplines addressing production, like operations management. Whereas description of nature is the ultimate goal of science, operations management, like any managerial science, also purports to provide prescription for action.

This is commonly acknowledged in production science[v]. Thus, the Committee on Foundations of Manufacturing, assembled in 1989 by the National Academy of Engineering of the United States, calls for the development of "foundations of manufacturing" (Heim & Compton 1992):

> The foundations for a field of knowledge provide the basic principles, or theories, for that field. Foundations consist of fundamental truths, rules, laws, doctrines, or motivating forces on which other, more specific operating principles can be based. While the foundations need not always be quantitative, they must provide guidance in decision making and operations. They must be action oriented, and their application should be expected to lead to improved performance.

Umble and Srikanth (1990), who require a manufacturing philosophy to contain the following elements, provide another interesting characterization:

- Definition of the common goal in terms that are understandable and meaningful to everyone in the organization
- Development of causal relationships between individual actions and the common global goal
- Guidelines for managing the various actions so as to achieve the greatest benefit.

Thus, the theories of production can be illustrated as in Figure 1. When considering an approach to production, we can discern three layers. The top-most level contains the conceptual notions of the approach. It answers the question: what is production? The intermediate level consists of principles, heuristics, etc., which describe the relations between the concepts[vi]. The two uppermost levels roughly correspond to the notion of theory. The bottom level consists of methods, tools, practices, etc., which embody the respective concepts and principles and which thus convert the theory into practical action.

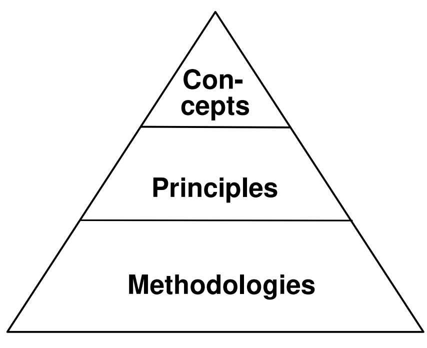

Figure 1. Practical methodologies are based on concepts and principles.

Development of a theory may occur in two directions: top-down or bottom-up. The former situation is typical when a scientist-originated method is marketed to the practice. In the latter case, new methods are applied without an explicit conceptual and theoretical foundation. Eventually the efforts of scientists also move towards clarification of concepts and theory.

In reality, to what extent there has been theory development in either direction? There are very few examples of theory-led development of production management (analysis of the development of production management in Chapters 3–5 will provide evidence for this). Academic production science has taken the role of interpreter, analyzer, critic, systematizer, observer and recommender, rather than the role of innovator[vii].

How, then, has the operations management discipline managed to articulate the theory of production based on methods used in practice, and to test its validity? The track record of production science in this regard is poor. Bloch goes as far as to argue that there is presently no science of manufacturing (Heim & Compton 1992, p. 16). Rather, production has been seen as the task of applying existing technology in a systematic way. The lack of explicit, coherent theories seems to be a common problem in the sphere of production and related engineering sciences. This situation seems to have developed under the influence of the dominating paradigm in operations/production management, focusing on abstract application of techniques and rarely involving empirical or theoretical studies. The attitude to theory has been negative, equating theory with lack of practical applicability (Filippini 1997). It is only in the 1990s that a number of researchers have argued for the importance of theories[viii] (Meredith 1992, Westbrook 1994, Hopp & Spearman 1996, Filippini 1997).

2.2.2 Production paradigms

Although originally used to refer to scientific activity, the concept and metaphor of paradigm is now used in many other contexts as well to describe the alternation of “normal” endeavor and the change from it. By techno-economic paradigm change, Freeman and Perez (1988) mean a radical transformation of the prevailing engineering and managerial common sense to best productivity and most profitable practice, which is applicable in almost any industry. Ranta (1993) states that *production paradigm* is the prevailing rationality, which controls the development of production as well as the use of production methods, tools, and knowledge.

It has to be noted that independently of the pursuits of production science, production paradigms are based on – mostly implicit – theories. Let us call these, following the example of Argyris and Schon (1978), theories-in-use, for differentiating them from the scientific theories.

As discussed already above, the development of production management has largely been due to advances achieved by practitioners, rather than advances achieved by scientists (Buffa 1961). It has been more a question of a succession of production paradigms than of a succession of paradigms of the discipline of production management. This poses several questions. How do production paradigms develop? What is the role of the scientific theory and paradigm, anyway?

First it has to be noted that there are several similarities between scientific and production paradigms, most notable the significance of exemplars for the promotion of the paradigm, and the direction given regarding search for improvements.

Historical analysis shows that exemplars of new production system, such as the Ford production system and the Toyota production system have played a crucial role in the succession of production paradigms. In these exemplars, all major aspects of production have, for the first time, consistently been realized on the basis of a new theory of production. In this study such concrete embodiments of a production paradigm are called *production templates*. The distinguishing feature of production templates is the fit or synergy between the various parts of the production system[ix].

As in science, a production paradigm directs and simultaneously restricts the search for improvements. It seems that a production paradigm in itself contains a recommendation for improvement, as, say, in mass production, on an increasing scale. The refinement of the template is another natural direction of progress (corresponding to normal science in Kuhn´s presentation).

However, it is necessary to keep in mind the essential differences between paradigms in science and production. The scientific paradigm is put forward by a scientific community; the progress of production paradigm is primarily propelled by the competition between firms, and diffusion in professional communities. The differences in aims and backgrounds contribute to two essential differences. In production, the criterion of an idea is its potential for inducing action in the short term, and benefits in the longer term, rather than its ability to explain and predict. In production, the underlying theory is not explicit.

The utilization of ideas in management for inducing action has been interestingly considered by Eccles and Nohria (1992). The constant competition in the realm of management causes a considerable demand for new ideas. This demand is satisfied by buzzwords and fads, initiated by leading practitioners, consultants, journalists and even academics. Even if management is about action, managers can create action only through rhetorics, i.e. persuasion. Eccles and Nohria advice managers to feel free to use buzzwords, if they have broad organizational legitimacy and clearly have something to offer, to their own ends[x] (that is, giving them a meaning of their own). However, in such a situation, it cannot be hoped that new concepts would become clarified and explained in the framework of a production paradigm. In addition, often a concept exists simultaneously both in the realm of management, as a buzzword, and in production science[xi], resulting in confusion.

However, whether the theory is explicit or not makes a crucial difference. There are several problems associated with implicit theories. Such theories are not generalizable or testable; their domain of feasibility is not known, so applying them to new situations is problematic; their transfer and teaching is difficult. Thus, the diffusion of a production paradigm takes the form of imitation of templates and implementation of methods and practices (that is, on a low abstraction level[xii]).

Thus, even if the development of production paradigms, initiated, diffused and refined in the framework of the community of production practitioners and professionals, is a powerful change factor, it has serious deficiencies. The role of production science is to complement the development of production paradigms through means it has at its disposal[xiii].

2.2.3 Validity of theories on production

The issue of validity of theories on production has been little discussed in the discipline of operations management[xiv]. However, analysis shows that this is an intricate and paradoxal subject.

The first difficulty is the requirement that a theory of production should be both a good model of its subject and useful in practical applications. Kochikar and Narendran (1994) aptly require that an abstract model should have both modeling power and decision power. For Yoshikawa (n.a.), the usefulness in the practical world is the only criterion of validity.

The relation between the degree of validation and the industrial interest towards the validation produces a paradox. The fact is that most theories-in-use have never been scientifically validated. However, if we view industrial practice as a large testing laboratory, we can say that the theories-in-use have been validated from industrial point of view. However, this has deficiencies with regard to the planning, selection, execution and evaluation of experiments.

This lack of scientific validation has stimulated a rich flora of research[xv] where, for instance, the impact of JIT production is investigated and the prescription implied by JIT is thus validated. However, from industrial point of view, such studies have little to offer.

On the other hand, new methods and practices not yet adopted by competitors or currently being adopted by them are particularly interesting from industrial point of view. A weaker form of validation, like an existing explanation or the observed functioning of the method in another company is enough for industrial experimentation or pilot implementation[xvi].

Thus, we have a paradox. When a production theory gets scientifically validated, it has already been used in practice for a long time, and the validation is of little value from the practical point of view (in fact, we could call this archival validation). Instead, the interest of practice is focused on theories so new that their validation can be shallow at best.

Obviously, we need to define different levels of validation or justification. Already a mere explanation provides the weakest level of justification, which can be added to by successful pilot implementations. The next level would be a successful full-scale implementation. On the other hand, for theoretical propositions to be taken into the doctrine of production management, a higher level of validation is needed.

This resembles the suggestion made by Kasanen et al. (1991). They suggest two types of validity tests, weak market test and strong market test. The former test asks whether at least one manager has actually implemented or experimented with the system developed by a researcher. The latter test refers to normal empirical validation where the impacts of the use of the system are compared with the baseline.

The conclusion that can be drawn from this discussion is that we have to consider validity in relative terms, in relation to the purposes at hand.

2.2.4 Functions of a theory of production

Firstly, a theory of production has the same functions as theories in general. On the basis of discussion above, these can be summarized as follows:

- *Explanation.* A theory provides an explanation of observed behavior, and contributes thus to understanding.

- *Prediction.* A theory provides a prediction of future behavior; in the case of production, especially of the contribution of action to goals.
- *Direction.* A theory pinpoints the sources of further progress.
- *Testing.* When explicit, it is possible to constantly test the theory to prove its validity.

Secondly, however, the functions of theory are more wide-ranging in the case of production management than in the case of natural and behavioral sciences. It will not only serve to research but also to practice. An explicit and adequate theory of production will provide the following functions, in addition to those presented above:

- *Tools for decision and control.* On the basis of a theory, tools for analyzing, designing and controlling production can be built (Kochikar & Narendran 1994).
- *Communication.* A theory, when shared, provides a common language or framework, through which the co-operation of people in collective undertakings, like a project, firm, etc., is facilitated and enabled (Heim & Compton 1992).
- *Learning.* A theory can be seen as a condensed piece of knowledge: it empowers novices to do the things that formerly only experts could do (Fenves 1996).
- *Transfer.* Innovative practices can be transferred to other settings by first abstracting a theory from that practice and then applying it in target conditions (Lillrank 1995).

2.3 What should a theory of production cover?

What requirements should we set to a theory of production? Setting requirements will help us in the evaluation of existing theories and in the exploration towards the best theory of production.

2.3.1 Core phenomena of production

In modern operations management, it is often thought (Womack & Jones 1996) that production consists of three core phenomena: product development, order-delivery and production proper, which all "face" the customer. These phenomena are interrelated in a complex way, and actually various production types can be distinguished on the basis of the patterns of these interrelationships. In this study, this extended notion of production[xvii] is subscribed to. However, the main emphasis is on product development and production proper; order-delivery is treated in conjunction with production proper.

2.3.2 Different sorts of management action on production

There are three generic actions[xviii], which we would like to be guided by a theory of production:

- Design[xix] of the production system
- Control of the production system in order to get the intended production realized
- Improvement of the production system.

Thus, a comprehensive theory of production should have a bearing on all of these actions.

2.3.3 Different goals of production management

There are no major differences regarding the definition of goals of production. Buffa (1961) mentions cost, consistent with quality and delivery commitments. Wild (1984) suggests that there are two objectives: service and utilization. The primary consideration in customer service is providing goods of a given, requested or acceptable specification, at the right cost and at the right time. The utilization objective equates to achieving agreed levels of utilization of materials, machines, and labor. Slack et al. (1995) list five performance objectives for operations: quality, speed, dependability, flexibility, cost.

Thus, based on views presented above, production appears to have three kinds of goal[xx]:

- The goal of providing the intended products in general (this may seem as so self-evident that it is often not explicitly mentioned)
- Goals related to the characteristics of the production itself, such as cost minimization and level of utilization (internal goals)
- Goals related to the needs of the customer, like functional performance, quality, dependability, flexibility (external goals).

Thus, as discussed above, the theory should contribute to the achievement of the goals of production. However, we could also anticipate that the goals are a part of the theory itself.

2.3.4 Different production situations

Obviously, different production situations should be covered by a theory of production. This must mean that there are situation independent parts of the theory, but also situation dependent. This is illustrated in Table 1, where the theory of production is structured at three levels.

Table 1. The different levels of theory with regard to production.

Conceptualization of production; related universal laws and principles
Taxonomy of production
Design, control and improvement principles for different types of production

In this study, the main focus is on the uppermost level: general concepts and principles of production, which would be valid with regard to all kinds of production situations. The issue of the application of the general principles to one particular type of production will be broached in the second part of this study where construction is the target industry.

On the two lower levels, there has been much more research and theory formation than on the most general level. Production situations differ, as do the suitable principles and techniques. Obviously, the production theory should guide us about which kind of production situation we are handling, and which kind of design and control solutions are appropriate. An example of this is provided by the product/process matrix (Hayes & Wheelwright 1984).

It has to be noted that a "pure" production theory focuses just on the act of production. It does not deal with such issues as what is the nature of machines or humans as workers or how production should be divided among individuals (the problem of organizing). Nor can a theory of production focus on behavioral or change processes, as defined by Garvin (1998). These issues warrant – and have – theories of their own, which have to be interfaced with the theory of production. The focus here is on the pure production theory, even if, in particular, the problem of organizing is occasionally commented on.

2.4 Is there a theory of production?

As stated above, it is easy to find claims on the lack of a theory of production or manufacturing in the operations management literature. However, theories of production have also been proposed. Thus, it is necessary to investigate whether we can justify any of these proposals as a theory of production.

Because it can be assumed that newer theories will be broader and deeper than older theories (as argued by Deutsch 1997), it is appropriate to start the search for a theory of production from the most recent theories. A survey of recent literature gives three major proposals available for a theory of production[xxi]. They will be reviewed in the following sections. The focus will be on the questions: What is the motivation for the theory? How is the theory derived? What is its domain of validity? How is production conceptualized? Which principles are put forward by the theory? How is it justified?

2.4.1 Generalized Walrasian production model

This theoretical framework[xxii] of production has been presented by a team of scholars led by Wortman (1992a); other originators include Rolstadås (1995) and Falster.

As a motivation for the theory, it is stated that the current theory on production is fragmented; consequently, an effort for integration is badly needed. It is a question of unification: "These views can be fit together into a single description scheme which corresponds to earlier developments in the analysis of production systems".

The starting point is "the Walrasian production model", which depicts the transformation process of production factors into finished product. The model is essentially made up of technical coefficients that equal the ratio of transformation between the amount of a certain production factor and the amount produced of a given product. However, there are limitations with this model, and to overcome these, three generalizations are made to it.

The first generalization of the Walrasian production model concerns the so-called Product Graph (P-graph), by means of which the ordering of the product into assemblies, subassemblies and components (bill-of-materials) can be represented, as well as the sequence of operations (routing). The P-graph defines the work to be done.

The second generalization concerns organizational structuring of resources. These are described by the so-called R-graphs, which define how resources are combined and ordered into groups, departments and factories. Resources provide capabilities and capacities. Both group social structure and physical layout are covered in this generalization.

The third generalization extends the Walrasian production model to a dynamic control model, where three control activities are recognized: management of resources, management of products, and coordination and synchronization (referring to the allocation of resources to products). These activities are considered on different time horizons. Indeed, the interconnection between the P-graph and R-graph can be seen as management of production. “The purpose of management is to *release and monitor work orders* for production and engineering” (Rolstadås 1995).

These three generalizations are also called workflow view, resource view and organizational/decisional view. It is claimed that these views are complementary.

Based on this theoretical model, a factory design framework focused on one-of-a-kind production, with several layers, is presented, where design choices and performance indicators are qualitatively connected.

Even if the theory is originally presented for the case of physical production, it is argued that it is applicable also for design and engineering (Rolstadås 1995).

2.4.2 Factory Physics model of manufacturing

This theory of production is presented in the book, “Factory Physics”, by Hopp and Spearman (1996). The authors review the history of manufacturing and analyze, in particular, inventory control models, material requirements planning and just-in-time. These techniques are inadequate for future needs.

Hopp and Spearman define their scope as an operations view on manufacturing. The operations view focuses on the flow of material through a plant. They claim “to seek a science of manufacturing by establishing basic concepts as building blocks, stating fundamental principles as ‘manufacturing laws’, and identifying general insights from specific practices”.

A manufacturing system is defined as follows (italics as in the original):

> A manufacturing system is an *objective*-oriented *network* of *processes* through which *entities flow*.

In this definition, the objective refers to the objective of manufacturing, like high profitability, low costs and high sales. The process refers to physical processes (or indirect steps like order entry, kitting, etc.) which interact with each other in a network. Entities include parts to be manufactured and control information. The flow describes how materials and information are being processed. The authors state that *the management of the flow* is a major part in a production manager's job.

The authors show that by means of queueing theory, various insights, which have been used as heuristics in the framework of JIT, can be mathematically proven. In totality, 15 laws[xxiii] on the behavior of production flow lines are presented. Maybe the most fundamental result regarding production control is that in view of a certain level of variability in production, there is always a penalty in one form or another, even if the control is the best possible. One has to select among three alternatives:

1. Buffering of flows (for increasing the probability that all parts are available at a workstation when needed), which leads to long cycle times and high work-in-progress levels,
2. Accepting lower utilization levels of resources, which equates to acquisition of extra capacity,
3. Accepting lost throughput (due to starvation of workstations).

The last part of the book addresses the practical implementation of this approach to problems commonly encountered in manufacturing[xxiv].

2.4.3 Product realization model

This approach has been described in publications by Cook and his co-authors (Cook 1992, Cook & Gill 1993, Kolli & Cook 1994, Cook & Kolli 1994, Cook 1997). The starting point is the dissatisfaction with the functional organization of product development.

The aim is to develop a common formalism or theory for the entire design and manufacturing process (Cook & Gill 1993). The central idea is to achieve such a structured methodology for product realization that all actions can be based upon their forecasted impact on the bottom-line metrics of product demand, market share, profits, and total quality (Kolli & Cook 1994). For achieving this, such methods as the quality theory of Taguchi, Quality Function Deployment, design of experiments, conjoint analysis, and microeconomic theory are unified into one framework.

One fundamental conclusion drawn is that the enterprise can be managed, in large part, by *managing total quality*, which is a strategic variable that reflects the overall impact of the product on the buyers and the rest of society as well as the profitability of the enterprise. Here quality is defined as the net value of the product to society, depending on the square of the difference between (absolute) value and cost.

In (Cook 1992), it is shown that the natural system/subsystem architectural breakdown of a product provides the best organizational structure[xxv] for developing and manufacturing the product, in the light of the theory developed.

The referenced sources contain several worked examples of how the new methodology can be applied in practice.

2.4.4 Discussion

An overview on these theories is provided in Table 2. Clearly, all these three approaches are (candidate) theories of production in the sense defined above in this chapter. Also, they are claimed to be theories by their originators who are acknowledged scholars[xxvi] in the field.

Table 2. Overview of proposed theories of production.

	Walrasian production model	*Factory Physics model*	*Product realization model*
Motivation	Fragmentation of the existing theory	Deficiencies of existing production control practices	Deficiencies of the functional organization
Strategy of theory formation	Unification of earlier developments in the analysis of production systems	Mathematical modeling by means of queueing theory	Generalization of Taguchi's theory of quality and unification with earlier developments from microeconomics and marketing
Domain	Production, engineering	Manufacturing, especially of "disconnected flow line" type	Product realization process (entire design and manufacturing process)
Conceptuali-zation of production	Transformation	Flow	Provision of total quality (defined as net value of a product to the society)
Goals addressed	Not explicit	Costs, sales	Value-to-the-customer, cost, pace of innovation
Major principles	Decomposition of products and resources	Variability reduction, control strategies	Quality loss reduction
Validity	Illustrative examples of application	Illustrative examples of application	Illustrative examples of application

However, it is somewhat troubling that these theories present not only different principles for management of production, but they disagree also regarding the basic nature of production. The theories proposed provide for three different concepts of production: transformation, flow and value generation. Indeed, the starting points of these theories are so widely different that one could ask whether they, in the first place, refer to the same object of consideration. Or would the situation rather be similar to that in the old story of the blind men encountering an elephant[xxvii]: lacking a view on the whole elephant, each of them claims that an elephant is like the part he happened to touch and examine?

For two of the theories, the rationale for their development has been the lack of a theory of production. In the justification of these theories, no reference is made to competing theories. Production management, as a scientific discipline, is clearly not in such a mature phase that there would be continuity in its theoretical discussion; rather, attempts at theorizing are isolated pursuits and evoke little interest[xxviii]. On the other hand, there is little attempt to provide an empirical proof of these theories.

Let us return to the main question: is there a theory of production? Obviously, the answer is negative. There are proposed theories, but they are widely differing in concepts and principles, and either they all are partial or some of them just not justifiable. There have been few efforts at validating these proposed theories.

A further puzzle is provided by the question: which theories haven been used in production practice? All in all, the tremendous social and economical changes of the 20th century have been based on a growing capability to produce infrastructure and consumer goods. There must have been an underlying theory of production and – judging from the widely increased productive power – it cannot have been without any merit.

2.5 Conclusions

In conclusion, we can now define the requirements for the theory of production we are looking for. A theory of production should have the following explicit elements:

- Concepts describing the phenomena in question
- Principles for pursuing goals and relationships between concepts

- Justification both from epistemic point of view (is this a good representation of reality?) and utilitarian point of view (is this useful?)
- A domain or range of validity.

Furthermore, the theory of production should cover all essential areas of production, especially physical production and product design. It should give guidance in design, control and improvement of production systems. It should contain concepts and principles valid across different production situations.

From the point of view of practice of production management, the significance of the theory is crucial: the application of the theory should lead to improved performance. In reverse, the lack of the application of the theory should result in inferior performance. Here is the power and significance of a theory from practical point of view: it provides a direct benchmark for practice.

A survey of recently proposed theories of production shows that they disagree even regarding the basic nature of production. No theory can be viewed as having more validity than the others. Thus, a valid theory of production does not exist. However, the concepts and associated principles put forward may provide a starting point for a formulation of the theory of production; however, we need a clearer understanding of their mutual relationship and their validity. In order to consolidate understanding accrued in prior analyses, it is necessary to carry out a historical analysis of the conceptual evolution and practical implementation of these concepts. In the following three chapters, the concepts underlying the three theories of production – transformation, flow, value generation – are taken as a starting point, and their evolution and possible implementation in practice are analyzed.

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[i] From The Concise Oxford Dictionary, 1964. Webster's Revised Unabridged Dictionary (1913) gives following meanings to *theory* (shortened): 1. Hypothesis, speculation. 2. An exposition of the general or abstract principles of any science. 3. The science, as distinguished from the art. 4. The philosophical explanation of phenomena.

[ii] The term *first principles* was introduced by Aristotle to refer to fundamental propositions that can be used for justifying other propositions but that do not need, for whatever reason, to be proven by means of other propositions (Ross 1998). In this sense the term is still widely used today.

[iii] *Doctrine* according to Webster's Revised Unabridged Dictionary (1913): 1. Teaching; instruction. 2. That, which is taught; what is held, put forth as true and supported by a teacher, a school; a principle or position, or the body of principles, in any branch of knowledge.

[iv] Note that explanation here refers to why exactly this theory is put forward; on the other hand, the theory in itself provides an explanation of the behavior of its subject.

[v] The term *production science* is used as shorthand to refer to disciplines addressing production, like operations/production management, industrial engineering, etc.

[vi] Taylor (1913): "... most of the readers of these papers [on scientific management] have mistaken the mechanism for the true essence. Scientific management fundamentally consists of certain broad general principles, a certain philosophy, which can be applied in many ways, and a description of what any one man or men may believe to be the best mechanism for applying these general principles should in no way be confused with the principles themselves."

[vii] Kasanen et al. (1991) use this characterization specifically in accounting (which largely developed in the framework of production in the beginning of the 20th century), but it can well be generalized to production science in general.

[viii] Filippini (1997) states: "Just as in other applied sciences, OM could benefit from theories which help to explain phenomena and the relationships between relevant variables". (Here OM refers to operations management.) It is striking that a view that would be self-evident in other disciplines has to be defended regarding operations/production management.

[ix] Milgrom and Roberts (1990) comment: "A striking feature of the discussion of flexible manufacturing found in the business press is the frequency with which it is asserted that successful moves toward « the factory of the future » are not a matter of small adjustments made independently at each of several margins, but rather have involved substantial and closely coordinated changes in a whole range of the firm's activities."

[x] This can be disputed. At the extreme, the recommendation of Eccles and Nohria leads to what could be called verbal engineering or concept engineering: belief, that terms and concepts in themselves would provide solutions to managerial problems. What are notoriously lacking are the explanations of proposed solutions. Instead of what Eccles and Nohria suggest, it could be proposed that managers should rather search for a basis for their rhetorics from explanations related to new schemes for solutions. After all, is it wise to implement a solution for which there is no proper explanation?

[xi] One example is provided by the concept of quality. Rogberg (1995) found, when studying quality implementation in large contractor organizations, that the term quality had been used for motivating the current improvement offensives. Business process re-engineering (BPR) provides another example, where a concept originally coined in research, started to live a life of its own as a buzzword and part of management rhetorics. Biazzo (1998) comments: "The term BPR has proved to be an attractive banner under whose shade it has been possible to initiate and legitimize even the most disparate projects for organizational change".

[xii] Lillrank (1995) has interestingly discussed the significance of the abstraction level in the transfer of managerial innovations.

[xiii] A quote from a foreword by Galbraith (1995) finely illustrates this (no italics in original) : « It offers the time-tested knowledge that has been accumulated through experience, as well as the current trends and innovative designs. It presents new ideas – like the virtual corporation, process organization, lateral organization, front/back models – as tools to be used *in combination* with the old standbys, which include functional structures and profit centers. This book is intended to provide a contrast to the oversell that often accompanies popular ideas. Sometimes the hype diminishes the usefulness of new ideas by turning them into fads. This book portrays the new ideas as useful but limited tools that ought to be *understood* and kept in every manager´s toolbox, to be taken out and used when appropriate. It also tries to suggest the appropriate *conditions* for using them. » Thus Galbraith endeavors (1) to put the new ideas in the context of the existing body of ideas, (2) to provide explanations for new ideas, and (3) to define the range of validity for them. These are examples of the possible contributions of theoretical analysis vis-a-vis approaches originated in practice.

[xiv] Meredith (1992) comments that in many research situations, the credibility of the model, framework, or theory is gained through its simple face validity (the intuitive recognition of its validity). He recalls that for establishing valid theories, theory building and testing go hand in hand.

[xv] Forza and Di Nuzzo (1998) were able to find 16 quantitative studies on the linkages between JIT and manufacturing performance for their meta-analytical research.

[xvi] Here it is appropriate to remember the situation of the Japanese developers of JIT production. They had just the theory and explanation provided by it at hand, maybe also isolated observations of related practices (like *Takt* time). This will be discussed in more detail in Chapter 4.

[xvii] Note that the term *production* is used in this presentation both in its narrow (production proper) and broad (product design, production, etc.) meaning. If the meaning is not clear from the context, the term is qualified, for example "production proper" or "physical production".

[xviii] This view has been established in operations management long since. For example, in the first edition of Buffa's (1961) well-known textbook on production management, one part (of four in total) is devoted to "Design of production system" and one to "Operation and control of production systems". In the latter, there is a chapter with the title "Control and Improvement of Production Costs", where improvement is mentioned briefly. The recent textbook by Slack et al. (1995) contains one part each for, respectively, design, planning and control, and improvement. This view is preferred here to the more popular view of strategic-tactical-operational decision-making, also a temporally based categorization, because of the incorporation of activities after production, namely improvement.

[xix] *Design* of a production system, as a level of managerial action, should not be confused with *design* of a product, as a phase of production. For avoiding tautology or the danger of confusion, the term structure (of a production system) is sometimes used instead.

[xx] Note that internal and external goals may be overlapping.

[xxi] Note that the focus here is on general concepts and principles of production, rather than on taxonomies and principles for handling specific production situations. An excellent overview of production theories based on production situation taxonomies is provided in (Melles & Wamelink 1993).

[xxii] This framework was prepared for the analysis of one-of-a-kind production, but it represents well repetitive production, too.

[xxiii] The book contains 20 laws, but five of them are related to people-issues or organizational issues and are thus not based on queueing theory analysis.

[xxiv] The domain of analysis in this book is manufacturing; however Reinertsen (1997) presents a view on product design and development also based on queueing theory.

[xxv] This means roughly that a leading unit takes care of system specification and assembly, and subordinate units take care of subsystem development, design and manufacturing based on the specifications received from the leading unit.

[xxvi] All originators of these theories are university professors.

[xxvii] In the Anglo-Saxon world, the poem of John Godfrey Saxe, based on this story, is famous. The last two verses of the poem make the point:

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right
And all were in the wrong!

So oft in theologic wars,
The disputants, I ween,
Rail on in utter ignorance
Of what the other mean,
And prate about an elephant
Not one of them has seen.

[xxviii] This is in stark contrast to such fields as physics, where proposed new theories ignite heated scientific discussion, as described by Kuhn (1970) and Deutsch (1997).

3. Transformation concept of production

It is argued here that the theoretical model of production that has dominated the major part of the 20th century – both in practice and in science – is the transformation[i] concept and its associated notions of organization and management. The rationale, conceptualization, principles, practices and paradigms based on the transformation concept are discussed in this chapter.

3.1 Rationale

It is appropriate to search for a rationale given for the transformation concept in the framework of scientific management. Taylor (1913) crystallizes the basic idea of scientific management in the following way:

> Perhaps the most prominent single element in modern scientific management is the task idea. The work of every workman is fully planned out by the management at least one day in advance, and each man receives in most cases complete written instructions, describing in detail the task which he is to accomplish, as well the means to be used in doing the work… Scientific management consists very largely in preparing for and carrying out these tasks.

Why is the task idea important? The following quote of Kendall (1912), another eloquent promoter of scientific management, illuminates this:

> The theory of the proper execution of work is that it should be planned completely before a single move is made – that a route sheet which show the names and order of all the operations which are to be performed should be made out and that instructions cards should be clearly written for each operation. Requisitions on the Stores' department showing the kind and quality of the materials and where they should be moved, lists of proper tools for doing the work in the best way, should be made for each operation, and then by time study the very best method and apparatus for performing each operation is determined in advance, and becomes a part of the instruction.

In substance, Kendall argues that it is necessary to define the tasks for two reasons: for making all the prerequisites of a task ready, and for ensuring that the best method is followed. In general, these arguments forward the well-known concepts and principles of systematic production planning: investigate what has to be done, decompose it into tasks and figure out their optimal method and order, ensure that all inputs will be available, and assign each task to an operative or workstation.

What is the production management practice that is to be replaced by these ideas of scientific management? The then conventional way of production, called unsystematized production, is characterized by Kendall as follows:

> Orders in the unsystematized shop are recorded in a simple manner, … These are described in part verbally to the superintendent, who may further enlighten the foreman on any details of such orders. It is assumed that the superintendent knows his business, and that the foremen know theirs, and they expect a workman to sense what is wanted and to ask questions when he is not sure… [The foreman] gives the work to each workman when he has finished his last job, and depends largely on the worker's knowledge of what to do and how to do it.

Regarding purchasing:

> The lack of well organized purchasing results in work progressing to a certain extent through the shop until it is stopped and occupies space waiting for some material which has been overlooked, or which is not suited for the purpose.

Regarding storage of materials:

> The effect of badly organized stores is (1) loss of time; work which should go through the manufacturing departments rapidly is held up at different places waiting for materials of the proper kind or amount, and this is a direct loss; (2) loss of space…; (3) loss of capital, because more money is tied up in stores which are not systematized and properly regulated, and more money is tied up in the jobs which represent labor and material sidetracked throughout the plant.

Kendall describes the effects of unsystematized production:

> This lack of planning at the start, of complete instructions, of co-ordinating the departments and the routing of work throughout each operation, results in a congestion of unfinished work at many points. This slows down the output, occupies space, and ties up capital. The frequency of mistakes in rush times and of shortages that must be afterwards be made up, are not always called to the attention of the management. It is exceedingly difficult, also, in this type of plant to secure a high quality of work and to maintain it uniformly.

Thus, unsystematized production is characterized by lack of planning, informal, decentralized management and reliance on tacit knowledge.

3.2 Conceptualization

Taylor conceptualized production as tasks, but gave no precise definition of the concept of a task. However, it can be argued that a more technical definition of production, compatible with the idea of task, already existed. The view of production as transformation can be traced back to the early economic analysis of production at the end of the 18th century (Grubbström 1995). A sharp definition was reached in the economic theory of Walras (1952), developed in the last three decades of the 19th century, according to which there is in production a transformation of production factors into products[ii]. Walras formulated the production function, basically equations where technical coefficients referred to the consumption of each production factor in the production of a certain amount of a product.

The conventional illustration of this model[iii], which here will be called transformation concept[iv], is presented in Figure 2. It has been commonly presented in textbooks and articles on production and operations management. For example, Starr (1966) formulates:

> Any production process can be viewed as an input-output system. In other words, there is a set of resources which we call inputs. A transformation process operates on this set and releases it in a modified form which we call outputs… The management of the transformation process is what we mean by production management.

Slack et al. (1995) state:

> All operations produce goods or services or a mixture of the two, and they do this by a *process of transformation*. By transformation we mean that they use their resources to change the state or condition of something to produce *output*s... All operations conform to this general input-transformation-output model.

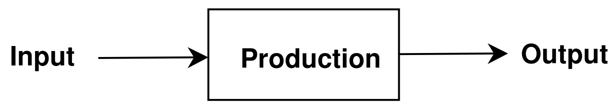

Figure 2. "Production is the transformation of one set of resources into a second set" (Grubbström 1995).

The striking feature of this model is that the production process itself is not actually dealt with, but only its inputs and outputs[v]. The technological content of the transformation has been abstracted away. It is also instructive to note that the model is directly associated with the notion of productivity, e.g. the ratio of output to the input (or a particular part of it) in a given time period.

3.3 Principles

For application to complex production situations, more practice-oriented principles are needed. The following principles seem to have been used in conjunction with the transformation concept. These can be justified by both empirical observation and the recent and still present doctrine of the production management discipline.

3.3.1 Decomposition

This principle can be stated as follows: *The transformation process can be decomposed into subprocesses, which also are transformation processes*.

This idea, presented in Figure 3, of breaking up the total transformation (production) into smaller, more manageable transformations (eventually to tasks in Taylor's sense) is actually equivalent to analytical reductionism, a well-known notion in the history of philosophy. Analytical reductionism[vi], which characterizes the Western intellectual tradition, has its origin in the second rule of Descartes (Checkland 1981):

> The second (was) to divide each of the difficulties that I was examining into as many parts as might be possible and necessary in order best to solve it.

This principle is presented by Slack et al. (1995) as follows:

> Look inside most operations and they will be made up of several units or departments, which themselves act as smaller versions of the whole operation of which they form a part.

Slack et al., choosing to call the total operation a macro operation and its constituent operations micro operations, define the similarity of these as follows:

> If micro operations act in a similar way to the macro operation, then all, or most, of the ideas relevant to the macro operation are also relevant to the micro operation.

In fact, this idea of similarity of transformation at different hierarchical levels is a powerful one. Thus, the same set of managerial principles can be used at any managerial level, which considerably simplifies the execution of management.

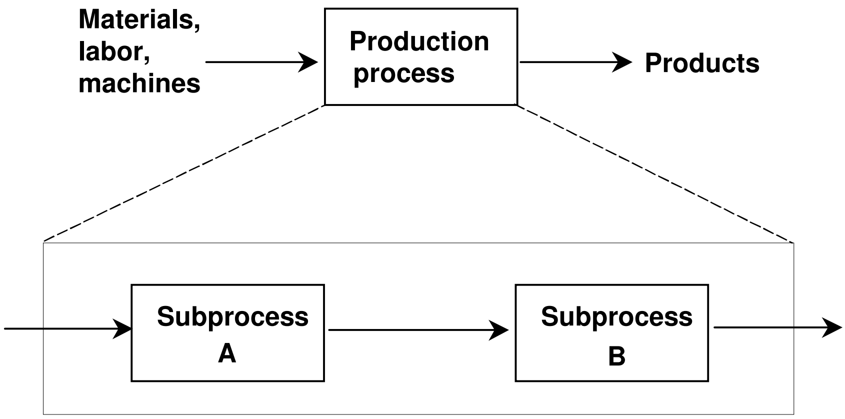

Figure 3. The view of a production process as a transformation process that can be divided hierarchically into subprocesses.

This principle has been used in production planning and control, as outlined above by promoters of scientific management and by the Walrasian production theory (Chapter 2). Note that, as implied in the Walrasian production theory, decomposition is also extended to the product and the production resources[vii]. In its most systematic form, this principle has been translated into a practical method in the framework of the MRP II. In this system for production and inventory control (Browne et al. 1988), the starting point is the explosion of an order into component requirements (Bill of Materials) and resource requirements (Bill of Resources). Thus, an order is hierarchically and stagewise decomposed into specific tasks (where production resources work on materials) on the shop floor.

3.3.2 Cost minimization

This is the core principle of the transformation concept: *The cost of the total process can be minimized by minimizing the cost of each subprocess***.**

Here the key issue is the assumption of the independence of subprocesses. In fact, this principle could be formulated also as follows: subprocesses of a total process are independent from each other.

This principle is embodied in and operationalized by conventional accounting theory, which is based on the following assumptions (Umble & Srikanth 1990):

- total cost of the production process equals the sum of the costs of each operation
- the total cost of each operation (excluding material cost) is proportional to the cost of direct labor for that operation

This standard cost procedure is reversed when estimating the profitability of an equipment investment (Umble & Srikanth 1990). If the labor cost of any operation can be reduced, the total cost will be reduced by both the relevant labor cost and the associated overhead cost. Thus the financial impact of any particular change on the whole production process can be determined.

Based on this principle, attention can be focused on cost management in each operation, subprocess or department. In a hierarchical organization the costs of each organizational unit have thus to be minimized. Alternatively, in a market based production organization, the costs of each procured work package have to be minimized.

This principle (or the independency principle) has not been explicitly put forward by researchers; of course, observation on the shop floor and logical thinking reveal that this principle is not defendable. Anyway, the methods of organization and accounting have been actually based on this idea: it was evidently meant that the interdependencies should be taken into account in an informal way by the management. In practice, when only this principle was embodied in the organization and performance measurements (rather than a corresponding principle for taking care of interdependencies), it gained predominance[viii].

What is the source of cost minimization of production that this model sheds light on? Very obviously, it is making the transformation process more productive, which is equivalent to reducing the costs of production for the same output. *Specialization* and *scale* were already offered as the main methods for productivity improvement by the early 18th and 19th century economists (Istvan 1992). This repertoire was augmented later with *technology*.

3.3.3 Buffering

A current formulation of this principle is presented by Slack et al. (1995): *It is advantageous to insulate the production process from the external environment through physical or organizational buffering.*

Actually, this principle is related to the independence assumption discussed above. If the transformation process is seemingly not independent from its environment, or the subprocesses from each other, they can be *made independent* by buffering. Also, this principle[ix] reflects the transformation model's underlying assumption that it is the transformation process that is most important, and it is thus a requisite to shield it from the erratic conditions in the environment.

This principle has been the subject of academic work since the beginning of the 20th century. It was mathematically formulated in the form of the economic ordering quantity model[x] and later further developed through inventory theory. Scholars in organization theory, like Thompson (1974) and Galbraith (1974) have used it as a starting point in the development of organizational theories.

3.3.4 Value

The principle on value can be expressed as follows: *The value of the output of a process is associated with value (or costs) of inputs to that process.*

Actually, value is not explicitly considered in the production theory based on the transformation concept. Indeed, the only way to conceive value of the output in this framework is to relate it to the input. Thus, an influential early accounting theoretician defines value as follows: "...value of any commodity, service, or condition, utilized in production, passes over into the object or product for which the original item was expended and attaches to the result, giving it its value." (from Johnson & Kaplan 1987). In practice, the value of the output can be raised by using better materials and more skilled specialists, the costs of which are higher.

This view is still prevalent in the notion of value added in economics. Value added is defined as "the difference between the costs of purchases (raw materials, components, subassemblies, supplies, energy) and the revenue from the sale of goods and services produced using those purchases" (Christopher 1993). Thus, the value of output equals to the sum of the value (that is, costs) of purchases and the value (that is, value added) of the transformation. However, under perfect competition, costs of production tend to determine the selling price, and thus value added is closely related to costs.

3.4 Production template

How have the transformation concept and related principles been implemented in practice? – Note that the methods and practices actually implemented are merely compatible with the concept and principles; they are not the only methods and practices that can be derived from the principles.

3.4.1 Design

From organizational point of view, *design* of the production system is based on the division of work both horizontally and vertically (planning and doing). Also the layout of the factory is organized according to technological processes, i.e. similar machines are grouped together.

3.4.2 Control

Control of production is based on centrally prepared plans, to be realized by the operatives. The mode of production is push: for example realized by a MRP system. In order to minimize the capacity losses due to set ups, it is the norm to produce in batches. In order to ensure a high degree of utilization, material buffers are used between subsequent workstations.

3.4.3 Improvement

In *improvement* of production, reduction of labor through technology and scale economies (including learning effects) is the major thrust, and productivity is the major measure for improvement. Product and process[xi] innovation is seen as the prime movers of change. Characteristic to both product and process innovation are innovative features embodied in a product or in production equipment. Innovation-oriented performance improvement is seen as an ongoing series of decisions as to whether the probable gain from each proposed improvement activity, independently considered, will exceed the expenditure to implement it (Hall et al. 1991).

3.5 Diffusion and evolution

3.5.1 Production paradigm

The different parts of a production template, based on the transformation concept, were developed by different industrialists and in different times, but by the First World War, they were ready to be assembled into a whole.

The movement of scientific management produced the line and staff structure of the firm (based on specialization and centralized control). Buffa (1961) claims that the ideas of Taylor "are so much a part of present-day organizational practice that it is hard to believe that the situation was ever any different". The accounting required was provided by the development of return on investment (ROI) as a measure for capital productivity in DuPont (Johnson & Kaplan 1987). It made it possible to evaluate the performance of different units in a functional or divisionalized organization. This facilitated the diffusion of "modern enterprise form" (Chandler 1977), which has two characteristics: it contains many distinct operating units and it is managed by a hierarchy of salaried executives. Finally, the example of Ford in mass production propelled the diffusion of related practices: product standardization, special purpose machines, and the use of a less skilled work force (Hounshell 1984).

After its formation, the template seems to have remained stable, barring incremental refinement. However, one major refinement is worth mentioning, namely "when scientific management met the computer" (Hopp & Spearman 1996), Material Requirement Planning (MRP) was developed to computerize and systematize the production control activities.

3.5.2 Benefits

Because this transformation concept of production never was presented as a testable theory, there is no scholarly work on its benefits. However, from the rapid proliferation of practices based on it, it is possible to come to a conclusion about the benefits provided.

The most fascinating outcome[xii] from this model, mass production, was definitely more effective than the partially craft-based production forms it substituted for. Since 1908, Ford succeeded in reducing the labor time to produce the Model T from 12.5 to 1.5 hours (Hopp & Spearman 1996).

3.5.3 Anomalies

This paradigm worked reasonably well for the major part of the century. It was in the 1980s that the first symptoms of anomalies[xiii] started to be visible. Interestingly, Schonberger (1996) found that in several major companies, Ford included, in 1950–1975 there was a constant tendency towards increasing amounts of work-in-process. This indicates that negative side effects of the paradigm were latently accumulating during a long period before becoming visible.

Skinner (1986) noticed that the efforts of American companies to regain competitive edge through productivity had been disappointing, even paradoxical: the harder productivity is pursued, the more elusive it becomes. Hayes, Wheelwright and Clark (1988) observed that the prevailing organization, divided according to functional and divisional lines, could not cope with the need for major improvements, which require cooperation between subgroups. Such cooperation could reflect poorly on the measures used to evaluate them. Thus, when faced with interlinked problems, the organization responded with segmented solutions and isolated experiments. Also the efforts to install MRP systems in factories encountered difficulties, and it was realized that the system actually could increase inventories[xiv], in contradiction to its original purpose (Hopp & Spearman 1996).

3.5.4 Scientific paradigm

In fact, already the earliest economic treatises dealing with production promoted principles related to the transformation concept (Buffa 1961). Specialization, or division of labor, is due to Adam Smith who observed three benefits from it: development of a skill when the same task is performed repetitively, a saving of time normally lost when changing from one activity to the next, and the invention of machines or tools that seemed naturally to follow from specialization. To these benefits, Babbage added that of purchasing just the amounts of skills needed, instead of paying according to the most difficult skill in the production sequence. Also otherwise, the view on production developed in economics came to dominate the conceptualization of production, as discussed above.

Another important early field was scientific management. The ideas of scientific management, developed by Taylor, Gilbreth and others, have had an immense influence on the discipline of production management in the 20th century. Gibson (1991) says of Taylor: “the general style he set became the universal paradigm for American engineering practice and for engineering education, and remains so even today".

However, after the active period of the most visible figures in scientific management, the scientific development of production management came to a halt (Buffa 1961). The same applies to accounting (Johnson & Kaplan 1987). A new interest in the field started to gather only after the Second World War. However, inspired first by the operations research activities in wartime, and later, by the advance of computers, the emphasis was laid on modeling of different, more or less stylized[xv] decisions in production management[xvi]. It has since been pointed out that the scientific community thus distanced itself from problems of practical significance.

That there have been very few attempts to consolidate the transformation model and its principles into a well-grounded theory is surprising. In textbooks, one can find brief explanations of the transformation, but the theme is not developed further[xvii]. One possible explanation is the attitude to theories in general in the framework of operations management (discussed in Chapter 2). On the other hand, this existence of tacit assumptions is one characteristic of a paradigm (Kuhn 1970).

Over the years, the role of the transformation model as the foundational theory became obscured or forgotten. In practice as well as in research settings, the transformation concept is most often implicit, and when made explicit, it is rarely treated as a testable and discussible theory[xviii]. This situation is connected with the long historical tradition of the concept. However, even if not explicit, the terms, tools, etc. based on the transformation model in themselves import the model into our minds[xix].

There have been a few attempts to scientifically derive principles compatible with the transformation model, as the examples of Galbraith and Thompson show. The only known endeavor to derive a theoretical framework on the basis of the transformation concept is that described by Wortmann (1992a), presented above.

3.6 Conclusions

Since the beginning of the 20th century, the dominating theory of production, both in practice and research, has been the transformation model. In this model, production is conceptualized as a process of transformation. The following major principles can be discerned:

- The total transformation can be decomposed into smaller transformations.
- The cost of production can be minimized by minimizing the cost of each decomposed transformation.
- It is advantageous to buffer production.

This theory has primarily diffused through practical templates, rather than as a complete theory. Only the buffering principle has been elaborated in operations management science, other principles have been implicit. However, from the way production organizations have been operating it is possible to justify that these principles actually have been used.

The transformation model as a foundational theory of production has been exceptionally influential and successful for the major part of the 20th century. It has influenced several fields, like organizational design, accounting, project management, and various branches of engineering, through which it has also been transferred into practice. Its success has been due to two factors: sufficient power to model reality, and excellent power of various tools based on it for analyzing and controlling production in an easy and simple way.

---

[i] Instead of the term of *transformation*, the author has used the term *conversion* in earlier texts on this subject (for example, Koskela 1992). However, due to historical precedence, it is more correct to use the transformation term.

[ii] In the original text (Walras 1952): "*Dans la production, il y a transformation des services producteurs en produits.*"

[iii] Of course, the notion of production function as used in economics is another name for this model.

[iv] Note that transport, service and supply can also be – and have been – interpreted through this model. For example, the function of transport is that of changing the location of something (Wild 1984).

[v] However, in the eighteenth century, the point of departure was agricultural production (Grubbström 1995). Indeed, the transformation model is an excellent abstraction of grain cultivation. The transformation, growing of the grain, takes care of itself, so we do not need to describe and understand its inner mechanisms. The quality of the output is primarily dependent on nature so there is no need to consider customers or their requirements.

[vi] Since the Second World War, analytical reductionism has been strongly criticized by the systems movement. It is argued that there exist, at certain levels of complexity, properties which are emergent at that level, and which cannot be reduced for explanation at lower levels. The idea is that the architecture of complexity is hierarchical and that different

languages of description are needed at different levels (Checkland 1981). However, the systems movement has not been able to convert the idea of emergency into practical tools that would adequately tackle the interdependence of subsystems (which obviously causes the emergency of properties that cannot be derived from subsystems as such). This is illustrated, for example, by the soft-systems methodology. The critical argument behind this methodology is that in situations involving humans, like in management, problems cannot be stated clearly and unambiguously (Checkland 1981). Thus, a methodology that is more geared towards organizing discussion, debate and argument is needed. The soft-systems methodology fulfills this requirement, while including also the appropriate parts of hard-systems methodology. However, even this methodology primarily subscribes to the transformation model.

[vii] The idea of the GRAI approach (Doumeingts et al. 1995) is just to allocate resources to materials.

[viii] This phenomenon has been critically discussed in (Hayes et al. 1988, pp. 99–106).

[ix] A good description of buffering as a part of modern operations management doctrine is in (Slack et al. 1995)

[x] For criticism of the economic ordering quantity model, see (Burbidge 1990).

[xi] In innovation literature, the term *process innovation* refers to transformation process innovation rather than to flow process innovation.

[xii] However, as argued in the next chapter, the transformation concept was not the only foundation of Ford’s mass production.

[xiii] The term anomaly is used throughout this thesis in Kuhn's sense: violations of paradigm-induced expectations (as defined in Section 2.1.4).

[xiv] The reason for this is a fundamental flaw in the assumptions of MRP, namely that the computed lead time does not consider the loading of the plant. Thus, it is assumed that the time required for a part to travel through the factory is the same whether the plant is empty or overflowing with work (Hopp & Spearman 1996).

[xv] Hopp and Spearman (1996) present the work on simplistic scheduling problems as an example. It produced, since the fifties, 30 years of literature and practically no applications.

[xvi] This was fully in line with the transformation concept and related principles, especially the reductionistic approach of dividing a problem into issues and considering each issue as such. However, it is then necessary to consider the constraints formed by the environment of the issue in focus as given. It is exactly the consideration of "givens" as decision variables that has later been observed as fruitful (Silver 1993).

[xvii] The transformation model was initially not treated in the textbook of Buffa (1961). In a later edition, it is explained in a footnote.

[xviii] This is well illustrated in the historical overview on production modeling by Grubbström (1995), where it is stated that production is transformation, rather than that such a view has been selected as a theoretical construct.

[xix] Rosenthal (1984) argues that *dominant* words direct us to think and act in certain ways.

4. Flow concept of production

The transformation model of production was not challenged in scientific discussion or industrial practice until the 1980's when a new approach started to cause cracks in the prevailing foundation of production. We now turn our attention to this new model of production and associated critique of the transformation concept.

4.1 Rationale

Taking into consideration the long dominance of the transformation concept, it is appropriate to present the rationale of the flow concept in terms of the critique against the transformation concept. Indeed, there are well-grounded theoretical arguments that claim that the transformation concept, as applied to the analysis and management of productive operations, is misleading or even false. The critique comes from the representatives of the just-in-time (JIT) camp.

4.1.1 The critique by Shingo

The theoretical rationale of the JIT movement can be explained well by the insight[i] of Shingo, which he claims to have had in 1945. The starting point, i.e. the prevailing erroneous view is explained by Shingo (1988) as follows:

> Process refers to an analysis of production in large units, and operation refers to an analysis of production in small units. Here apparently, processes and operations are considered only categories differing in size of units of analysis. Since processes and operations are perceived as phenomena that can be expressed on the same axis, there may be an unconscious assumption at work, that improvements made in small-unit operations necessarily lead to improvements in collective processes.

Shingo's invention was made up by the following observation:

> Production is a network formed by intersecting axes of process (*y* axis) and operation (*x* axis). The two phenomena lie on different axes and their flows are, by nature, dissimilar.

Here, Shingo made the following distinction between process and operation[ii]:

> Process refers to the flow of products from one worker to another, that is, the stages through which raw materials gradually move to become finished products.
>
> Operation refers to the discrete stage at which a worker may work on different products, i.e. a human temporal and spatial flow that consistently centers around the worker.

Another illuminating characterization:

> Flow along *y* axis represents the change taking place in the material being worked on, that is, the *object* of production. Flow along the *x* axis represents the operations being performed on the material by workers and machines, that is, the *subject* of production.

The point of this distinction was the following:

> It follows from this that the improvement of operations requires an approach that uniquely responds to the characteristics of operations. Similarly, process improvements must be carried out from a point of view that corresponds to the characteristics of processes.

The conventional approach had either confused these two concepts or forgotten the process concept:

> The West, therefore, ended up imagining that processes and operations are nothing more than overlapping phenomena lying on a single axis... We can see where this led. Some people thought that production as a whole would improve once you improved operations, the smallest units.

In consequence, process improvement had been practically neglected in the West.

4.1.2 Discussion

The erroneous view referred to by Shingo is obviously the decomposition in the transformation model of production. He claims that there is another dimension of production that is not captured by the transformation model, namely, what is happening between the transformations. This becomes apparent if we try breaking down the total transformation into the smallest transformation units and compare the results with what actually happens in production. On the shop floor we soon encounter activities, like transfer or inspection of material, which are not transformations (in the sense that they could be derived from the total transformation by decomposition).

In practice, this dilemma can be (and has been) solved in two ways: (1) these non-transformation activities are left out of consideration or (2) all activities are viewed as transformation activities.

The first solution leads to a situation where there is no aim to control or improve these non-transformation activities. If there is a tradeoff between transformation and non-transformation activities, it is thus apparently beneficial to improve the transformation activity, because the deterioration of the non-transformation activity is not directly visible. An example is provided by the principle of cost minimization of each subprocess, which leads to the need for buffers that allow high utilization rates.

The second solution leads to a situation where approaches to improvement of transformation activities are applied to non-transformation activities. This, in turn, leads to investment in and technological development of non-transformation activities (storage, transfer, inspection), which would be better suppressed.

Thus, these erroneous interpretations and their implications are present in production control methods and performance improvement efforts based on the transformation concept.

By focusing only on transformation subprocesses, the transformation model not only neglects, but also diminishes overall flow efficiency. In fact, leading authorities in production control attribute the fact that "manufacturing is out of control in most companies" directly to the neglect of flows (Plossl 1991). In addition, poor ability to control manufacturing makes improving transformation processes more difficult: "Major investments in new equipment are not the solution to a confused factory" (Hayes et al. 1988).

4.2 Conceptualization

The theoretical invention made by Shingo was presented above. What is the core of this invention? There are two main points. Firstly, the introduction of time as an input (or resource) in production[iii] (of course, the concept of time has always been used in production control, but in other purposes, like temporal coordination in scheduling). Thus, we are interested in the amount of time consumed by the total transformation and its parts. As is the case with other inputs, the less the better; shortening of the total time of production was a major goal already in classical industrial engineering[iv] (Anon. 1921, Miller 1922, Clark

1922a). The following two quotes from Ford (1926b) also show that time was understood as one production factor among others in that period:

> The time element in manufacturing stretches from the moment the raw material is separated from the earth to the moment when the finished product is delivered to the ultimate consumer.
>
> Time waste differs from material waste in that there can be no salvage. The easiest of all wastes, and the hardest to correct, is this waste of time, because wasted time does not litter the floor like wasted material.

But the introduction of time also implies that production is conceived as a physical process rather than as an economic abstraction in cost terms or in productivity terms. This has an important consequence: it is possible to model the behavior of production as a physical process using appropriate models. As Hopp and Spearman (1996) have convincingly shown in their book "Factory Physics", queueing theory provides the basic, physical model of production. Through an analysis based on queueing theory, we also become interested in variability inherent in production, which is the major explanatory factor for the time needed in production.

The second (and related) main point is in the observation that time is consumed by two types of activities when viewed from the point of view of the product: transformation activities and others, apparently non-transformation activities, categorized by the Gilbreths (1922) as transfer, delay and inspection activities[v] (Fig. 4). Obviously, these non-transformation activities are unnecessary from the point of view of the transformation. So, the less of them the better; best if there are none of them. As Shingo indicates, the approaches to improving these two types of activities are totally different: making the one more efficient; trying to eliminate the other. It has to be noted that also part of a particular transformation may be waste if that part could have been removed or alleviated by doing things in a different way at some other stage[vi].

These two points reveal more or less the same source of improvement: eliminating the unnecessary from production (because the share of the unnecessary time is generally dominating). In industrial engineering, all unnecessary in production has traditionally been called *waste* or *non-value-adding*. All what is necessary for creating a perfect product is called *value-adding*[vii]. Thus, the founding principle based on the flow concept can be worded as follows: eliminate non-value-adding phenomena from production (or: reduce the share of non-value-adding activities).

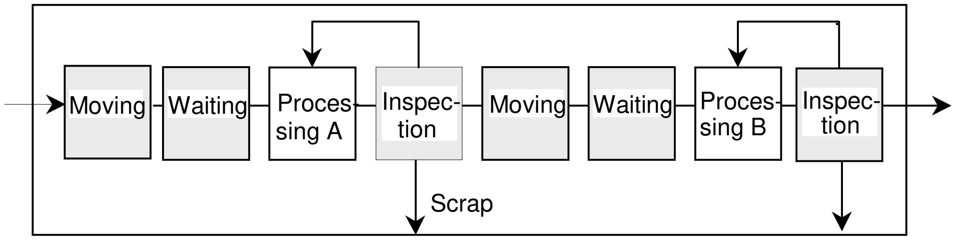

Figure 4. Production as a flow process. The shaded boxes represent non-value-adding activities, in contrast to value-adding processing activities.

4.3 Principles

4.3.1 Introduction

In the following, the most important flow concept-related principles for production system design, control and improvement are examined. There are three types of principles. The first type consists of a principle that actually is part of the theoretical and conceptual foundation; it indicates the fundamental source of improvement:

Reduce the share of non-value-adding activities (waste).

Secondly, there are principles that can be derived from theory:

Reduce lead time.
Reduce variability.

Thirdly, there are more or less heuristic principles, that have been observed to be useful in practice but are, as yet, less directly connected to theory, such as:

Simplify by minimizing the number of steps, parts and linkages.
Increase flexibility.
Increase transparency.

These principles are presented in turn below. In order to justify the principles in view of the well-known practice of JIT and lean production, the measures by means of which they can be practically implemented are also briefly listed.

4.3.2 Concept of waste

Ohno (1988) identified the following seven wastes, of which the first five refer to the flow of material, the two last ones to work of men:

- waste of overproduction
- waste of correction
- waste of material movement
- waste of processing
- waste of inventory
- waste of waiting
- waste of motion.

Originally, the most important type of waste is considered to be within the process, i.e. stagewise movement of the material through the production system. As evident from the waste list of Ohno, there can be waste also in the utilization of labor and machines. Thus, a current account of the Toyota production system (Monden 1994) finds four kinds of waste: excessive production resources, overproduction, excessive inventory and unnecessary capital investment.

Why are there non-value-adding activities in the first place? There seems to be three root causes: the structure of production system, the way production is controlled, and the inherent nature of production.

The structure of the production system determines the physical flow that is traversed by material and information. Thus, waste exists by design in hierarchical organizations: every time a task is divided into two subtasks executed by different specialists, non-value-adding activities increase: inspecting, moving and waiting. Similarly, the layout of a factory dictates the amount of waste associated with moving material from workstation to the next.

The way production is controlled affects waste in at least two ways. The control principles used may produce more or less waste. Secondly, deficiencies in conforming to the intended principles may cause waste.

It is in the nature of production that waste exists: defects emerge, machines break down, accidents happen. Especially, variability of all productive activities seems to be an inherent feature, as well as human error. Characteristically, this variability is statistical by nature, and often it can be assessed only by monitoring the production system long enough.

Thus, these three root causes of waste differ regarding their time frame. The waste associated with the structure is determined at the time of design of the system, and is thus tackled in advance. The waste associated with control is tackled during the production. The waste associated with the inherent nature of production is dealt with after the production. Evidently, this means that the methods of attacking these three sources of waste are also different. So here we have the rationale of distinguishing the three aspects of production management (discussed in Chapter 2): design, control and improvement of production.

With respect to all three causes, it is possible to eliminate or reduce the amount of waste. However, this principle cannot be used simplistically. Some non-value-adding activities produce value for internal customers, like planning, accounting and accident prevention. Such activities should not be suppressed without considering whether more non-value-adding activities would result in other parts of the process. However, accidents and defects, for example, have no value to anybody and should be eliminated without any hesitation.

Most of the principles presented below address suppression of waste. However, it is also possible to directly attack the most visible waste just by flowcharting the process, then pinpointing and measuring non-value-adding activities[viii].

4.3.3 Reduce the lead time

It is a basic improvement rationale to compress the lead time by eliminating non-value-adding time. The lead time[ix] refers to the time required for a particular piece of material to traverse the flow[x]. The lead time can be represented as follows[xi]:

Lead time = processing time + inspection time + wait time + move time

Lead time compression forces the reduction of inspection, move and wait times. Experience shows that non-value-adding activities dominate most processes; usually only 3 to 20 % of steps add value (Ciampa 1991), and their share of the total lead time is negligible, from 0.5 to 5 % (Stalk & Hout 1990). The progression of lead time reduction through successive process improvement is depicted in Figure 5.

In this regard, the effort is directed towards elimination of reprocessing (rework), inspection, moving and waiting. Remarkably, the basic elements of a JIT system can be derived from this (Shingo 1988, Monden 1994).

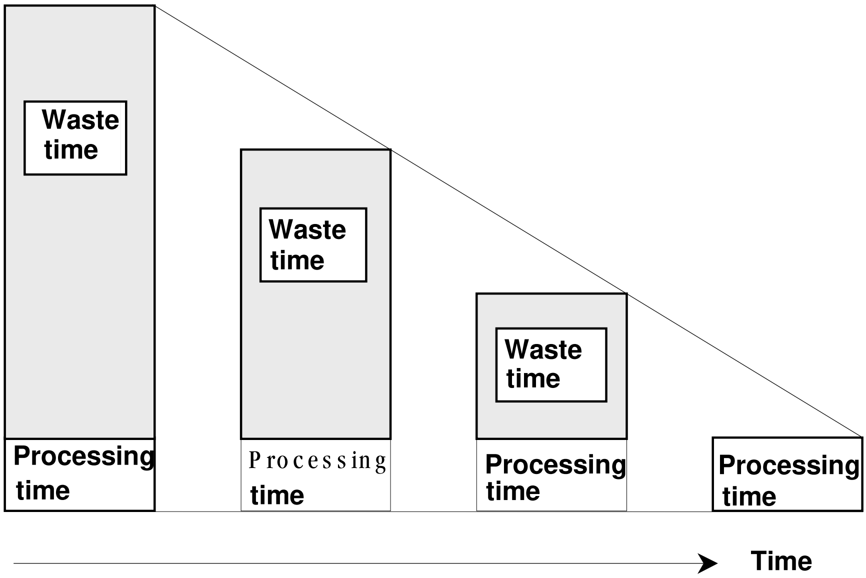

Figure 5. Lead time can be progressively compressed through elimination of non-value-adding activities and variability reduction (Berliner & Brimson 1988).

Elimination of redoing requires elimination of defects, an objective that can be attained either through classical quality measures or the autonomation method that uses 100 % inspection through autonomous checking for the abnormal in a process.

Elimination of waiting requires several things (Shingo 1988, Monden 1994). One type of delay is the lot delay. Through set-up time reduction it is possible to reach one-piece lot. This, in association with the pull method of production control, achieves one-piece flow. Another type of delay is the process delay. One method for its reduction is line balancing, which is supported by such practices as work standardization. It can also be reduced through using several low capacity machines, instead of one high capacity machine that will form a bottleneck.

Elimination of moving requires a process-based layout (production cell) so that transport distances are practically eliminated.

Thus, the basic elements of JIT are consequences of waste reduction. More detailed graphical presentations of the interdependencies of the JIT practices are presented by Shingo (1988), Monden (1994) and Schonberger (1982).

An important relationship between work-in-progress and lead time was revealed by Little (1961), who derived the following formula:

$$\text{Lead time} = \frac{\text{Work-in-progress}}{\text{Output}}$$

Thus by reducing work-in-progress the lead time is reduced, provided output remains constant.

A further finding is related to the way of controlling the movement of material in the production system. Push systems schedule the release of work, while pull systems authorize the release of work on the basis of system status (Hopp & Spearman 1996). The underlying feature of the pull systems, like kanban, is that they establish a cap for work-in-progress, which, as Little's law shows, will also keep the lead time in control. Beyond this, there are several other benefits associated with pull systems in comparison to push systems[xii].

In addition to the forced elimination of waste[xiii], compression of the total lead time gives the following benefits (Schmenner 1988, Hopp et al. 1990):

- faster delivery to the customer
- reduced need to make forecasts about future demand
- decrease of disruption of the production process due to change orders
- easier management because there are fewer customer orders to keep track of.

The principle of lead time compression also has other interesting implications. From the perspective of control, it is important that the cycles of deviation detection and correction are speedy. In design and planning, there are many open-ended tasks that benefit from an iterative search for successively better (if not optimal) solutions. The shorter the cycle time, the more cycles are affordable. From the point of view of improvement, the cycle time from becoming conscious of a problem or an opportunity to the implementation of a solution is crucial. In traditional organizations, this cycle time is sometimes infinite due to lack communication where no message is passed, or a long channel of communication where the message gets distorted. Indeed, every layer in an organizational hierarchy adds to the cycle time of error correction and problem solving. This fact provides motivation to decrease organizational layers, thereby empowering the persons working directly within the flow.

Practical approaches to lead time reduction include the following (for example, Hopp et al. 1990, Plossl 1991, Stalk & Hout 1990): eliminating work-in-progress (this original JIT goal reduces the waiting time and thus the lead time); reducing batch sizes; changing plant layout so that moving distances are minimized; keeping things moving; smoothing and synchronizing the flows; reducing variability; changing activities from sequential order to parallel order; isolating the main value-adding sequence from support work; in general, solving the control problems and constraints preventing a speedy flow.

4.3.4 Reduce variability

There are two types of variability[xiv] in flows of production: process-time variability and flow variability (Hopp & Spearman 1996). Process-time variability refers to the time required to process a task at one workstation. Process-time variability consists of natural variability (minor fluctuation due to differences in operators, machines and material), random outages, setups, operator availability and rework (due to unacceptable quality). Flow variability means the variability of the arrival of jobs to a single workstation.

It can easily be shown through queueing theory that *variability increases the lead time* (Krupka 1992, Hopp et al. 1990). Indeed, as presented in Chapter 2, an analysis based on queueing theory reveals that if it is not possible to reduce variability, one or more of the following have to be accepted: long lead times and high WIP levels, wasted capacity, lost output (Hopp & Spearman 1996). Another important result of a queueing theory analysis is that variability early in the line is more disruptive than variability late in the line.

Thus, reduction of variability within flow processes must be considered as an intrinsic goal. Schonberger (1986) states strongly: “Variability is the universal enemy.”

The practical approach to decreasing variability then consists of finding and eliminating its root causes. Thus, attention has been focused on maintenance for minimizing outages, set-up time reduction, and improved quality for reduction of rework. The statistical quality control theory (Shewhart 1931) was the first systematic methodology in this area.

4.3.5 Simplify

Other things being equal, the very complexity of a product or process increases the costs beyond the sum of the costs of individual parts or steps. Conventional accounting shows the price differential of two materials, but not the additional costs created in the whole production system by using two instead of one (Child et al. 1991). Another fundamental problem of complexity is reliability: complex systems are inherently less reliable than simple systems. Also, the human ability to deal with complexity is bounded and easily exceeded.

Simplification can be understood as reduction of the number of components in a product or reduction of the number of steps and linkages in a material or information flow. Simplification can be realized, on the one hand, by eliminating non-value-adding activities from the production process, and on the other hand by reconfiguring value-adding parts or steps.

Organizational changes can also bring about simplification. Vertical and horizontal division of labor always brings about non-value-adding activities, which can be eliminated through self-contained units (multi-skilled, autonomous teams).

Practical approaches to simplification include: shortening the flows by consolidating activities; reducing the part count of products through design changes or prefabricated parts; standardizing parts, materials, tools, etc.; decoupling linkages; minimizing the amount of control information needed.

4.3.6 Increase flexibility

Manufacturing flexibility can be grouped into four basic types: mix flexibility (number of different products produced); new product flexibility (speed of product introduction); volume flexibility (ability to vary production); and delivery time flexibility (Suarez et al. 1995).

The thrust of JIT production was on mix flexibility. At first glance, increase of mix flexibility seems to be contradictory to simplification. However, many companies have succeeded in realizing both goals simultaneously (Stalk & Hout 1990). Some of the key elements are modularized product design in connection with an aggressive use of the other principles, especially lead time compression and transparency.

Practical approaches to increased flexibility include (for example Stalk & Hout 1990, Child et al. 1991, Upton 1995) minimizing lot sizes to closely match demand, reducing the difficulty of setups and changeovers, customizing as late in the process as possible, training a multi-skilled workforce, training the workforce in operational flexibility, and using general purpose machines.

4.3.7 Increase transparency

Stalk and Hout (1990) observed that companies practising time compression had adopted an objective to make the production process transparent and observable for facilitation of control and improvement: "to make the main flow of operations from start to finish visible and comprehensible to all employees". This can be achieved by making the process directly observable through organizational and physical means, measurements, and public display of information.

In a theoretical sense, transparency means a separation of the network of information and the hierarchical structure of order giving (Greif 1991), which in classical organization theory are identical. The goal is thus to substitute self-control for formal control and related information gathering. Generally, it can be assumed that lack of transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement.

Practical approaches for enhanced transparency include the following (Greif 1991, Nakamura 1993, Galsworth 1997): establishing basic housekeeping to eliminate clutter (the method of 5-S[xv]); making the process directly observable through appropriate layout and signage; standardization; rendering invisible attributes of the process visible through measurement; embodying process information in work areas, tools, containers, materials and information systems; utilizing visual controls to enable any person to immediately recognize standards and deviations from them; reducing the interdependence of production units (focused factories).

4.4 Production template

In the production templates based on the flow concept, the central focus is on flows. However, note that the transformation concept is not totally rejected, but used where applicable[xvi].

4.4.1 Design

Regarding factory layout, product centered is preferred. Organizationally, complete flows or subflows are similarly the preferred building blocks, leading to focused factories, production cells and self-directed teams (Stewart 1992). Inter-organizational transactions are also conceived as flows, which lead to long term co-operation with suppliers with the goal of deriving mutual benefits from an optimized total flow.

4.4.2 Control

The primary consideration of control is to mitigate waste. There are three central methods for this, all discussed above. Firstly, the pull method, instead of push. Secondly, from the internal point of view, one-piece lot is aimed for. Thirdly, visual control (transparency) is realized.

4.4.3 Improvement

In improvement, Kaizen (continuous improvement) focusing on variability elimination, and aiming at perfection, has the central role (Imai 1986). Improvement is supported by performance measurement focusing on various types of waste.

4.5 Diffusion and evolution

4.5.1 Production paradigm

4.5.1.1 Origin

The first and impressive application of the flow concept to production was in mass production at Ford's factories. According to Ford (1926a), three principles underlie mass production:

- the planned orderly progression of the commodity through the shop
- the delivery of the work instead of leaving it to the workman's initiative to find it
- an analysis of operations into their constituent parts.

According to Ford, these are distinct but not separate tasks; all are involved in the first one. Thus, it has to be concluded that the flow aspect was the primary one.

To most of us, the concept of mass production brings the moving belt conveyor into mind. However, this concrete idea of a moving belt seems effectively to have prevented us from seeing the purpose of it (Ford 1926b):

> The thing is to keep everything in motion and take the work to the man and not the man to the work. That is the real principle of production, and conveyors are only one of many means to an end.

In addition to this general approach, several methods and practices, later attached to JIT, were used. Factory layouts were devised with the objective of minimizing the movement of parts between subsequent workstations or workers. There was continuous improvement of the process and the product. Freedom from defective parts was ensured by inspectors and automatic devices (later called *poka-yoke*). The practice of target costing was utilized[xvii]. In one case, even the division of labor was abolished, and the system of multifunctional employees was introduced[xviii].

Ford's production concept was subject to wide interest and publicity (Hounshell 1984). However, it seems that these aspects of Ford's mass production were generally misunderstood or simply not conceived. The template of mass production that started to diffuse contained primarily those features of Ford's mass production model that belonged to the domain of the transformation concept of production.

4.5.1.2 Re-emergence

However, as accounted by Wada (1995), somehow the idea of "flow production" kept alive in Japan and became a focus of interest in the late 1930s. The ideas of mass production were taken as the starting point. However, they were modified into a template called high-volume production, which was different from mass production in two ways. Firstly, it was not possible to utilize special-purpose machines extensively. Secondly, the essence of mass production, smooth flow of production, was to be achieved without any mechanization.

It was aircraft production during the war that gave a decisive step to translate the ideas into practice in Japan. One notable achievement was the introduction of the *Takt* system, aimed at synchronization of production, and originally invented in German aircraft production. After the war, many engineers of the wartime aircraft factories changed to the car industry. Also, the association *Noritsu Kyokai* (The Association of Efficiency) actively diffused this kind of production control.

However, the breakthrough in the implementation of flow production ideas happened in the Toyota Company, and the resultant production template became known as the Toyota production system[xix]. Also the name just-in-time became common.

Outside Japan, information and understanding of the new production approach was first very limited. However, the ideas started to diffuse into Europe and America in about 1975, especially in the automobile industry. During the 1980s, a wave of books were published which analyzed and explained the approach in more detail (Schonberger 1982, Schonberger 1986, Hayes et al. 1988, O'Grady 1988, Béranger 1987).

In the beginning of the 1990s, the new production philosophy, which was known by several different names (world class manufacturing, lean production, new production system) emerged as the new mainstream approach. It is now practiced, at least partially, by major manufacturing companies in America and Europe. The new approach has also diffused into new fields, like customized production (Ashton & Cook 1989, Colin 1997), services (Schonberger & Knod 1994), and administration (Harrington 1991).

4.5.1.3 Further evolution

A number of subfields or further developments of the methods and practices based on the flow concept have emerged. Most of them have been originated by practitioners or consultants with little theoretical background. In the following, the most visible of them are characterized.

Continuous improvement, associated with JIT and TQC, has emerged as a theme in itself especially after the book by Imai (1986). A key idea is to maintain and improve the working standards through small, gradual improvements. The inherent wastes (as characterized in section 4.3.2) in the process are natural targets for continuous improvement. The term "learning organization" refers partly to the capability of maintaining continuous improvement (Senge 1990).

Time based competition was popularized by the book by Stalk and Hout (1990). Time based competition refers to compressing time throughout the organization for competitive benefit. Essentially, this is a generalization of the JIT philosophy, well known to the JIT pioneers. Ohno states that shortening lead time creates benefits such as a decrease in the work not related to processing, a decrease in the inventory, and ease of problem identification (Robinson 1991). Time based competition has become popular, especially in administrative and information work, where the JIT concepts sound unfamiliar.

Re-engineering refers to the radical reconfiguration of processes and tasks, especially with respect to implementation of information technology (for example Hammer 1990, Davenport & Short 1990, Rockart & Short 1989). According to Hammer, recognizing and breaking away from outdated rules and fundamental assumptions is the key issue in re-engineering. Conceptually and theoretically, its roots are in industrial engineering[xx].

Supply chain management refers to supplier coordination and development (Hines 1994). From early on, it was a part of the JIT approach and was extensively practiced in Japan. Another, roughly corresponding term is *extended enterprise* (Sehdev et al. 1995, Childe 1998).

Agile manufacturing is essentially an American concept, characterized "as the next paradigm beyond Lean" (Roos 1995, Goldman et al. 1995). It is largely based on the same elements as lean production, but tries to achieve significantly more flexibility. Also, the application of advanced information technology is in a more prominent position in agile manufacturing. Agile manufacturing is still largely a vision, rather than existing practice.

The *Fractal Factory* (or Company) (Warnecke 1993) is an European based interpretation of the evolution of production thinking, where the concept of fractal (based on fractal geometry developed by Mandelbrot) is used as an allegory of the new organization principle. However, the substance of this approach is for the most part not dissimilar to the new philosophy as interpreted by Japanese or American authors.

4.5.2 Benefits

The benefits of the approaches based on the flow model in terms of productivity, quality and other indicators have been tangible enough to ensure a rapid diffusion of the new principles.

In an early statistical study covering 400 manufacturing plants, mostly in the U.S. and Europe, it was found that of all the possible techniques for improving productivity, only those related to JIT were demonstrably effective (Schmenner 1988). Later, Holmström (1995) was able to show that there is a strong positive correlation between speed and efficiency in different manufacturing industries.

One of the best-researched industries is car manufacturing (Womack et al. 1990), where lean production was found to halve usage of resources in comparison to conventional production[xxi]. The same order of magnitude of benefits in other industries is substantiated by other authors. For example, improvement results from applying lean production in a wide variety of plants are reported by Schonberger (1986) and Harmon and Peterson (1990). Japanese companies have typically doubled factory productivity rates over a 5-year period while implementing the new principles (Stalk & Hout 1990). A reduction of manufacturing space by 50 % is a typical target (Harmon and Peterson 1990).

The competitive benefits created by means of the new approach seem to be remarkably sustainable. Toyota, the first adopter, has had a consistent lead in stock turnover and productivity as compared to its Japanese competitors (Lieberman 1990).

4.5.3 Anomalies

In the 1990s, discussion on the limits of lean production, the primary production template based on the flow concept, has flamed (Cusumano 1994, Vedin 1993). It is argued, that practical limits of lean manufacturing have been reached, especially by Japanese car producers. The limits refer especially to problems of acquiring suppliers and labor[xxii], traffic congestion, and excessive product variety. The physical distribution problems caused allegedly by JIT manufacturing have been discussed in Japan since the beginning of the 1990s (Monden 1994, Vedin 1993). Also it is argued that the strategic benefits of lean production are decreased when everybody is applying it (Stalk & Webber 1993, Vedin 1993). Nevertheless, as Vedin concedes, it is the very success of the new philosophy that has led to these situations.

These anomalies seem to have been caused by over-reliance on the flow concept at the cost of the transformation concept or other considerations.

4.5.4 Scientific paradigm

4.5.4.1 Flow concept in classical industrial engineering

In fact most of the underpinnings of the flow concept were discussed in classical industrial engineering. The concept of waste was already widely used in the twenties, and the relation between time compression and waste was well known. In the Report on Elimination of Waste in Industry, the following is stated (Anon. 1921):

> Conscious production control tends to reduce or eliminate waste by shortening the total time of production.

In a similar vein, Miller (1922) says:

> ...(T)here must be avoidance of the large industrial wastes that come from overloaded inventories; slow movement of materials through the successive operations of manufacturing; ...

Clark (1922a) repeats:

> One of the striking wastes in many plants is the unnecessarily large investment in inventories of raw material, work in process, and finished goods.
>
> The longer it takes to manufacture, the more finished goods must be kept in stores and the heavier will be the burden of inventory.
>
> In order to reduce the manufacturing time, that is, the time required for the material to move through the plant until it becomes finished goods, the way must be cleared and the material kept moving.

It is recommended that processes should be addressed first, before individual activities; today we would call this as process-orientation (Clark 1922a):

> The part of the work of management described above, that is, keeping work moving through the plant at a rapid pace, should be well organized before very much time is devoted to individual production, because the delays under the control of management are usually much greater in extent than those under the control of individual workmen, and because improvements in the management will have an appreciable effect on the output of the workmen.

Interdependence between process parts as the rationale of process redesign and improvement is formulated by Frank and Lillian Gilbreth (1922) in a paper advocating process modeling as follows:

> Every detail of a process is more or less affected by every other detail; therefore the entire process must be presented in such a form that it can be visualized all at once before any changes are made in any of its subdivisions.

The Gilbreths refer to improvements that presently would obviously be called re-engineering:

> In many instances recording industrial processes in process-chart form has resulted in astonishing improvements.

However, for unknown reasons[xxiii], these ideas fell into disgrace, and were taken seriously and re-adopted only decades later; first by Shingo (1988), who explicitly refers to the above quoted paper of the Gilbreths as the stimulus to his production theory (presented above), and then, under the title of JIT, by other manufacturing circles. Thus JIT and all later associated approaches make up a continuation of the research agenda and the tradition of industrial engineering at the beginning of the 20th century.

4.5.4.2 Flow concept in modern operations/production management

In the West, the flow concept was effectively forgotten, and it took a long time for the scientific community to acquire a grasp of JIT. The flow concept was presented as a foundation in Shingo's books (for example, Shingo 1988), but they were translated relatively late into English or other Western languages, and his views were not generally acknowledged.

In fact, the conception of the new production mode of JIT evolved through three stages (Plenert 1990). It has been understood primarily as

- a set of tools (like kanban)
- a production planning method (like JIT)
- a general management philosophy (referred to as lean production, world class manufacturing, JIT/TQC, time based competition, etc.).

This progression is due to the pattern of diffusion of the new approach. It was largely diffused without any scientific, formalized basis; factory visits, case descriptions and consultants have been the means of technology transfer.

The conception of the new production philosophy as a general management philosophy was first promoted by Schonberger (1990 and 1996), the NPS Research Association (Shinohara 1988), Plossl (1991) and Womack and Jones (1996). Each has formulated a set of implementation principles. Wider academic interest into lean production has also started to gather[xxiv].

However, there have been contributions related to the flow model, even if they are not based on the original conceptualization by the Gilbreths. Goldratt's theory of constraints (Goldratt & Cox 1989) was based on the flow conceptualization. Little's (1961) law revealed important relationships in queues. The endeavor of Hopp and Spearman (1996) to create a foundation of production was a major step towards clarification of the queueing–theory- based understanding of flows.

All in all, the flow concept has still a marginal position in the discipline of operations/production management. Thus, factually, the operations/production management community has largely adopted the implications of the flow concept, but not acknowledged the concept itself – a phenomenon not uncommon in science (Deutsch 1997).

4.6 Conclusions

A second foundation of production – flow concept of production – has been presented, consisting of conceptualization of production and principles for production management. In the flow view, the basic thrust is to eliminate waste from flow processes. Thus, such principles as lead time reduction and variability reduction are promoted. Most of the principles have been presented in prior research, but individually, rather than as a set. Methods and practices based on the flow concept have become common especially after the 1980s; however, the flow concept itself has not generally been acknowledged.

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[i] Although Shingo states this clearly in his books, this fact is rarely acknowledged in the literature. Thus, this issue deserves to be treated at some length.

[ii] The terms *process* and *operation* of Shingo correspond, roughly, to the terms *flow* and *task*, respectively, as used in this thesis.

[iii] Walras (1952), who gave a sharp formulation, still currently used in economics, to the transformation concept, was very well aware that time had been abstracted away from it: "*Mais il y a une seconde complication. …La production exige un certain délai. Nous résoudrons cette seconde difficulté en faisant ici purement et simplement abstraction de ce délai.*"

[iv] Just before this publication went to the press, the author came across a remarkable book on Gantt charts by Clark (1922b) that puts forward further evidence on the preoccupation with time by industrial engineers in the 1920s. The appendix by Polakov (1922) contains an eloquent argument for viewing time (rather than money) as the dimension of production. The Gantt chart itself is said to provide a presentation of facts in their relation to time. One can find here the significance of and tools related to planning of work, also on weekly basis, as well as comparing realization to plan and finding causes for deviations. It is suggested to act on these causes: of course, today we call this continuous improvement. In Clark's words: "The chart itself becomes the moving force of action." Clark even mentions that a shortening of manufacturing time due to Gantt charts usage has been observed. Thus, interpreted with present theoretical terms: time compression due to variability reduction through improved planning and removal of deviation causes is recognized. Again this example shows that the rich legacy of the pioneers of industrial engineering has been wasted; what is said in present textbooks on Gantt charts is a very small part of the understanding and tool arsenal that existed around them.

[v] Instead of transfer and delay, often the terms *moving* and *waiting* are used.

[vi] Shingo (1988) calls this *process-oriented processing improvement*: "Machining operations that simplify the machining in a later operation are performed in earlier operations".

[vii] For example, Monden (1994) defines: "Conversion or processing operation that increases the value of raw materials or semi-finished products by adding manual labor."

[viii] A detailed methodology for administrative processes is presented, for example, by Harrington (1991).

[ix] Often the term cycle time is used.

[x] There often are several flows that unite or diverge in the total production process. However, it is generally possible to recognize the main flow and the side flows, which have to be assessed separately.

[xi] Another, more complicated time-based decomposition of processes is presented by Bartezzaghi et al. (1994).

[xii] A production control system can also be a mixed push-pull system. Huang and Kusiak (1998) present a push-pull system that pushes through certain manufacturing stages and pulls elsewhere based on the characteristics of these stages. They argue that this is superior to a push system, while avoiding some inherent problems of pull systems.

[xiii] Krupka (1992) argues that time is a natural metric for flow processes: it is a more useful and universal metric than cost and quality because it can be used to drive improvements in both.

[xiv] In this context, variability refers to random variation, a consequence of events beyond our immediate control (Hopp & Spearman 1996). Also it has to be noted that there is variability in dimensions other than time, for example geometric variation in the output of a task. However, such variability will impact also on time variability, when leading to rework or rejected parts. The quality movement has put forward that also this general variability should be suppressed (Sullivan 1984).

[xv] The method of 5-S takes its name from the initials of five Japanese words referring to organization, orderliness, cleanliness, personal cleanliness and discipline (Imai 1986). The method is used for creating a basic workplace organization. Galsworth (1997) presents a Westernized version of 5-S.

[xvi] For example, bills of materials are used, tasks are defined and assigned, etc.

[xvii] Ford (1926b) states: "In our own production, we set ourselves tasks – sometimes we arbitrarily fix prices, and then invariably we are able to make them; whereas, if we merely accepted things as they are, we should never get anywhere".

[xviii] This concerned a railway company acquired by the Ford Motor Company (Ford 1926b): "The idea is that a group of men have been assigned to run a railroad, and among them they can, if they are willing, do all the work. If a specialist has some of his special work on hand he does it; if he has no such work he does labourer's work or whatever there may be to do."

[xix] That the ideas of Ford also directly influenced the developments at Toyota, is illustrated by the following anecdote concerning Taiichi Ohno, transmitted by Bodek (1988): "When

bombarded with questions from our group on what inspired his thinking, he just laughed and said he learned it all from Henry Ford's book".

[xx] Actually, in an early contribution, Davenport and Short (1990) suggested calling the emergent new approach new industrial engineering. However, the term re-engineering (or business process redesign, BPR) became established. The relationship between the flow concept and BPR becomes even clearer when the history of this approach is considered. The idea of business process re-engineering (or redesign) was developed during the study of the impact of IT on organizations by MIT. Business process redesign was defined as one of five levels of IT-induced reconfiguration of organizations (Venkatraman 1991). It was stated that our current principles of organization are geared towards expoiting the capabilities offered by the Industrial Revolution. It was argued that the IT revolution could alter some of these principles. Another article by participants in the study mentioned (Davenport & Short 1990) illuminates which kind of new principles were thinkable. However, it was only the article of Hammer (1990) and the subsequent book (Hammer & Champy 1993) that sparked the general interest to BPR. Close reading of the seminal articles and books reveals that what were considered to be problems to be addressed were dysfunctionalities caused by the transformation concept, like excessive buffers, fragmentation, and inadequate feedback along chains. What was recommended as a solution were process design principles or solutions emanating from the flow concept, augmented with IT capabilities. Meanwhile, BPR was developed into consulting package, and it became a buzzword. The first examples of BPR were from administration and services, and this focus prevailed, but also manufacturing companies started their re-engineering initiatives.

[xxi] These results have been challenged by Williams et al. (1992), who criticize the validity of performance comparisons in the study, on which the book by Womack et al. is based.

[xxii] The position of suppliers and labor has been addressed critically in connection with JIT and lean production. The weakened position of suppliers of a JIT manufacturer has already been considered in 1977 by the Japanese Fair Trade Commission (Monden 1994). The discrepancy between quantities ordered by the predetermined monthly production plan and the daily kanban instructions was considered to be the main problem. Thus, the Fair Trade Commission guided paternal manufacturers not to violate existing laws on subcontracting when applying the JIT system. Leading JIT manufacturers, like Toyota, have then countered these problems in different ways. Another problem pointed out in the Japanese discussion is the allegation that the JIT system will force the intensification of labor (Monden 1994). In Toyota's newer factories, much more emphasis has been laid on working conditions and ergonomy (Fujimoto & Matsuo 1995). This indicates that the criticism has been grounded. However, regarding both suppliers and labor, the problems seem to have been caused rather by management policies than by the internal logic of JIT and lean production.

[xxiii] However, Ford (1926b) gives a hint: he warns against seeing business as a financial instrument; of course, exactly this financial view became dominant, and the physical view provided by the flow concept was sidestepped.

[xxiv] For example, the International Journal of Operations & Production Management published a Special Issue on lean production and work organization in 1996 (volume 16, number 2).

5. Value generation concept of production

However, the transformation concept of production has also been attacked from another direction. Almost simultaneously with the critique originating from the flow concept, the prevailing foundation of production was criticized by those using approaches having their origin in the value generation[i] concept. This concept is the subject of the present chapter.

5.1 Rationale

The rationale of the value generation concept of production can best be recognized by contrasting it to the transformation concept. It was Levitt who, in 1960, attacked the then prevailing production paradigm:

> Mass-production industries are impelled by a great drive to produce all they can. The prospect of steeply declining unit costs as output rises is more than most companies can usually resist. The profit possibilities look spectacular. All effort focuses on production. The result is that marketing gets neglected.
>
> The difference between marketing and selling is more than semantic. Selling focuses on the needs of the seller, marketing on the needs of the buyer. Selling is preoccupied with the seller's need to convert his product into cash, marketing with the idea of satisfying the needs of the customer by means of the product and the whole cluster of things associated with creating, delivering and finally consuming it.
>
> …a truly marketing-minded firm tries to create value-satisfying goods and services that consumers want to buy.

Much later, Drucker (1989) formulated the same point as follows:

> Finally the most important single thing to remember about any enterprise is that results exist only on the outside. The result of a business is a satisfied customer… Inside an enterprise there are only costs.

In essence, Levitt and Drucker argue that the value of a product can be determined only in reference to the customer, and the goal of production is satisfying customer needs. This is in stark contrast to the very internally oriented managerial model, based on the transformation concept, where internal production matters were emphasized rather than the customer[ii].

5.2 Conceptualization

5.2.1 Concept of value generation

Levitt and Drucker thus proposed a conceptualization of production that incorporates the customer. In fact, such a conceptualization had already been developed by Shewhart (1931) at the outset of the quality movement, as the following quote shows:

> Looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kinds. These wants are statistical in nature in that the quality of a product in terms of physical characteristics wanted by one individual are not the same for all individuals.
>
> The first step of the engineer in trying to satisfy these wants is therefore that of translating as nearly as possible these wants into the physical characteristics of the thing manufactured to satisfy these wants. In taking this step intuition and judgement play an important role as well as the broad knowledge of the human element involved in the wants of individuals.
>
> The second step of the engineer is to set up ways and means of obtaining a product which will differ from the arbitrarily set standards for these quality characteristics by no more than may be left to chance.

The customer-supplier relation, as described by Shewhart, has been presented in the quality movement as shown in Figure 6. This framework introduces the customer and the product with its features. It makes it evident that it is not the transformation itself that is valuable, but the fact that the output corresponds to the requirements, wishes, etc., of the customer.

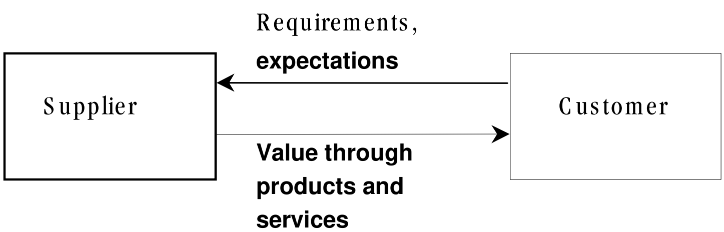

Figure 6. The conceptual scheme of a supplier-customer pair.

However, this model is a black box model: it does not tell us anything about the internal mechanisms inside the supplier, ensuring value generation. In order to be operational, the black box in the value generation model has to be opened. A first consideration is to discover which are the major subsystems and what happens in them. Shewhart, speaking of mass production, recognized two subsystems: product design and production. However, for a general case, we have to take a third subsystem, namely order-delivery. The situation is depicted in Figure 7. In the design function, the wishes and requirements of the customer are translated into a product design and specification. In the order-delivery function, an appropriate due date is set based, among other things, on information from the customer. In the production function, the product design and specification, as well as the due date control the transformation of production factors into the product and the associated flows.

The functional performance of the product, a primary attribute of customer value, is determined in design, barring defective production. Thus the role of design in value generation is crucial. It will be explored in more detail in Chapter 7, while the issues pertinent to production in general are assessed here.

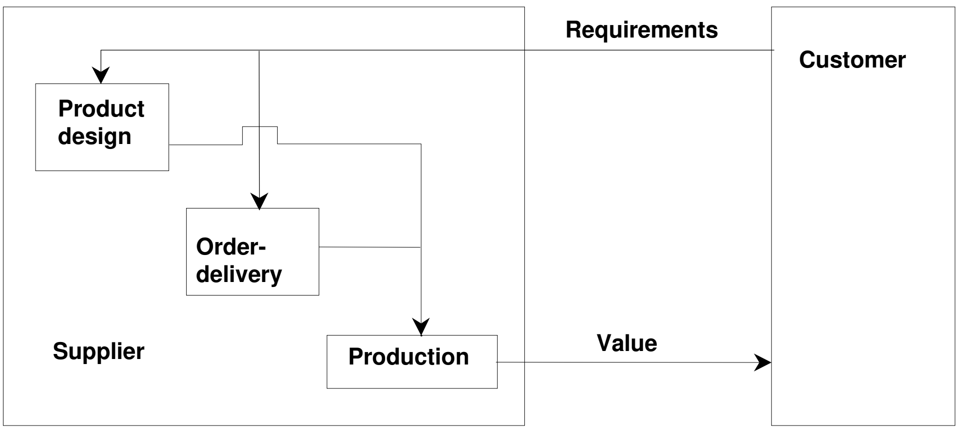

Figure 7. The black box of value generation opened. As in IDEF0, control is indicated by an arrow hitting the top of a box.

In what way is this model different from the transformation model of production, also a black box model, as introduced in Chapter 3? Firstly, by definition, the value generation model considers all activities taking place inside the supplier, rather than just the physical production[iii]. Secondly, the model covers the customer, abstracted away in the transformation model. Thirdly, in this model, the input is made up by customer dependent information, and the output is the fulfillment of customer needs, or value, whereas in the transformation model all inputs are considered, and the output consists of the products (or services). Fourthly, this is not a hierarchical model: all activities are not similar (to be developed further below). In particular, the product development and design activities are intrinsically different from production activities. Thus, in conclusion, it can be said that this model is inherently different from the transformation model.

But how are the phenomena described in this model related to the phenomena described in the transformation model or the flow model? In the value generation model, the focus is on control of the transformation and the flow, namely *control for the sake of the customer*. This control aspect is especially clear in the production phase, but also in the design, it is the requirements that control the transformation of all information needed into a design solution. Thus, in opposition to the transformation concept and the flow concept, the value generation concept does not focus on any particular aspect of physical production but rather on its control.

5.2.2 Requirements and value

The two entities which exchange in this model, requirements and value, merit a further analysis. How exactly do requirements control production? There seems to be two extreme possibilities. The first is that the needs and wishes of a customer (or the customers) are condensed[iv] into a specification of the product (Karlsson et al. 1998), and that the specification controls[v] the design function. In turn, the documented design of the product controls the production function. The second possibility is that the customer communicates directly with all design and production parties[vi], making decisions relevant to him, either on his initiative or by their initiative. Both possibilities have benefits and drawbacks, and, in practice, a mixture of the two is used.

Regarding then value, essential issues involve how to define and measure it. As Cook (1997) states, one way of solving this is to view value as the price that the customer paid for the product. However, if value is a fundamental property of a product, it cannot be set equal to a price that is arbitrary. Cook proposes a method to estimate the absolute value of a product, basing on microeconomic theory. By subtracting the price of the product from its absolute value, we come to the net value of the product for the customer. Barnard (1995) defines value as benefits/price. Still another possibility is to analyze the relative value of a product in comparison to its competitors (Cook 1997).

Womack and Jones (1996) have suggested viewing the provision of a wrong product or service as *muda*, i.e. waste. However, this phenomenon is in the domain of value generation, and, for clarity, in this study the concept of *value loss* is adopted to refer to the part of value not provided even if potentially[vii] possible. This concept is one way of measuring value in relative terms.

One associated question is how the customer is defined. Taguchi proposes that any deviation from a target value in the product causes a loss, which is a quadratic function of the deviation, to the user and wider society (Taguchi 1993). Thus, by definition, wider society should be included as one customer.

5.2.3 Use of the value generation concept in internal analysis of production

Because in value generation transformations and flows are controlled for the sake of the customer, attributes of transformations and flows impact directly on the resultant value. However, the same attributes are also often interesting regarding internal goals of production. Thus, it is no wonder that notions derived from the value generation concept were soon generalized for internal analysis of production.

At the outset, the major focus of the quality movement was the customer value and the point of view was conformance to specification. It soon became evident that the same approach could also be used internally in production. The critique against the transformation model from such an internal quality point of view points out that the output of each (elementary) transformation is usually variable to such an extent that a part of the output does not fulfill the implicit or explicit specification for that transformation and has to be scrapped or reworked[viii]. The recognition of variability opened up the possibility of using methods based on statistics in quality control of production.

The other critical observation was that the specification for each transformation is imperfect; it only partially reflects the true requirements of the internal customers (subsequent activities). Ishikawa (1985) writes: “I invented the phrase ‘the next process is your customer’ while working with a steel mill from August 1950 to September of that year”. Through this conceptualization, the interdependencies between production activities can be captured and the optimization of activity sequences can be approached in a structured way. However, it should be noted that even if these internal customerships can be analyzed in a similar way to external ones, they should be subordinate to the consideration of the customer proper, upon whose satisfaction the existence and profitability of the production system is dependent.

Note that both of these two issues have also been addressed based on the flow concept of production, but not with the same rigor. The contribution of the quality movement lies, firstly, in the recognition of variability as a part of industrial life and the development of related methods, and secondly in the conceptualization of the internal supplier-customer relationship.

5.3 Principles

The results of prior research can be structured into five principles, which, more or less, cover the whole cycle of value generation, as illustrated in Figure 8. These principles will be elaborated next.

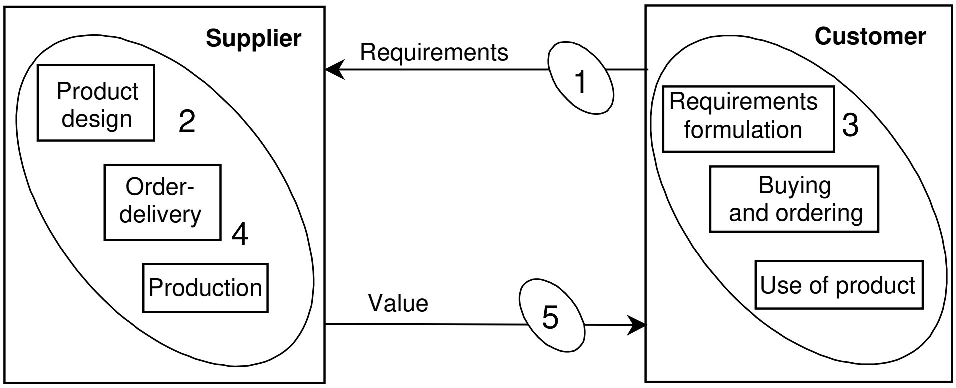

Figure 8. Principles related to the value generation concept. The numbers refer to principles as follows: 1. Requirements capture. 2. Requirement flowdown. 3. Comprehensiveness of requirements. 4. Capability of production subsystems. 5. Measurement of value.

5.3.1 Requirements capture

Principle**:** *Ensure that all customer requirements, both explicit and latent, have been captured.*

It is obvious that the capture of all customer requirements is requisite, as a first step of value generation. In this regard, the Kano model of customer satisfaction has become popular (Bergman & Klefsjö 1994). It argues that needs and requirements can be separated into three groups: basic needs, expected needs, and exciting requirements. The basic needs are so obvious that the customer might not describe them even if asked. On the other hand, the customer can usually not even imagine exciting requirements. When asked, the customer will usually discuss expected needs.

5.3.2 Requirement flow-down

Principle: *Ensure that relevant customer requirements are available in all phases of production, and that they are not lost when progressively transformed into design solutions, production plans and products.*

There are two developments from which this principle can be derived. Firstly, Quality Function Deployment, which makes visible the flow-down of requirements across all stages. Secondly, various organizational means have been used to ensure that the customer voice is being heard (Griffin et al. 1995). Interaction with the customers has, in general, been increased. Also, interaction of employees directly with the customer has been encouraged (Ostroff & Smith 1992).

5.3.3 Comprehensive requirements

Principle: *Ensure that customer requirements have a bearing on all deliverables for all roles of the customer.*

All deliverables to the customer have to be taken into consideration. These can conveniently be grouped into three major platforms: product, service, and delivery (Kim & Mauborgne 1997). Research shows that for the majority of cases, the problems customers encounter in regard to products are related to poor quality of services rather than to the product itself (Whiteley 1991). In addition, all the actual roles of the customer have to be taken into account. The customer has not only the role of user, but also the roles of buyer, product co-producer[ix] (or co-designer) and resource (Lengnick-Hall 1996).

5.3.4 Ensuring the capability of the production system

Principle: *Ensure the capability of the production system to produce products as required.*

However, even the best control does not ensure generation of value if the production system is not capable of designing, producing and delivering products as required by customers. Thus, the controllability of the production system from the point of view of the crucial control goals should be ensured. Obviously, the basic goal of having production under statistical control (Shewhart 1931) is salient here. In addition, attributes related to speed of production and dependability of production play a role (Slack et al. 1995).

5.3.5 Measurement of value

Principle: *Ensure by measurements that value is generated for the customer.*

The importance of measuring the actual value (or customer satisfaction) of the products of a company is widely emphasized (Whiteley 1991, Kordupleski et al. 1993). Research has shown that customers only rarely complain, even if they have good grounds to do so (Whiteley 1991, Bergman & Klefsjö 1994). Thus, the acquisition of information on actual customer satisfaction requires specific efforts[x].

5.4 Production template

Treacy and Wiersema (1993) distinguish three different emphases in customer orientation: operational excellence, customer intimacy, and product leadership. Operational excellence refers to providing customers with reliable products or services at competitive prices and delivered with minimal difficulty or inconvenience. Customer intimacy means tailoring offerings to match exactly the demands of customers in selected niches. Product leadership means offering customers leading-edge products and services that consistently enhance the customer's use of the product. This typology is instructive in reminding us that superior customer value can be created in a number of ways, and stressing different parts of the production cycle. Also, the resulting production templates are quite different.

It cannot be argued that there would be a mature template based on the value generation concept. However, the following features of an emerging production template are prominent.

5.4.1 Design

Regarding design of production systems, the major implication seems to be that customers are used as a structuring principle (Schonberger 1996). The elimination of barriers to collaboration in the interest of customer satisfaction is one feature[xi]. Another possibility is to make an alliance with the customer. An even more far-reaching solution is to change the transaction with the customer: instead of being concerned with the product with its functionalities, the transaction is geared to address the functionalities themselves[xii] (with or without the transaction of the product itself).

Juran (1992b) argues that the customer value principle leads to redesigning jobs in ways that bring the worker closer to the status of artisan, who is directly exposed to the needs of various customers and who is his own customer, over and over again.

5.4.2 Control

Regarding control, the facilitation and management of the value generation cycle seems to be the prioritized issue. Systematic methods, like Quality Function Deployment, frequent customer contacts, etc., are used.

5.4.3 Improvement

Regarding improvement, such issues as measurement of customer satisfaction, related targeting, and linking of incentives to customer satisfaction seem to proliferate.

5.5 Diffusion and evolution

5.5.1 Production paradigm

Depending on the starting point, two evolutionary trajectories can be recognized, one for quality-based methods, another for marketing-originated value-based methods.

5.5.1.1 Quality methods

The work of Shewhart was mainly focused on the second step (of product realization as discussed by him, section 5.2), namely how to get products, which conform to specification. His successors, Deming, Juran and Feigenbaum also initially concentrated on this second step, which actually brought them to consider product quality as freedom from defects. It is only in the 1980s that the quality movement started to elaborate the first step. It was realized that the specification could also be imperfect, not genuinely reflecting the true requirements of the final customer. This kind of quality was named Biq Q, in contrast to the little q, that is, the earlier emphasis on product quality (Juran 1992a).

The quality methodologies have developed in correspondence with the evolution of the concept of quality. The focus has changed from an inspection orientation (sampling theory), through process control (statistical process control and the seven tools[xiii]), to continuous process improvement (the new seven tools[xiv]), and to designing quality into the product and process (Quality Function Deployment).

As a production paradigm, the quality movement originated in Japan. Quality issues were attended to by Japanese industry under the guidance of Deming, Juran and Feigenbaum. The quality movement in Japan soon evolved from mere inspection of products to total quality control (or management). The term total refers to three extensions (Shingo 1988): (1) expanding quality control from production to all departments, (2) expanding quality control from workers to management, and (3) expanding the notion of quality to cover all operations in the company. In the West, Deming (1982) presented a general management philosophy based on quality ideas. International standardization of quality concepts, methods and practices (SFS–ISO 9000 1988) has been significant in the diffusion of the quality paradigm.

5.5.1.2 Value based methods

Already Ford (1926b) was distanced from the view of business as "making of money": "The organization of industry to serve the people will not interfere with the profitableness of industry, as some seem to imagine."

It seems that a growing number of companies have since the beginning of the 1980s adopted features based on the value generation model. The initiatives have been called by differing names, like value-based management, customer-driven company, customer orientation, and mass customization.

The study of Griffin et al. (1995) gives an interesting picture of a number of manufacturing companies that have launched customer-oriented initiatives. It was found that the improvement of customer satisfaction typically started in service, repairs and maintenance, progressing then to order fulfillment and delivery and the (internal) quality process. Surprisingly, improvement of product development was the last to be addressed, and, according to the research, some confusion existed as to what to do in this field. A relatively wide variation in approaches was found.

5.5.2 Benefits

Benefits due to methods based on the value generation concept have been studied surprisingly little. A study based on the PIMS data (Buzzell & Gale 1987) shows that perceived quality strongly impacts on returns on investment (ROI). Whereas the companies ranked in the top quintile in their industries achieved a ROI of 32 %, the two lowest quintiles of companies reached a ROI of 18 % on average. Similar results are reported by Laitamäki & Kordupleski (1997). Based on empirical data, Kim & Mauborgne (1997) argue that a strategy based on value innovation (quantum leaps in value to the customer) leads to high growth in both revenues and profits in contrast to a strategy stressing incremental innovations. Ollila (1995) finds that those companies using certified ISO 9000 quality systems have been able to improve their quality, according to customer satisfaction measurements.

5.5.3 Anomalies

Evidence on anomalies is anecdotal at best. Already Levitt (1975) noted that some companies have become "obsessively responsive to every fleeting whim of the customer", losing thus the existing benefits of mass production. Similarly Porter (1996) found that some managers mistake customer focus to mean they must serve all customer needs or respond to every request from distribution channels.

5.5.4 Scientific paradigm

Value generation has, from various viewpoints, been scientifically treated in the domains of quality, marketing, business management, strategy, design and microeconomics, at least. However, these pursuits have largely progressed in isolation from each other. Grant et al. (1994) trace back reasons for this situation regarding the incompatibility of theories of quality and management. They state that intellectual origins, sources of innovation, national origins and the dissemination process of TQM are different from those of conventional managerial theories, based on the economic model of the firm. Thus, TQM has not raised interest on the part of management theorists.

Indeed the work of Cook (1997) seems to be the first attempt at unification of various conceptual strands of value generation.

5.6 Conclusions

A conceptualization explaining how, in production, value is generated for the customer has been discussed. The associated concept of production focuses on the interaction between a customer and a supplier (producer), where requirements are provided by the customer and value by the supplier. The associated principles of production address requirements capture, requirement flowdown, comprehensiveness of requirements, capability of various supplier subsystems and value measurement. A production template based on this conceptualization has been introduced in industrial practice. Scientific understanding of value generation is still fragmented, but the pursuit at unification has started.

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[i] There would have been several alternative names for this concept. However, the term *value generation* provides a neutral alternative that is not associated with any particular existing approach. This term has been used by Cook (1997), for example (p. 87: "How does your product generate value for your customer…").

[ii] The detailed description, based on IDEF0 models, of manufacturing processes by Harrington (1984) is especially cogent. His pictorial model of "manufacturing products" does not include any information flow starting from customers. Even in product development, the product specification is received from corporate management.

[iii] Even if the transformation concept can also be used for design, it originally referred only to physical production.

[iv] In fact, this formulation of a specification has been abstracted away from Figure 7.

[v] Specification can also be seen as an *input* to the design process, corresponding to the transformation view. This is not contradictory, indeed specifications have these two roles, as suggested by Reinertsen (1997).

[vi] This has been suggested by Chase & Garvin (1989), for example.

[vii] Of course, the notion "potentially possible" is crucial here. One way of determining it is to look at competitors; if they provide more value, is it potentially possible also for the enterprise in question. Another way is to determine the potential value is to estimate the value in case the whole product realization cycle were ideal; for example, there were no defects.

[viii] As Garvin (1988) notes, Shewhart was the first to realize that variability was a fact of industrial life and that it could be understood using the principles of probability and statistics.

[ix] For example, Udwadia and Kumar (1991) argue that co-producing requires such capabilities as rapid prototyping, customer experimentation with the product, and flexible manufacturing.

[x] In his study on quality in the room air conditioning industry, Garvin (1988) found that data on service calls were reported at much higher levels and in much greater detail at plants with superior quality. At the poorest plants, such information was seldom available.

[xi] Galbraith (1995) says on this topic: “In my view, organizational designs should make it simple for the customer to do business with the organization. Designs should also make it easy for employees with customer and product contact to execute their roles.”

[xii] For example, instead of a ventilation system, an agreed level of its functioning is delivered to the customer.

[xiii] Pareto-diagram, cause-and-effect diagram, histogram, control chart, scatter diagram, graph and checksheet.

[xiv] Relations diagram, affinity diagram, tree diagram, matrix diagram, matrix data-analysis diagram, process decision program chart, and arrow diagram (Mizuno 1988).

6. The transformation-flow-value generation concept of production

In the preceding three chapters, it was found that three major concepts of production have actually been used during the 20th century. These concepts have, for the major part, been implicit, and they have not been used in balanced combination, but rather with emphasis on one model, resulting in the neglect of issues contained in other models. What should be put forward as a theory of production, based on these findings? And how it is related to other contemporary theories or conceptualizations of production, aiming at comprehensiveness?

6.1 Integration of the different concepts

6.1.1 Are all three concepts always needed?

A historical analysis has thus revealed that there are three concepts of production. In the first concept, production is viewed as a transformation of inputs to outputs. Production management equates to decomposing the total transformation into elementary transformations and tasks, acquiring the inputs to these tasks with minimal costs and carrying out the tasks as efficiently as possible. This is a perfectly sensible view on production which, of course, we have encountered numerous times both when observing practice or studying theory.

The second concept views production as a flow, where, in addition to transformation, there are waiting, inspection and moving stages. Queueing theory, which applies to such flows, teaches that variability is the crucial determinant of the behavior of flows. Production management equates to minimizing the share of non-transformation stages of the production flow, especially by reducing variability. Again, this makes sense, and the triumph of the JIT and lean production has practically proven the power of this conception.

The third concept views production as a means for the fulfillment of customer needs. Production management equates to translating these needs accurately into a design solution, and then producing products that conform to the specified design. Once more, we are ready to accept this view, which long since has been advocated by the quality movement.

Are all three concepts needed for every production situation? This question is best examined by considering the counter-question: in which situations would some concept not be needed?

It is very difficult to imagine a productive activity where there is no transformation. Even if production just consists of gathering the fruits of nature, there is the task of spatial transformation.

Is there a productive activity where there is no flow? Only in an extreme case, if input is taken from an infinite, direct source, and output is sent directly to the customer, with infinite capacity, one hardly needs to take care of the flow nature of production. This would be the case in the fictive case where the decomposition of coal-dioxide into its constituents[i] is commenced as a countermeasure to the greenhouse phenomenon.

Do we always have to attend to the value generation nature of production? Apparently no, or at least very little, if the productive transformation has only one end state, in which case there is no possibility or need to control it. The extermination of insects is such an activity; however, even in this case, we hope that the extermination is not harmful to other living creatures[ii].

Thus, we have to believe that the three concepts each capture an intrinsic phenomenon of production, and in a practical production situation, we should almost always act on the basis of advice derived from each of them.

Additional support to this view is given by the consideration of the history of the transformation view. The situation of the transformation concept as the sole foundation of production led, as explained in Chapters 3–5, to anomalies, i.e. counterproductive methods, because the principles emanating from the flow concept or the value generation concept were either neglected or simply violated. Anomalies due to a similar source could also be found regarding the production paradigms based on the flow or value generation concept.

6.1.2 Integrating partial concepts of production

These observations provide justification for the following argument: *In production management, the management needs arising from the three concepts should be integrated and balanced.*

The three concepts of production are thus not alternative, competing theories of production, but rather partial and complementary[iii]. Each of them focuses on certain aspects of the production phenomenon: the transformation concept on the value-adding transformation; the flow concept on the non-value-adding activities; and the value generation concept on the control of production from the customer point of view.

As a first step towards integration, we can conceptualize production simultaneously from these three views. An overview of such an integrated transformation-flow-value generation concept of production is presented in Table 3. Let us call this model *the TFV theory of production,* made up of the T, F and V concepts (or T, F and V views[iv]) and associated principles. The crucial contribution of the TFV theory of production is in extending attention to modeling, designing, controlling and improving production from all these three points of view. Regarding practical management, let us call the domains of management corresponding to the three views as *task management, flow management and value management*[v].

Table 3. Integrated TFV view on production.

	Transformation view	*Flow view*	*Value generation view*
Concept-ualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main principles	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices (examples)	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirements capture, Quality Function Deployment
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name for practical application of the view	Task management	Flow management	Value management

A number of principles[vi] stemming from each view have been induced from practice or derived from theory (Table 4). However, we have to make several reservations. Firstly, even if there are grounds for believing that there is a domain of validity for each principle, they are presently not well known. Secondly, production concepts have been developed in particular industrial settings, especially the car industry, and, without systematic investigation, it cannot be ruled out that the principles reflect the specificities of this industry to some extent. Also, it is probable that we still do not know all the essential principles.

Table 4. Principles of production.

Main principles	*Associated principles*
Transformation view: Realize value-adding activities efficiently	Decompose the production task Minimize the costs of all decomposed tasks
Flow view: Reduce the share of non-value-adding activities	Compress lead time Reduce variability Simplify Increase transparency Increase flexibility
Value view: Improve customer value	Ensure that all requirements get captured Ensure the flowdown of customer requirements Take requirements for all deliverables into account Ensure the capability of the production system Measure value

What is the significance of this conceptualization? This is the best theory of production that is available, and thus the functions of the theory should be realized in a superior way. Let us consider some key functions.

This theory includes an *explanation* of how the goals of production can be reached. The goal of getting intended products produced is realized by task management. The goal related to cost minimization is attributable to both the efficiency of the transformation activities performed (in the domain of task management) and the amount[vii] of non-value-adding activities through which the transformation activities are bound together[viii] (in the domain of flow management). The external customer-related goals of production are realized by value management. However, it is not enough to carry out task, flow and value management as separate functions. They have to be balanced and their interactions have to be controlled for avoiding anomalies. This will be discussed below in section 6.1.3.

Secondly, this theory provides a *prediction***.** Evidently, a production system where the operational principles of all three domains are implemented at all levels of managerial action (design, control and improvement), should have better performance than one where principles are implemented less comprehensively. This subject is discussed at greater length in Chapter 11.

Thirdly, this theory – or its gaps – provide *direction* for research and experimentation. This will be discussed in more detail below, in section 6.1.4.

Fourthly, the theory, when explicit, can be *tested* regarding its validity. This will be discussed in section 6.1.5.

Fifthly, this conceptualization might be instrumental in *transferring* and translating practices developed in one production situation to other, different production situations, where similar methods and practices still do not exist. This issue will be touched later in Chapter 10.

6.1.3 Balancing the views for avoiding anomalies

Thus, we have three different sets of principles, partly contradictory, on the basis of which we can design, control and improve our production system. Which principles should be used in a particular situation? Actually, this is largely a research question, which has been tackled only for a small part in prior research. Regarding the general case of balancing between the different concepts, our understanding is only starting to develop. In the following, these issues are illustrated firstly regarding the problem of production system design and secondly generally regarding the types of interaction between the concepts.

6.1.3.1 Balancing at the level of production system design

In the three production templates based, respectively, on T, F, and V concepts, the production system was designed based on considerations deriving from the respective concept. Does a "TFV production system design", based on all three concepts, exist?

In advanced production in industries like those producing cars or information and communication technology, there are attempts underway for simultaneously implementing all three concepts, but it is still too early to judge whether a template has been formed. Interesting ideas in this respect are presented by Womack and Jones (1996), who, for the most part, propose flow management to be the primary structuring factor. However, for functional management (here called task management), they foresee the role of a functional home, where the improvement of transformation capability is the primary goal. The place of value management is still missing from this proposal. However, the recent trend of defining value management (led by a value manager) from prior functions of marketing, selling and customer-wise product design (Stenberg 1997) provides for one possible solution.

Thus, it would seem that the different views on production relate to such distinct phenomena that if a particular view is not used as a primary structuring factor, it must at least have "a corner of its own" in the overall production system design. On the other hand, obviously different production situations require different decisions regarding the selection of the primary structuring view for a production system.

6.1.3.2 Interactions between concepts

It is easier to achieve a balance between the views if we know the interactions between the views in question. An initial overview on the interaction between phenomena covered by different concepts of production as treated in the literature is presented in Table 5.

Table 5. Interaction between phenomena covered by different concepts of production.

	Impact on T	*Impact on F*	*Impact on V*
Impact from T on another concept		More expensive transformation technology will provide for less variability.	More expensive inputs contribute to better product.
Impact from F on another concept	Flows with less variability require less capacity. It is easier to introduce new transformation technology, if there is less variability.		More flexible production system allows the satisfaction of more variable demand pattern. Production system with less internal variability is capable of producing products of higher quality.
Impact from V on another concept	More variable demand patterns prevent scale benefits and high utilization.	Perfection of internal customer-supplier relationships contributes to reduction of waste.	

Interaction between T and F concepts

As discussed above, in Chapters 3 and 4, the phenomena covered by the T concept and the F concept are intimately interconnected. This has implications for the order and priority of different improvement needs.

Shingo (1988) argues that "only after opportunities for process improvement are exhausted should operations improvements corresponding to the process be started". There are two underlying motivations for this. First, better flows require less transformation capacity and thus less equipment and facility investment. Secondly, more controlled flows make implementation of new transformation technology easier. Implementation of new technology is difficult when there are many intervening disturbances (Hayes et al. 1988, Chew et al. 1991) Also, poor flow efficiency is a barrier to (transformation) innovation, because the benefits of an innovation become invisible in the confused environment (Imai 1986).

On the other hand, new transformation technology may provide smaller variability and thus flow benefits. Therefore, after exhausting flow improvement potential realizable in the framework of flow management, technology investments may be aimed, besides transformation benefits, at flow improvement or redesign.

Interaction between F and V concepts

Interactions between the flow and value generation concepts have to some extent been discussed above in Chapter 5. As found already by the early quality movement, a production system with less internal variability is capable of producing products of higher quality (with less defects). A more flexible production system allows the satisfaction of a wider or variable demand pattern and thus more value can be generated. The perfection of internal customer-supplier–relationships contributes to a reduction in waste.

Interaction between T and V concepts

In Chapter 2, it was found that better, and thus more expensive, input usually contributes to a better product. Scale benefits and high utilization, as aimed in the production paradigm based on the T concept, are difficult to reach if we simultaneously try to provide highly customized products.

Conclusions

This initial overview reveals that the different views imply both divergent and parallel advice for design, control and improvement. A trade-off must be found regarding divergent advice, and synergy must be utilized regarding parallel advice. All in all, interactions between the views have to be better understood.

6.1.4 Direction for creating added understanding

As discussed above, the TFV concept in itself calls for a better understanding of interactions between the views. This is just an example of how a theory gives direction for further search of understanding. In addition, the juxtaposition of the three concepts might facilitate finding generic principles or methods, applicable to each of them, and having a sharper definition of each concept and its implications. Also, the present state of the theory calls for unification.

6.1.4.1 Understanding generic principles in management concerning these views

Are there generic principles in management concerning all these three views? While there is no definite answer yet, we are tempted to develop two hypotheses by induction. Historical analysis reveals that the transformation view has developed, firstly, through explicit representation of the production process, aiming at clarity and transparency, and, secondly, through introduction of systematic methodologies for planning, controlling and monitoring the production process. An example of the first feature is provided by Work Breakdown Structure (WBS), and of the second feature, by Material Requirements Planning (MRP).

Support for the thought that similar principles also apply in the other two views is given by such methods as flow modeling (in the flow view) and Quality Function Deployment (in the value generation view), which actually contain both the features discussed. Thus, it is justifiable to think that *(1) transparency of the production system from one view, achieved through explicit modeling and other means, as well as (2) use of systematic methodologies to manage the production system from one view is conducive to a successful outcome of production from that view.*

6.1.4.2 Understanding each view

Obviously, we need to create understanding and to accumulate knowledge on each view. Concepts should be clarified, methods developed and tools tried out.

The *transformation view* has been used a long time, and thus it should be the best-understood view. However, there might be room for refinement and augmentation of the methods and tools in this view. For example, Cooper (1995) reports that leading implementers of lean production also have innovative cost management systems. Of course cost management is one core application of the transformation view.

The understanding of the *flow view* has recently widened in the sense that physical laws have been formulated (Hopp & Spearman 1996) for this view. However, much remains to be clarified.

The *value generation view* is the least understood among the views. Thus, at the outset, exploratory research is needed besides experimentation with associated methods.

6.1.4.3 Unified concept of production

Even if the TFV concept of production is, at the moment, the best conceptualization available, it can easily be recognized as insufficient as such because it consists of three partial conceptualizations. The ultimate goal should be a unified conceptualization of production.

6.1.5 Validity of the TFV theory of production

The validity of the TFV theory of production can be sought in at least three ways. Firstly, there is historical justification. It has been shown, in Chapters 3–5, that each of the three concepts has been the dominating idea of a major production template. Each template has brought about performance gains in comparison to its predecessor. Thus, there are grounds to think that all three concepts are necessary parts of a theory of production.

Secondly, we can compare this theory to prior theories of production. Is it possible to pinpoint problems, inconsistencies and deficiencies in these theories through this new theory? Such a comparison will be carried out below in section 6.2.

Thirdly, as the most severe test, we can find out whether the theory contributes to new understanding and improved performance when applied to specific production situations. Such an exercise will be discussed in the second part of this study, where construction is the industrial field being considered. In fact, construction, having defied most modern movements for efficiency, provides for an excellent platform for this kind of test.

The results from these three ways of validation will be integrated and discussed in Chapter 12.

6.2 Comparison of the TFV theory to contemporary theoretical approaches to production

In the following, contemporary theories of production are analyzed from the point of view of the TFV theory of production. The goal of the analysis is to clarify, whether it is possible to pinpoint problems, inconsistencies and deficiencies in these theories through the new theory.

6.2.1 The three production theories revisited

How should the three production theories, considered in Chapter 2, be evaluated on the basis of preceding analysis and discussion? Obviously, the conclusion must be that all three are partial and complementary.

The Walrasian production theory and the approach of Cook unify prior developments concerning production, and function thus as valuable pieces for further unification. The Factory Physics presented by Hopp and Spearman essentially aims at giving a solid physical foundation for production management, by means of which both the traditional MRP oriented and the newer JIT oriented production practice could be explained. Indeed, it is a major contribution to knowledge.

However, there is a critical gap in the conceptualization presented by Hopp and Spearman: there is no sharp recognition of waste in production. Would JIT production have been created if its originators had had access to Factory Physics laws, rather than the legacy of classical industrial engineering? The answer must be: probably not, or at least it would have taken considerably longer. Hopp and Spearman suggest that reducing variability and adding capacity are, in principle, interchangeable options. However, due to intangibles (like learning) associated only to variability reduction, they "believe that variability reduction is generally the preferred improvement option, which should be considered seriously before resorting to capacity increases". This lukewarm recommendation is far away from the strong ethos of waste elimination, the founding idea of JIT production.

6.2.2 Value chain theory

Porter's value chain theory of the firm (1985) represents well the modern thought in managerial sciences. It has been extremely influential since its publication. Although it focuses on the competitive position of the firm it evidently also covers the production stage, and in practice it has been understood as a theory of production as well, and it is frequently referred to in operations management literature. Thus, it is instructive to compare it with the TFV concept of production.

The foundation of Porter's theory is as follows (Porter 1985, p. 39):

> Economists have characterized the firm as having a production function that defines how inputs are converted into outputs. The value chain is a theory of the firm that views the firm as being a collection of discrete but related production functions, if production functions are defined as activities. The value chain formulation focuses on how these activities create value and what determines their cost, giving the firm considerable latitude in determining how activities are configured and combined.

So far, more or less according to the transformation concept: all activities in a value chain are "value activities". However, the assumption of the independence between activities is relaxed:

> ...the value chain is not a collection of independent activities but a system of interdependent activities. Value activities are related by linkages within the value chain. Linkages are relationships between the way one value activity is performed and the cost or performance of another.

Rightly, Porter presents the Japanese manufacturing practice as the source of the recognition of the linkages:

> Linkages imply that a firm's cost or differentiation is not merely the result of efforts to reduce cost or improve performance in each value activity individually.

According to Porter, linkages can lead to competitive advantage in two ways: optimization and coordination. Optimization is needed for tradeoffs among activities to achieve the same overall result. Coordination is needed, for example, for reducing the need for inventories throughout the firm. Linkages arise from a number of generic causes; Porter lists four of them:

- The same function can be performed in different ways.
- The cost or performance of direct activities is improved by greater efforts in indirect activities.
- Activities performed inside a firm reduce the need to demonstrate, explain, or service a product in the field.
- Quality assurance function can be performed in a number of ways.

The value chain theory partially addresses the same deficiencies of the transformation model as noted by JIT and quality critique. The empirical and theoretical recognition of interdependencies between activities is handled through a new concept of linkage. However, as the list of the causes of linkages makes evident, it is not possible to explain the interdependencies through this concept, neither does it help to chart existing interdependencies systematically. The important distinction between value activity and "non value activity" is not recognized. Thus, although the value chain theory rightly pinpoints the linkages between activities as a major source of improvement, the direction given is too vague to be practical, and the conceptual tools provided are ill suited for the task[ix].

Porter presents linkages as one of ten cost drivers, by means of which cost can be reduced for competitive advantage. However, as the rapid triumph of JIT and lean production has shown, attention to the elimination of non-value-adding activities has, simply, produced superior results in comparison to other alternatives. In fact, Womack and Jones (1996) take the view that competitive strategy can simply be forgotten[x]; what is needed is concentration on the elimination of waste[xi].

The other major deficiency of the value chain theory is that it does not – in spite of its name – explain or predict how value is generated for the customer. This paradoxical situation is caused by using the term "value" to refer to price (p. 38):

> …value is the amount buyers are willing to pay for what a firm provides them. Value is measured by total revenue.
>
> The value chain displays total value, and consists of value activities and margin.

However, value as just defined and value – apparently – as benefits/price are mixed in the text, like the following sentence shows[xii] (p. 3):

> Value is what buyers are willing to pay, and superior value stems from offering lower prices than competitors for equivalent benefits…

According to Porter, a firm differentiates itself from its competitors if it can be unique at something that is valuable to buyers. This differentiation strategy seems to be in the same domain as the V concept, but there is at least one important difference at the outset. According to the value chain theory, customer value should be created only to the extent that it creates a competitive benefit, rather than as a goal in itself, as in many approaches[xiii] based on the V concept.

Again, in the differentiation strategy there are a number of drivers; the most important being policy choices, linkages, timing, and location. The single most important uniqueness driver, policy choices, warrants a closer look. According to Porter, firms make policy choices about what activities to perform and how to perform them. Typical policy choices include product features and performance offered, services provided, etc.

Of course it is true that such policy choices have an impact on the level of uniqueness; in fact, we could even claim that all factors affecting uniqueness are ultimately policy choices. The problem is that the term 'policy choices' does not explain anything. The interesting question is how policy choices should be made regarding, say, product features, in order to create the needed uniqueness. However, on this issue, Porter is silent. The puzzling fact is that product development and design, the major stage regarding value creation, is not presented in Porter's pictorial scheme of value chain nor included in the index of the book.

Thus, in summary, in his value chain model, Porter tries to catch phenomena that simply lie beyond his theoretical framework. He can list them, but lacking a suitable theory, he cannot explain them. In critical evaluation, the value chain theory of firm must be characterized as an attempt to patch up the old theory, rather than as a new theory. It fails to explain the formation of cost and value, its very focus. The basic problem is that it is not possible to explain phenomena of the F and V domain through concepts of the T domain.

This said, it must be acknowledged that this theory has produced valuable insights into strategy, and it has been a major contribution in its time. However, the theory was created at the beginning of the 1980s and it was based on the theoretical underpinnings then at hand. Now, after the assumptions on which it is based have been challenged, it is also opportune to re-evaluate the value chain model.

6.2.3 Lean thinking

"Lean production is 'lean' because it uses less of everything compared with mass production: half the human effort in the factory, half the manufacturing space, half the investments in tools, half the engineering hours to develop a new product in half the time." This characterization of lean production, as presented in the book "The machine that changed the world" by Womack et al. (1990), has captured the attention of production practitioners and researchers world wide since its publication. The term "lean production" has become widely used for referring to a set if principles of production or a specific template and practice of production.

The description of lean production by Womack and his co-authors has proved to be a highly useful synthesis of advanced manufacturing practices. However, as admitted later by these authors (Womack and Jones 1996), the book mentioned above did not concisely summarize the principles of lean production. Neither did it try to trace the intellectual history of lean production, or to relate these principles to other principles of production management.

In their newer book (1996), the authors endeavor to improve the theoretical side of the discussion of lean production. They summarize Lean Thinking in the following principles:

1. Precisely specify value by specific product.
2. Identify value stream for each product.
3. Make value flow without interruptions.
4. Let the customer pull value from the producer.
5. Pursue perfection.

Indeed, the authors cover a number of crucial principles or practices related to the F concept; the core concept of flow itself, however, is not treated. Moreover, the treatment of the V concept principles is deficient: it concentrates only on the requirements capture, but the subsequent process of translating the requirements into product characteristics is outside its scope. The T concept is not discussed at all (except maybe by a critique against batching).

On closer analysis, the five principles turn out to be rather like slogans. For example, regarding the fourth principle, it has been shown that either the push or the pull method is appropriate depending on the characteristics of the production stage in question (as stated in Chapter 4). Thus, the wording of the principle is too categorical.

The terminology used by Womack and Jones merits a critical note. What means: “value flows without interruptions”? Obviously, the authors mean that material and information – work-in-progress – proceeds from one value-adding activity to the next value-adding activity without staying in any non-value-adding activity. However, it is confusing to call work-in-progress value. In some other instances in the book, the term flow actually refers to continuous flow. Simply, the authors are using imprecise and unsystematic terms.

In summary, Lean Thinking contains an interesting discussion of some key ideas of production and related cases of implementation, but the treatment is practically confined to one conceptualization of production, and the terminology used is confusing. It fails to provide a proper theory of (lean) production.

6.2.4 Economic explanation of production and its organization

Above, it was stated that the classical view of economics on production has been the basis of the T concept of production. However, it would be wrong to assume that those views have been rejected in economics; on the contrary, they still are a part of the economic doctrine. Beyond that, various new theoretical positions, based on economics and bearing on production have been developed recently.

6.2.4.1 Production function

According to the well known text book[xiv] by Samuelson and Nordhaus (1985):

> Economics is the study of how people and society choose to employ scarce resources that could have alternative uses in order to produce various commodities and to distribute them for consumption, now or in the future, among various persons and groups in society.

Thus, production is clearly one of the subjects of economics. Promisingly, the textbook referred to has a section titled “The theory of production” (p. 579):

> The theory of production begins with specific engineering or technological information. If you have a certain amount of labor, a certain amount of land, and a certain prescribed amounts of other inputs such as machines or raw materials, how much output of a particular good can you get? The answer depends upon the state of technology: if someone makes a new invention or discovers a new industrial process, the obtainable output from a given factor inputs will go up. But, at any given time, there will be a maximum amount of output that can be produced with a given amount of factor inputs.

The technical law relating inputs to outputs, called production function, is defined as follows:

> The production function is the technical relationship between the maximum amount of output that can be produced by each and every set of specified inputs (or factors of production). It is defined for a given state of technical knowledge.

Further, an example of a production function for generating electricity is given:

> A book of blueprints shows the combination of plant, turbines, cooling ponds, and labor needed to produce 1 million kilowatts of power. On one page is a blueprint for an oil-fired plant – whose capital costs are low and whose fuel costs are high. On the next page would be the blueprint for a coal-fired plant: high capital costs (in part to remove the noxious emissions), but much lower fuel costs…. When all the different blueprints for 1985 are put together, these form the production function for electricity generation for 1985.

This, in substance, is what this enormously influential textbook has to say on production. The treatment of production is disappointingly shallow, even misleading. The first problem is that factually the output of production is dependent on two sets of factors, firstly, the technology, as proposed above, but also the level of production management. The huge differences in the level of production management have been commonly known at least from the twenties[xv]. Research shows that even within one company, performance differences may be as great as 2:1 (after controlling for other differences in age, technology, etc.) between the best and worst plant (Chew et al. 1990). However, economists have failed to act upon this knowledge.

It has to be noted that it would have been easy to formulate economic problems on the basis of the insight that the level of production management is a major determinant of production. As Moskowitz (1993) has formulated, one problem is how an enterprise should allocate its resources among production activities and process improvement activities, given that the latter cost the firm because of loss of production and other costs. Another problem is the allocation of resources for new technology or process improvement.

The second problem is, of course, that the production function does not say anything about how useful the output of production is. For the example given, electricity, this is not a major problem, but for most products, it is crucial which are the functionalities and whether there are defects.

In fact, the theory of production is not treated in the textbook of Samuelson due to the intrinsic interest of production, but rather “as a prelude to our general discussion of distribution of income”. This is not a different position given to the theory of production in comparison to Walras[xvi] (1952).

Thus, unfortunately, in just only repeating the views of classical economists, brilliant in their time, economists have failed to cultivate understanding about production. Rosenberg (1982) argues that there seems to have been cultural barriers preventing a closer study of technology (closely related to production):

> Economists have long treated technological phenomena as events transpiring inside a black box. They have of course recognized that these events have significant economic consequences, and they have in fact devoted considerable effort and ingenuity to tracing, and even measuring, some of these consequences. Nevertheless, the economics profession has adhered rather strictly to a self-imposed ordinance not to inquire too seriously into what transpires inside that box.

6.2.4.2 Economic explanation of the “modern manufacturing model”

Milgrom and Roberts (1990, 1992) define modern manufacturing as follows: vision of a flexible multiproduct firm that emphasizes quality and speedy response to market conditions while utilizing technologically advanced equipment and new forms of organization. Evidently, this is a variant of the lean production model.

The main question Milgrom and Roberts (1990) address is the following:

> This paper seeks to provide a coherent framework within which to understand the changes that are occurring in modern manufacturing. We ask, Why are these changes taking place? Is it a mere coincidence that these various changes appear to be grouped together, or is there instead some necessary interconnection between them and common driving force behind them?

According to Milgrom and Roberts, the root explanation to these questions is that technological change has reduced the costs of data collecting, organizing and communicating, product design and development, and flexible manufacturing. These price changes have thus, taking into account the complementarities between activities, and “non-convexities in the problem”, resulted in the adoption of the modern manufacturing principles, like the close coordination between functions.

However, the discussion on these exogenous variables is wrong twofold. The cheapening of data, design and flexibility was not originally realized by technology, but by new organizational and managerial methods, like kanban, visual management, concurrent engineering, and rapid set ups. Secondly, this cheapening was not a cause, but a result of a more profound change in the theory of production, and the action resulting from it.

The fact that comprehensive changes in production have occurred can, of course, be explained by the change in the underlying theory of production, leading also to all-encompassing change of principles and methods.

It cannot de denied that changes in input prices may affect the way manufacturing is managed. However, as it has been argued in Chapter 4, the rise of lean production is ultimately due to widened theoretical understanding on production rather than to input price changes.

6.2.4.3 Transaction cost economics

The transaction cost approach developed by Williamson (1979) and others recognizes that economics cannot deal only with costs of products and services bought. Rather, there are costs associated with every act of trading, called transaction costs. They are made up from search and information costs, bargaining and decision costs, policing and enforcement costs (according to Dahlmann (1979), referred in (Walker 1996)). In the language of industrial engineering, it could be said that one form of waste is thus recognized by economists.

The transaction costs of different organizational forms (especially market vs. hierarchy) vary, according to situational factors, especially transaction frequency, uncertainty and asset specificity[xvii]. According to the transaction cost theory, those organizational forms that minimize transaction costs are in the long run preferred. Thus, the theory can also be – and has been – used for explaining various existing organizational solutions in the sphere of production.

Unfortunately, other kinds of waste are not recognized by the transaction cost theory, because it views production as consisting of transactions (defined by Milgrom and Roberts (1992) as the transfer of goods or services from one individual to another; here, transfer refers to change of ownership). Clearly, this is a very narrow view of production, one that overlooks, for example, the transformation aspect of production[xviii]. In fact, the transaction cost theory argues that production should be organized on the basis of the costs of buying.

Of course, buying is not the essence of production. The objective should rather be to find organizational solutions to minimize all kinds of waste, rather than a specific type of waste associated with one function of production. On the other hand, in Chapter 5 the pursuits of companies were described as finding organizational forms that facilitate value creation for customers. Simply, it is not justified from the outset to seek a *general* explanation for the selection of an organizational form of production on the basis of the transaction costs. However, this does not exclude the possibility that there might have been periods when the pursuit of waste minimization and value generation were weak, and transaction costs were indeed the driver of the selection of organizational form.

It has to be noted that the preceding critique did not address the transaction costs approach as such, that is, as an explanation of behavior between parties making transactions. Rather, the use of the transaction cost approach for explaining organization of production was criticized.

6.2.4.4 Conclusions

Of course, economics is the mother of the T concept, and it is no surprise that no traces of F and V concepts can be found in its theory of production. But even its more recent offsprings, like organizational economics or transaction costs economics unfortunately inherit the conceptual deficiencies of the conceptualization of economics.

6.2.5 Discussion: partial theories, conceptual confusion

The review of contemporary theories bearing on production reveals, firstly, the strong foothold occupied by partial, one-concept theories of production, and, secondly, a scarcity of a sound theoretical foundation to many an approach. Comparison reveals that the TFV concept of production can be argued to be deeper[xix] than prior theories on production.

This present state of affairs has a regrettable consequence related to terminological clarity. Even such central concepts as “process” and “value” are being used in different, often contradictory ways. Confusion is bound to result[xx].

6.3 Conclusions

In this chapter, a new theory of production was proposed, and by comparison it was shown that it is deeper than prior theories of production. It explains and predicts the fulfillment of the central targets set to production. It gives direction for research and practical experimentation, and it adds to conceptual clarity. This theory of production is further explored in subsequent chapters.

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[i] Obviously, the resulting oxygen can be released back into the atmosphere. However, regarding coal, let us assume that it can be disposed of in a harmless form, say, in the ocean.

[ii] Even more discouraging for those of us wishing to neglect the value generation view is the macabre anecdote, related by Reinertsen (1997), on insecticide product development, where it was found that it was not enough that the insecticide kills the bugs. Rather, the customers wanted to see the bugs instantly on their backs, and their suffering before death. It is not only the end state that counts but also the style whereby it is reached.

[iii] The idea that processes have to be described from several points of view is well established in process modeling, having recently developed into an emergent discipline in itself. The aim of this discipline is to further develop the methods and tools of process descriptions. It has to be noted that this purpose is different from theory building for production where particular concepts related to production processes are selected as founding blocks for system design, control and improvement. In process modeling, there are four common perspectives to processes (Curtis et al. 1992):

- *Functional* represents what process elements are being performed, and what flows connect these elements.
- *Behavioral* represents when process elements are performed, and how they are performed through feedback loops, iteration, decision-making conditions, etc.
- *Organizational* represents where and by whom process elements are performed.
- *Informational* represents the informational entities produced or manipulated by the process.

These views do not directly match with the concepts suggested here. However, from these views, functional roughly corresponds to the transformation concept, behavioral in turn to the flow concept. For the organizational view, especially if extended to cover internal and external customer-supplier relations, the nearest counterpart is the value generation concept.

[iv] As defined by Wortmann (1992a), views represent particular, complementary aspects of reality. The term view is used here roughly in the same meaning as the term concept.

[v] The selection of the terms *flow management* and *value management* is obvious. Following Taylor's example (Chapter 3), management focusing on transformations is called *task management*.

[vi] The buffering and value principles of the transformation view are not presented here because they deal with special cases; the more general corresponding principles are presented in the framework of the flow and value views.

[vii] To be accurate, the efficiency of non-value-adding activities should also be taken into consideration.

[viii] In the discussion on strategy, the former has been called core competence, the latter capability (Stalk et al. 1992).

[ix] For another critical view of the value chain conceptualization, see (Womack & Jones 1996).

[x] Womack and Jones (1996) provide the following advice to lean firms: "To hell with your competitors; compete against *perfection* by identifying all activities that are *muda* and eliminating them."

[xi] These views have stimulated a sharp counter-attack by Porter (1996).

[xii] In later writings (Porter 1996), Porter has started to use the term "non-price value" for referring to a value concept not related to price.

[xiii] For example, Taguchi (1993) suggests that in product development, the cost is reduced and the quality improved as much as possible before a specified deadline; one can never know in advance what the quality levels and production costs of competing products will be.

[xiv] Since 1948, 15 editions of this book have been published, and more than 4 million copies sold (The Economist, August 23rd, 1997, p. 60). The book has been translated into 41 languages.

[xv] One example being the report "Elimination of waste in industry" (Anon. 1921).

[xvi] Walras (1952) explains that by means of the production theory, he aims to clarify the determination of prices of production factors: "*…par la théorie de la production, la determination des prix des matières premières et services producteurs…*"

[xvii] Milgrom and Roberts (1992) add two items to this list: difficulty of performance measurement, and connectedness to other transactions.

[xviii] However, it is fully compatible with the decomposition principle of the transformation model, assuming that production is conceived as the purchase of decomposed tasks or goods.

[xix] The TFV concept of production is even deeper than its constituent concepts collectively because the interaction of them can be explained by means of it.

[xx] For example, the article by Kim and Mauborgne (1997) in Harvard Business Review dealt with value innovation, stressing value for customers. In a reader's letter (Harvard Business Review, July–August 1997, p. 157), the article was praised because of its potential contribution to value for the shareholders; indeed, the letter does not mention value for customers, the core issue of the article, at all. In their reply to the letter, the authors made some effort to clear the resulting confusion.

7. Product development and design from the operations management point of view

The TFV concept, as presented in the previous chapter, was derived from an analysis of practice and science of production rather than that of design. However, the T, F and V concepts have been used, individually, also for analysis of design (section 2.4). Thus, an interesting question arises: Is the TFV concept valid and useful also in product development and design? For answering this question, the development of design practice and science is analyzed in order to uncover the underlying concepts and principles.

7.1 Introduction

7.1.1 Evolution of design management practice

The evolution of design management practice can conveniently be grouped into three periods: design as craft, sequential engineering, and concurrent engineering (CE).

Up to the Second World War, most industrial design was carried out by a small group of designers or a single generalist designer[i]. The products were simpler; the production processes were simpler. Thus, there were no major needs for systematized methods of design management and coordination.

The period after the Second World War was characterized by the diffusion and further development of methods originated in wartime production of weapons. Also the development of large-scale systems such as telephone, television etc. stimulated this evolution. Such approaches as systems engineering and project management grew out of these efforts. In established industries like car production, product development and design was organized in a roughly similar fashion to production: experts were grouped into different sections, departments etc., and the design work flowed between these. The common feature was to organize design as a sequential realization of design tasks.

During the 1980s, the new concept of concurrent (or simultaneous) engineering emerged. In 1986, a report by the Institute for Defense Analyses coined the term Concurrent Engineering to explain the systematic method of concurrently designing both the product and its downstream production and support processes. That report provided the first definition of Concurrent Engineering as follows (Carter & Baker 1992):

> Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements.

Today, concurrent engineering is widely applied in practice (Trygg 1993), and it is also an increasingly popular research topic. However, a closer study of related case studies, reports and books shows that there is little agreement on the definition, basic features, and methods of concurrent engineering[ii]. Thus, in a recent overview on concurrent engineering (Prasad 1996) not less than eight common definitions of concurrent engineering are listed.

7.1.2 Evolution of design science

Design methods received substantial academic recognition only in 1962 when the first conference on design methods was held (Cross 1993). Since then, several theoretical approaches to design have been presented, including the Design Science originated by Hubka (Hubka & Eder 1992), the General Design Theory originated by Yoshikawa (Taura & Yoshikawa 1994), and the Axiomatic Design Theory by Suh (1990).

However, the existing design science has contributed little to advances of design practice, like the rise of concurrent engineering (Cross 1993). It is widely argued that engineering design lacks sufficient scientific foundation, and that without an adequate base of scientific principles, engineering design education and practice are too much guided by specialized empirism, intuition and experience (Dixon 1988). Current design practice and the foundations for many existing design tools have evolved from collections of ad hoc practices and heuristics that are believed to have worked in the past or in other circumstances (Improving Engineering Design 1991).

7.1.3 Characterization of design from the operations management point of view

There are intrinsic differences between material production and such intellectual activity as design. Some of the most striking differences between design and production are (based partially on Giard & Midler 1993):

- There is much more iteration in design than in physical production.
- There is much more uncertainty in design than in production.
- Design is a non-repetitive (i.e. a project type) activity, production is often repetitive.

However, maybe the most fundamental difference between design and production is in relation to the customer, as analyzed in Chapter 5. In design, the customer requirements are translated into a design solution. In production, this design solution is realized. Thus the functional performance, the primary attribute of customer value, is determined in design, barring defective production. Thus the value aspect in design is much more significant, and by nature different in comparison to production.

7.1.4 Interpretation of the evolution of design from the TFV concept point of view

The basic argument is that in the conventional, sequential way of design and engineering, it is viewed as transformation, whereas concurrent engineering is based on mostly intuitive understanding of design and engineering as flow and value generation. This argument will be justified in the following sections.

7.2 Design as transformation

7.2.1 Sequential design

The ideas of scientific management soon diffused into the management of design. As a solution corresponding to the assembly line, serializing the design process, and determining a standard flow of design, was reached (Dasu & Eastman 1994). Specialization and associate division of work formed another part of the solution (Midler 1996). These ideas seem to have guided design management in established industries, like car manufacturing, where product design is a recurrent activity.

However, the efforts to tackle large, unprecedented engineering projects in the war and in the 1950s stimulated new developments (Morris 1994). One precursor was systems engineering[iii], which aimed at systematizing large-scale system development (Hall 1962). A generic flow of engineering tasks is one core issue of systems engineering (for a contemporary systems engineering methodology, see, for example, (Methodik…1986)).

Another newcomer was project management. Morris describes the classic[iv] – and still current – project management approach as follows (Morris 1994):

> ...first, what needs to be done; second, who is going to do what; third, when actions are to be performed; fourth, how much is required to be spent in total, how much has been spent so far, and how much has still to be spent. ... Central to this sequence is the Work Breakdown Structure (WBS)...

According to Turner (1993), scope management is the *raison d'être* of project management. The purpose of scope management can be defined as follows: (1) an adequate or sufficient amount of work is done; (2) unnecessary work is not done; (3) the work that is done delivers the stated business purpose. The scope is defined through the work breakdown structure.

Thus, it is obvious that the project management discipline is a pure application of the transformation concept and its principle of hierarchical decomposition. Also project management tools, like cost control and the Critical Path Method (CPM), are typically based on the transformation way of thinking.

The transformation concept is also generally acknowledged in design science. Hubka and Eder (1988) state:

> Engineering Design is a process ... through which information in the form of requirements is converted into information in the form of description of technical systems...

In a similar vein,[v] (Mistree et al. 1993):

> Designing is a process of converting information that characterize the needs and requirements for a product into knowledge about a product.

Indeed, the conventional conceptualization of design, in practice as well as in research, is based on the transformation model. In the framework of this conceptualization, improvement of design and design management has become channeled – beyond tools for coordinating the whole design effort, as discussed above – into tools for enhancing the efficiency of individual tasks (CAD, calculation models, simulation models, decision support tools). The focus may be on decision making, with the premise that the principal content of design tasks is made up of decisions (Mistree et al. 1993), or on problem solving (Murmann 1994).

7.2.2 Anomalies

The identification of the problems caused by the prevailing organization and management of product development and design started a search towards new methods in the 1980s. Putnam (1985) observed:

> Slow product launch, poor quality, and inefficiency are not isolated problems, nor are they symptoms of failure of individual functions of the business. The problems are related and reflect trouble in how those functions interact. The typical U.S. business links its design, manufacturing, and quality control departments only at points where a product moves from one department to the next. In other words, it allows engineering to function apart from the rest of the company.

Clark and Fujimoto (1991) found the following problems in conventional design: difficulty in designing for simplicity and reliability; excessive development times; weak design for producibility; inadequate attention to customers; weak links with suppliers; neglect of continuous improvement.

7.2.3 Discussion

Obviously, the T concept has been the foundation for product development and design management from the Second World War up to the 1980s. From the principles associated with the T concept, in particular the decomposition principle has been utilized. However, in a similar way to the situation in production, the T concept is not sufficient for the understanding or improvement of design processes. This is due to the bold idealization inherent in this concept:

- There are also activities in design that do not contribute to transformation. For example, information is inspected, stored and communicated; these activities are not explicitly represented.
- Neither the total design process nor its parts are conceptually related to their customers.

Factually, the transformation view addresses only the first of the three questions posed by Turner above. In consequence the single-minded use of this view has contributed directly and indirectly to many persisting problems in design projects[vi], identified as anomalies above.

Clausing (1994) sees that the traditional design process has not moved far enough beyond partial design, i.e. design from the point of view of one engineering discipline. Thus, according to Clausing, the traditional approach suffers from failure of process (missing clarity with regard to the activities) and failure of co-operation (missing unity within the team). Solutions for these failures have been sought in the framework of concurrent engineering, characterized (Rolstadås 1995) as an endeavor for shortening lead time and for life cycle engineering.

In the following, it will be argued that it is no coincidence that various writers have recognized *two* motivations for or *two* fundamental aspects of concurrent engineering[vii]. This is because the principles and methods of concurrent engineering are – predominantly implicitly[viii] – based on two distinct concepts lacking from conventional approaches to design: the flow concept and the value generation concept (Figure 9).

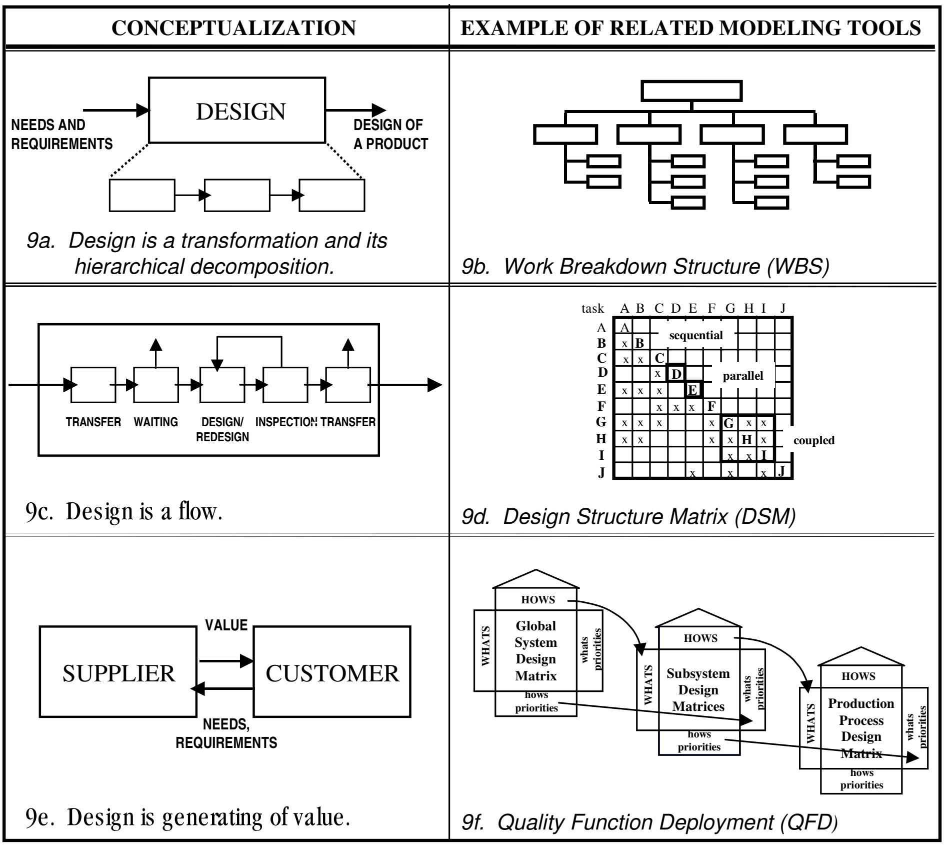

Figure 9. Transformation, flow and value generation view in design: conceptualization and modeling (Koskela & Huovila 1997).

7.3 Design as flow

7.3.1 Conceptualization

If design is seen as a flow process, there are four different stages at which a piece of information may be: transformation, waiting, moving, and inspection (Fig. 9c). In fact, only transformation can be part of the design proper, other activities are basically not needed (and therefore called waste in industrial engineering), and should be eliminated rather than made more efficient. But a part of transformation, namely rework (or added work) due to errors, omissions, uncertainty, etc., is also waste.

In the literature on concurrent engineering, this view[ix] has been acknowledged only rarely. Augustin and Ruffer (1992) suggest using logistic thinking in the analysis of product development. Adachi et al. (1995) suggest conceiving concurrent engineering as the application of JIT ideas to design. In their book on design improvement, Sekine and Arai (1994) focus on what happens to information in design: "things are made through the flow of information". The unit of analysis is the total flow of information[x]. Reinertsen (1997) develops an approach on design management based on queueing theory.

In this view, improvement of design equals eliminating waste and related shortening of design time[xi]. This view is significant because the amount of waste is large in any complex operation like engineering. When design information flows are analyzed in more detail, it is typically found that the share of transformation in the total flow time is very little. In general, the principles and methods of design waste elimination, to be analyzed next, are related to the root cause of each waste category.

7.3.2 Rework

Cooper (1993) estimates that in complex electronic systems development projects, there are typically one to nine rework cycles. In design of large construction projects, there are typically from one-half to two and one-half rework cycles, according to Cooper. Reduction of this waste provides very worthwhile potential for improvement.

The major general cause for rework is variability associated with uncertainty (missing or unstable information). Thus, a variety of methods are required, in accordance with the nature of uncertainty. Especially, it is paramount to reduce aggressively uncertainty in the early phases of the engineering project (Bowen 1992).

Changes in requirements or scope are disruptive for a product development and design project. Thus, it should be ensured that the scope is defined carefully, eliminating (avoidable) scope changes (Laufer 1997).

Iterations may be needed due to constraints of downstream stages overlooked in upstream stages. This can be avoided by considering all life cycle phases simultaneously from the conceptual stage onwards. In practice, teamwork is often used for this purpose.

The need for iterations may also arise due to poor ordering of tasks. The Design Structure Matrix (DSM) method (Eppinger et al. 1994) allows the representation of information flows between design tasks, and makes it possible to order the design tasks in such a way that the number of cases where a task has to send feedback to an earlier task is minimized (Fig. 9d). Thus it is possible to minimize the waste due to unnecessary iterations. Also, a DSM analysis provides a starting point for scheduling, and helps to make the total design process transparent, which contributes to more effective design management.

Uncertainty may be due to intrinsic lack of definite information on matters under development. Prototyping, simulation etc. can be used to decrease this kind of technological uncertainty (Barkan et al. 1992, Schrage 1993).

Uncertainty may also be reduced by decision. In later phases of the design project, especially, the design solution is often frozen in order not to complicate the realization stage and its preparation.

Rework is also caused by the need for correcting design errors. Various tools of quality management can be used for reduction of errors.

7.3.3 Transfer of information

The time and effort needed for all the necessary transfer of information can be reduced through team approach, especially when the team is collocated (Reinertsen 1997). In a team, much information can be transferred informally and orally, without paper or communication devices. Another option is in the elimination of vertical and horizontal divisions of labor and the resultant reduction in need for communication[xii]. This means that the team is empowered to make decisions, which, earlier, were made by higher hierarchical layers.

7.3.4 Waiting of information

One reason for long waiting times of information is that output from each phase is transferred to the following phase in large batches (Reinertsen 1997). Thus, splitting of design tasks, intense informal communication, and concurrence provide a solution to this. On the other hand, long waiting times may be due to poor control of the product design and development process, like too high a level of capacity utilization (Reinertsen 1997). Still another cause of waiting, especially in design for one-of-a-kind products, is the need to wait for customer decisions. This problem may be alleviated through better integration of customer decision making into the design process.

7.3.5 Unnecessary work

Design can also be conceived as pairs of supplier-customer. Poor specification of a supplier's work in relation to an internal customer's needs leads to added effort in the customer's activity, and also possibly to rework or continued work in the supplier's activity. Here, the consideration must be extended beyond design to manufacturing, which is the major internal customer of the design function. Several related methods (often called Design for X's) like Design for Manufacturability and Design for Assembly have emerged.

7.3.6 Technological solutions

Theoretically, the best solution is to eliminate a non-value-adding activity through new system structure, enhanced control or continuous improvement; for example, data transfer by collocation. If it is not possible to eliminate the non-value-adding activity, the "second best" alternative is to make it more efficient. In this respect, various technological solutions for collaboration, engineering databases etc. are instrumental, and, of course, increasingly important. On the other hand, information technology may provide new sources of waste. For example, non-compatibility of design tools causes one type of (set-up) waste: manual data conversion[xiii].

7.3.7 Discussion

On the basis of the preceding considerations, it is justifiable to state that the majority of the prescriptions of concurrent engineering can be explained through the F concept. From the principles associated with this concept, especially those advocating waste elimination and variability reduction have been utilized.

7.4 Design as value generation

7.4.1 Conceptualization

This view[xiv] focuses on value generated by a supplier to the customer(s). Value is generated through fulfillment of customer needs and requirements (Fig. 9e). This fulfillment is carried out in a cycle, where customer requirements are captured and converted, through one or several stages, to a product or service delivered to the customer.

Product design comprises all stages where the functional features of a product are determined. In this cycle, at least three problems may emerge: requirements capture is not perfect; requirements get lost or remain unused; and transformation is not optimal. The elimination of these problems[xv], to be discussed in the next sections, is the main focus of this view, and thus the source of improvement suggested.

Note that this view is analogous to mining, rather than manufacturing (as the previous view). The issue is to find the ore (requirements) and to have it processed so that no metal is rejected in slag (avoidance of loss), and to produce an end result with as little impurity as possible (optimization).

7.4.2 Missing or evolving requirements

Why may part of the requirements be missed at the outset of the design? This may be due to a poor requirements analysis as such[xvi], or specific features of the situation. One type of problem is due to the fact that the customer consists of a great number of people, and it is difficult to consolidate individual requirements into a coherent single set of requirements. Also, the number of requirements may be large or they may vary so much (Suh 1995) that their management gets cumbersome. It has also been argued that problems in the early design stages may, *sui generis*, defy any attempt at predefinition (Green & Simister 1996). In particular, regarding one-of-a-kind products, a certain evolution of requirements, reflecting changes in or enhanced understanding of customer needs, technology or manufacturing opportunities, should be allowed (Ashton 1992, Cusumano 1997).

Obviously, mass products, customized mass products and one-of-a-kind products present very different challenges to requirements capture.

The solution to this problem is a rigorous needs and requirements analysis at the outset in close co-operation with the customer(s). Several methods and tools have been developed for this purpose (Reinertsen 1997, Green & Simister 1996). For example, conjoint analysis helps in figuring out the customer priorities between requirements (Cook 1997).

7.4.3 Loss of requirements

Another problem is that part of the requirements may be lost during the many-staged design process. For example, the design intent of a designer is not communicated for later steps, and may be spoiled by decisions in these (Fischer et al. 1991). Requirements may be prioritized otherwise than meant by the customer.

For this problem, specific methods, like the Quality Function Deployment (QFD) method (Akao 1990, Cohen 1995), have recently emerged. It provides a formal linkage between requirements and corresponding solutions throughout the engineering (and production) process (Fig. 9f). It also provides a systematic method of setting priorities, based on requirements as prioritized by the customer. Another, less formal tool is the method of Key Characteristics (Lee et al. 1995). Key Characteristics attempt to identify and track features that significantly affect customer value. Thus, they provide a focus (rather than systematic elaboration, provided by QFD) on the most important product features.

7.4.4 Optimization

Often one requirement has to be realized jointly by several product subsystems, designed by different specialists. Inversely, one subsystem has often to fulfil several requirements. Thus, optimization in design consists of a myriad of trade-offs to be made wisely in the framework of global customer requirements. It is thus critical to know how relevant knowledge of individual designers can be enlarged (Yoshimura & Yoshikawa 1998).

The method of QFD is instrumental also for optimization. One important precondition for optimization is teamwork together with such cultural features as commonly held goals, complete visibility, mutual consideration of all decisions, collaboration to resolve conflict, and equality among discipline specialists (Linton et al. 1992). The various methods of value engineering[xvii] or value analysis are also useful (Fowler 1990).

The difficulty of catching all the variations in customer-use conditions, where the requirements should be fulfilled, was noted already by Shewhart[xviii] (1931).

For creating products that consistently satisfy customer requirements, the Taguchi methods are instrumental (Taguchi 1993, Clausing 1994).

7.4.5 Discussion

Methods and tools instrumental from the point of view of the V concept have been developed both in the framework of the concurrent engineering movement and in other professional communities. From the associated principles, those stressing requirements capture and flowdown as well as system capability have, in particular, been utilized in practice.

7.5 The TFV concept in design

7.5.1 Integration of the three concepts

A summary of all three views on design is provided in Table 6. It has to be noted that even if the three views have been presented as separate, they, in reality, exist as different aspects of design tasks. Each task in itself is a transformation. In addition, it is a stage in the total flow of design, where preceding tasks have an impact on it through timeliness, quality of output, etc., and it has an impact on subsequent tasks. Also, certain (external and internal) customer requirements direct the transformation of all input information into solutions in each task.

Table 6. Transformation, flow, and value generation concepts of design.

	Transformation concept	*Flow concept*	*Value generation concept*
Conceptualization of design	As a transformation of requirements and other input information into product design	As a flow of information, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main principles	Hierarchical decomposition; control of decomposed activities	Elimination of waste (unnecessary activities); time reduction, rapid reduction of uncertainty	Elimination of value loss (gap between achieved value and best possible value), rigorous requirement analysis, systematized management of flow-down of requirements, optimization
Methods and practices (examples)	Work breakdown structure, Critical Path Method, Organizational Responsibility Chart	Design Structure Matrix, team approach, tool integration, partnering	Quality Function Deployment, value engineering, Taguchi methods
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner

However, conventionally, it has only been the transformation view that has been explicitly modeled, managed and controlled. The other two views have been left for informal consideration by designers. The major contribution of concurrent engineering is in extending modeling to the flow and value views, thus subjecting them to systematic management.

How do the concepts interact? Do similar balancing issues arise as in production? Actually, our understanding of these questions is based on the predominance of the transformation view. Related empirical observations are discussed below.

Firstly, it is a commonly occurring phenomenon that in task management, often too little time is reserved for needs analysis[xix] and other issues of value management. This might be because value management is simply not conceptually captured in task management, based on the transformation view. However, poor definition of needs (domain of value management) causes disruption to task and flow management through untimely design changes.

Secondly, in conventional design, it is common practice for each task to produce a single design solution. In complex design situations, it is usual to iterate one alternative until a satisfactory solution emerges. It is assumed that each task can find the best solution in one shot. In fact, the transformation and flow views dominate in such practice, at the cost of the value view: the transformation view stresses getting each task done, and the flow view presupposes each activity to have a short and predictable duration. However, in the value view, the primary issue is in finding a still better solution for each task, using all the time available. This conventional practice, which can be called point-to-point design, is predominant in the current understanding of concurrent engineering. However, recently, it has been pointed out that an alternative set-based type of concurrent engineering is being used by Toyota (Ward et al. 1995, Sobek & Ward 1996). Here, designers explicitly communicate and think about sets of design alternatives. They gradually narrow the sets by eliminating inferior alternatives until a final solution emerges. Thus, set-based concurrent engineering represents an approach in which the transformation, flow and value views are pursued in a more balanced way.

Thirdly, in design task management, the need for a joint solution by designers of different disciplines, arising either from flow concept (i.e. a block of interrelated tasks in a DSM matrix) or value concept (different product subsystems contributing to one requirement) is usually not recognized (that is, there are no joint assignments) (Ballard & Koskela 1998).

On the basis of these observations, it is justifiable to claim – like in the case of production – that in design management, the management needs arising from the three views should be integrated and balanced.

7.5.2 Implications

The lack of an adequate theory of engineering design is a major bottleneck, both for practice and research, including the information technology oriented endeavors (Fenves 1996). Thus, further building, formalizing and integration of the theory of design should be among the primary tasks of the design science community. We need a conceptual framework where all three approaches (transformation, flow, and value) are integrated. This is needed especially in view of the pursuit of formal process models, used in computer-based description, analysis and simulation of engineering processes.

Let us take an example on the significance of theoretical understanding of design. In practice, establishing teams is often equated to concurrent engineering. However, the results may be disappointing. Indeed, the teams in themselves are not a solution. More systematic flow and value generation processes would be the solution that, of course, is enabled by team organization. Without ambitions and tools to model and manage the flow and value generation processes, team working degenerates into interaction for interaction's sake which does not correlate with performance, as Kahn (1996) has shown.

7.6 Conclusions

The historical development of design has many similarities to that of production. Originally, the first systematical attempts to manage design were based on the T concept, as in production. In the West, design anomalies caused by the idealization error implied by the T concept were increasingly recognized in the 1980s – the same happened roughly simultaneously in production. Then concurrent engineering emerged representing a similar theoretical shift to that in the case of lean production. The new methods of concurrent engineering were based primarily on the F concept but also on the V concept.

It is evident that the TFV concept provides a theory of design, too. Due to the intrinsic nature of design, the methods and practices are slightly different from those in production. The transformation view is instrumental in discovering which tasks are needed in an engineering undertaking. In the flow view, the basic thrust is to eliminate waste from the design processes. Thus, such practices as reduction of rework, team approach, and releasing information for subsequent tasks in smaller batches are promoted. In the value generation view, the basic thrust is to reach the best possible value for the design solution from the point of the customer. Such practices as rigorous requirement analysis, systematized management of requirements and rapid iterations for improvement are put forward.

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[i] Midler (1996) stresses the entrepreneurial nature of design in this era, as described by Schumpeter.

[ii] The literature study shows that there are subsequent views on the basic nature of concurrent engineering (CE):

1. *CE equals teamwork***.** As Schrage (1993) states: "Unfortunately, many companies believe they are implementing CE by convening multifunctional teams, which in reality is only one of 10 characteristics".
2. *CE requires computerizing***.** "All characteristics (of CE) are dependent on a computing environment..." (Schrage 1993).
3. *CE is a special approach to engineering*. This view is exemplified by the recent Guide to the Project Management Body of Knowledge (Project Management Institute 1996) with a very short discussion of Fast Tracking as the only reference to the ideas of CE. Thus, it is implied that there is a mainstream approach to engineering projects, and CE is a special approach, rarely needed.
4. *CE is a philosophy.* "Concurrent engineering is a philosophy and not a technology" (Jo et al. 1993).
5. *CE is a set of methods or tools.* This "recipe view" is common among the many authors giving "how to" lists for CE implementation.
6. *CE is a Western attempt to understand Japanese product development practices* (Tomiyama 1995). After all, many, if not most, practices of CE have their origin in Japan (Barkan 1991, Sobek et al. 1996).

[iii] It is interesting to note that rather similar factors stimulated systems engineering as concurrent engineering forty years later. According to Hall (1962), the emergence of systems engineering was due to growing complexity, expanding needs and environment, and shortage of manpower. Also the goals seem strikingly similar: "systems engineering...attempts to shorten the time lags between scientific discoveries and their applications, and between the appearance of human needs and the production of new systems to satisfy these needs" (Hall 1962).

[iv] Morris (1994, p. 217) comments: "...(W)hile the subject of "project management" is now comparatively mature, and recognized by thousands if not millions of managers as vitally important, it is in many respects still stuck in a 1960s time warp".

[v] In fact, the two definitions presented are slightly erroneous because in design, plenty of other input information is needed besides requirements.

[vi] Also, the Critical Path Method, when used in design and engineering management highlights the shortcomings of the transformation view. Because time has been abstracted away from the foundational concept of activity, it is difficult to present iterations in this method.

[vii] The characterization by Rolstadås (1995) of concurrent engineering as an endeavor for shortening of lead time and life cycle engineering matches with these two failures to overcome (failure of process and failure of co-operation) well.

[viii] In contradiction to lean production, concurrent engineering originally evolved solely through engineering practice, rather than in interaction with new theoretical insights (Sobek & Ward 1996).

[ix] A related perspective is adopted by Adler et al. (1994, 1996) who study the management of the development process in product development departments; thus their unit of analysis is not one project, as here, but rather the “development project factory”.

[x] Sekine and Arai (1994) argue that there are seven types of waste in design: preparing new drawings, retrieving or searching for drawings or material, permitting designers to set their own schedules, questioning unclear requirements and specifications, attending too many meetings and conferences, designing new estimate drawings and reference drawings, and altering designs to correct defects.

[xi] Note that in design, shortening of lead time is much more an intrinsic goal than in production, where it is also, and often primarily, a means for cost reduction.

[xii] Soderberg (1989) notes: “Like a manufacturing process with too many steps, an engineering organization with overly compartmentalized specialists builds up excess “WIP” between steps. The inevitable results: throughput delays and a rich supply of hidden problems that drive ineffective downstream activities.”

[xiii] Surely, the solution put forward is standardization of information structures but this has proven to be extremely difficult (Björk 1995).

[xiv] That this is a new perspective is supported by the following anecdote by Soderberg (1989): “As an ex-chief engineer of a major new automobile model ruefully noted: ‘I discovered rather late that an engineer’s design work is aimed at consumers so the final product can be marketed and purchased. For 20 years I thought engineers worked to create new designs’”.

[xv] The solutions to these problems further clarify the implementation of principles of the value generation concept, as seen from the point of view of product develoment and design. Especially, the principles on requirement capture, requirement flow-down and capability of the production system (here design subsystem of it) are involved.

[xvi] Reinertsen (1997) comments: “If there is one weakness in most product specification processes it is that the design team does not achieve an adequate understanding of the customer.”

[xvii] Originally, value engineering focused on cost reduction. Although it is not uncommon to find this focus in current value engineering, modern value analysis looks rather at both the worth and cost of a product (Fowler 1990).

[xviii] Shewhart (1931, p. 356) says: “Obviously, when equipment goes into the field it meets many and varied conditions, the influence of which on the quality of product is not in general known.”

[xix] As indicated by Reinertsen (1997).

8. Evolution of construction: practice and theory

To what degree has the conceptual and methodical development in construction been analogous to that in manufacturing, analyzed in the first part of this thesis? What are the causes of the well-known problems of construction? These are the basic questions addressed in this chapter. To answer them tentatively, development of construction practice and theory will be analyzed on the basis of the literature.

8.1 Overview on the evolution of construction

Earlier in history, master builders, who were responsible for both the architectural design and the execution of the works, took care of major construction projects. In the 19th century, the role of an architect as an agent for the client and as responsible for the design was established. Over time, the number of other specialist designers grew. (Higgin & Jessop 1965)

The construction of a building designed by an architect was contracted out to a contractor through bidding. The contractor used his own tradesmen for the majority of works, but also let various special works be carried out by subcontractors, selected through bidding or through negotiation.

Since the Second World War, building construction has changed considerably from the technological and market demand points of view (Sebestyén 1998). One driving factor has been the development of new materials, prefabrication and equipment. Construction projects have become larger, and the time pressures more urgent. The variety of different subcontracting companies has also grown, and the share of subcontracting has risen (Hughes et al. 1997).

The new developments have in many ways penetrated the nature of construction. There has been a diffusion of the ideas of scientific management and mass production into construction, which has led to the introduction of centralized, formalized management and prefabrication. Also, due to new materials and prefabrication, the skill requirements of operatives have decreased.

Thus, in contrast to most other production industries, craft production prevailed largely in construction for the first part of the 20th century, and it has still persisted into the second part of the century to a remarkable extent. The evolution of construction has not been similar to that of manufacturing, where generally steady, at times dramatic, productivity increases have occurred during the 20th century due to changes in templates of production.

The striking fact that problems of construction have, throughout the century, been discussed, in almost the same words, is taken as a starting point for a more detailed analysis in this chapter. Next, the evolution of construction practice will be described. Finally, the evolution of the theory of construction will be considered.

8.2 Problems of construction management

Performance problems of construction seem to have been discussed throughout the 20th century, and they are equally real still today. This will be illustrated by short historical reviews of related discussion in the United States and United Kingdom; two countries from which the majority of published scientific papers on construction management originate. A description of the current situation in three Nordic countries will round up the consideration of this theme.

8.2.1 United States

One of the first studies of the problems of the construction industry is contained in the Report on Elimination of Waste in Industry[i] (Anon. 1921), where six industries were considered. A number of problems of construction were encountered in this remarkable study, as the following quotes indicate.

On planning and material control:

> The average building contractor has no calendar of operations except the dates of starting and finishing a job. He largely regulates deliveries on materials by visits to job, or through statements received from the job superintendent.

On design:

> Standardization of the thickness of certain walls might mean a saving of some $ 600 in the cost of the average house. Standardized mill work, such as window frames, doors and other similar items, would reduce the cost.

On production control:

> The lack of adequate methods of production control is evident in every industry studied. It is one of the outstanding weaknesses.

On labor control:

> The building trades have given little consideration to the subject of labor turnover... Employment managers are rarely employed even upon the largest jobs, and “hiring and firing” is at the will of the foreman or superintendent.

That problems have persisted since this study is indicated by the fact that, especially after the Second World War, there have been several attempts to measure and improve construction productivity (Siegel 1980). One of the most influential has been the study More Construction for the Money (The Business Roundtable 1983). The motivation behind the study was the declining productivity of construction. It was found that more than half of time wasted during construction is attributable to poor management practices. Other explaining factors considered were fragmentation and related confrontation (especially in relation to labor), codes and other governmental related problems. A number of action points are suggested. Regarding construction management, the following was stated:

> Critics complain, with considerable justification, that the construction industry has been sluggish in adoption of modern management systems to plan and build projects.
>
> What is needed, briefly stated, is much more accurate and timely controls over design, planning and scheduling, budgeting, procurement, material logistics, and quality assurance.

8.2.2 United Kingdom

Since the Second World War, there has literally been a stream of official investigations on various facets of construction (Walker 1996). Among the most influential of them are the Emmerson Report in 1962 and the Banwell report in 1964. The Emmerson report contained the famous sentence: "In no other important industry is the responsibility for design so far removed from the responsibility for production." The Banwell report focused on the unnecessarily restricted and inefficient practices of the professions.

Another interesting analysis of the problems of construction, initiated by the construction industry itself, was made by the Tavistock Institute. In their report (Higgin & Jessop 1965), four project level problems were discussed. These apt and pertinent characterizations are of lasting value. Regarding client related issues, it is said:

> There is seldom a complete enough exploration of all client's needs and of the limitations he must accept – nor is he sufficiently informed of all the possible means of meeting his ends. The matching of needs and possibilities is seldom fully achieved, so the brief can rarely be adequate and clearly understood by all. This can lead to difficulties and reduced efficiency at all subsequent stages of the project.

Regarding design management:

> Sufficient thought and time does not seem to be given to ensuring, either as a design team brief or during the designing process, that all who must contribute understand the common objective similarly and fully. There is seldom a full awareness of all the steps necessary to realise an optimum overall outcome without loss of time, and the means of ensuring coordination is often not clear.

Regarding contracting:

> But when a contract is entered into it is unusual for any of those concerned to know with any degree of certainty just what he can expect of others, and what others will expect of him. The nature of relationships is defined afresh for everybody as any project develops, at the price of delays and confusions.

Regarding control of construction:

> The basic decisions of construction control are often incomplete or unduly rushed because necessary information is not available sufficiently ahead of time, or is not complete enough. On many occasions members of the construction team could, but do not, ease this problems by supplying the data that would facilitate the preparation of fuller and more useful information by others. Building construction is remarkable among industrial activities for the lack of detailed information about how it proceeds.

In the 1990s, much attention has been directed to the Latham report (Latham 1994), with focus on procurement and contractual arrangements. According to it, previous reports on the construction industry have either been implemented incompletely, or the problems have persisted. A number of recommendations to the various parties involved in construction are given, like "a check list of design responsibilities should be prepared", "the role and duties of project managers need clearer definition".

Finally, the report Rethinking Construction[ii] (Department of the Environment, Transport and the Regions 1998) argues that radical changes are needed to the processes through which the construction industry delivers its projects. It sets ambitious targets of 10 % annual construction cost and time reduction across the industry. These suggestions have been based on the achievements of leading organizations in their own construction programs.

8.2.3 Nordic countries

8.2.3.1 Finland

In Finland, the quality of construction has become an issue in the 1990s. Such problems as frequent occurrence of mould, sick building syndrome and premature renovation needs have contributed to this. In a national study on quality development in different industries, construction was the least developed industry. The leading companies in the construction industry were at the level of 200–350 points[iii], when the best companies in other industries reached the level of 600 points (Silén 1997). Thus, the Ministry of Trade and Industry (KTM 1997) requires that quality be made a priority:

> It will be possible for the construction sector to convert its poor quality image to a quality-based success through investing to quality improvement, clarifying the responsibilities in construction and producing products of sufficient variety, which fulfill client's requirements.

8.2.3.2 Norway

The following account on the situation in Norway speaks for itself (Haugen 1999):

> In 1998 the Norwegian building industry had another *Annus Horribilis*. A number of large projects were presented in the media as nearly continuous disasters. Romeriksporten, a large rail tunnel project in Oslo, will be delayed by approximately one year and the budget will be exceeded by billions of NOK. The new state hospital in Oslo is another example from the public sector, creating serious discussions at the top political level. The situation in the private sector is not very much better, but only a few projects are discussed in the media. These situations leave the industry with a bad reputation among most people, and with a big problem in recruiting good young people to the building and construction sector. Unfortunately again, the situation in Norway is not extraordinary compared to other countries.

8.2.3.3 Sweden

In Sweden, an ambitious program of one million dwellings was realized in 1965–75. One of the targets was to develop building technology through industrialization. Paradoxically, the costs of housing production have increased more than other costs since 1975. As a consequence of high costs and simultaneous decrease of governmental support, housing production has been reduced to a very low level in the 1990s. One possible explanation for high costs is that that the complicated regulatory framework and associated organizational network, erected for social housing, has hindered market competition and innovation (Kommerskollegium 1996). As one related measure, the Swedish government recently established a Delegation for Construction Costs, the mission of which is to stimulate the development of less costly construction methods[iv].

8.2.3.4 Conclusions on Nordic countries

The experience of Finland, Norway and Sweden shows how vulnerable the situation of construction is: given unfavorable conditions, productivity, quality and cost problems easily exceed the limits considered to be normal.

8.2.4 Discussion

Technologically, there has been a more or less complete change in construction in the 20th century. However, it can be concluded that during this period, construction in industrialized countries has been plagued by problems of high costs, low productivity growth and poor quality[v]. Recurrently, deficient management and organization have been pointed out as the main reasons for these problems. Developments in construction technology and market demands, like the increasing variety of materials and components, and requirements for shorter project duration, have apparently further tended to aggravate these inherent problems in construction processes.

8.3 Evolution of construction practice

The many problems of construction have led to various development efforts, initiated both by governments, the industry itself and scientific communities. These efforts include industrialization and mechanization, attempts to change contractual and organizational relations, computer integrated construction and construction automation, quality, and recently also, to some extent, lean production. In the following discussion, these efforts will be separated into two groups: on the one hand, attempts, starting from the 1920s, to modernize the then craft-based construction, and on the other hand correctives to the resultant mainstream construction, as launched from the 1980s onwards.

8.3.1 Developments towards modernizing construction

8.3.1.1 Scientific management

Construction was addressed by leading figures of scientific management; in fact, Gilbreth was a contractor, and made detailed studies on the effectiveness of bricklaying. However, for this part of the legacy of scientific management, follow-up in construction has been weak. The authors of a leading volume in productivity improvement state that “adoptions [of techniques for improving productivity have] seldom occurred” (Oglesby et al. 1989).

On the contrary, the idea of centralized and formal production control, as promoted by scientific management, has been widely adopted as an ideal in construction. The development of the critical path method and related software, as well as other project management techniques, has provided the tools for this.

However, in practice the penetration of the idea of formal and centralized control has been slow: “Today, it is the unusual contractor who does formal preplanning” (Oglesby et al. 1989). Similarly, materials management is found to be generally neglected (Oglesby et al. 1989). “...many small and medium sized contractors do not readily accept the notion that their profitability can be substantially improved through better material management” (Thomas et al. 1989). “...few materials-management systems are presently being effectively utilized by the industry” (Bernold & Treseler 1991).

8.3.1.2 Industrialization

Under the influence of the widely reported success of mass production of cars,[vi] the idea of industrialized construction caught the attention of the public and construction professionals early. Already in the 1930s, Gunnison organized a house factory, with a moving belt, in the United States. However, "Fordized, mass-produced housing never caught on" (Hounshell 1984).

Since the Second World War, the idea of industrialization has received much attention both in Europe, North America and elsewhere. However, in spite of a great number of attempts, there has been a relative lack of success of industrialized building methods (Warszawski 1990). The share of prefabricated components has gradually risen, but a breakthrough for industrialized construction has still not occurred. Nevertheless, there are some examples of advanced industrialization of construction, notably the Japanese house producers (Gann 1996) and the American metal-building providers (Ellifritt & LaBoube 1993).

8.3.1.3 Mechanization

Mechanization of construction, especially building construction, has advanced slowly. Such machines as tower cranes and mobile concrete mixers have been widely used since the 1950s (Sebestyén 1998). Small electric tools, like power drills, started to become common somewhat later. However, notably the many different trade work activities, such as bricklaying, still lack special purpose tools and machines.

Construction automation has been a research-led initiative, started in the 1980s. However, progress has been slow, when measured against usable end products (Warszawski & Navon 1998).

Mechanization of intellectual work by means of computers started in the 1960s (Grierson 1998). Computers are now widely used for automating and supporting various tasks in construction. Increasingly, computers are also used for supporting and automating the information flows that integrate these tasks. However, as yet no real computer-integrated construction has evolved (Laitinen 1998).

Howard et al. (1998) report on the benefits of construction IT in Scandinavia: "Most applications showed little change…[]. There are very similar responses from each country with design and administration showing high levels of benefit while management applications have resulted in little change. Sweden indicated 60 % of firms making some savings in administration. Although a high proportion of their responses came from contractors, they reported little change in productivity resulting from materials or site management." Other studies[vii] corroborate these findings.

Thus, the impact of technological initiatives has been disappointingly modest, even if it would be erroneous to deny any impact. With regard to information technology, reasons for this disappointment will be analyzed in Chapter 12.

8.3.1.4 Features of mainstream construction

To summarize, we can try to characterize the current mainstream template of construction, being a mixture of the influence of the T concept principles and the legacy of the craft period. There are three major features: separation of design and construction, procurement through bidding and institutionalized roles and division of work.

In sequential design and engineering, the total task is divided into sequential tasks, which are given to different specialists for execution. This has been the conventional method of organizing product development in manufacturing. In construction, the traditional approach to project execution (for example, Barrie & Paulson 1984) is similar. Here, the client first selects an architect, who prepares overall designs and specifications. Designs for structural and mechanical disciplines are then prepared. Construction is the responsibility of a general contractor under contract to the client. Thus, the participants of the construction project change during its execution: the contractor is not participating during the design, and design consultants may not be participating during construction.

The motivation behind procurement through bidding is to find the supplier providing the cheapest price in the market. After finding the cheapest supplier, the parties enter into a contract concerning the terms of delivery. Earlier, this method was applied first by the client for the procurement of the total construction, and next by the contractor for the procurement of materials. Increasingly, this method is also used by the contractor for the procurement of work packages, i.e. in the form if subcontracting.

There are two levels of specialization in construction. The first, a legacy from the craft period, is a rigid division into design disciplines and (construction) trades. The second is specialization at the company level. For example, the purchase of materials is often handled by a special department in a contracting company.

Thus the ideas of the transformation concept have, in several waves, rolled over construction and left their imprints on the industry, but achieved relatively little impact regarding performance.

8.3.2 Correctives to the mainstream construction model

8.3.2.1 Introduction

By the beginning of the 1990s, the problems of the conventional managerial model for construction, as described above, were discussed in most industrialized countries (CIB Working Commission W82 1997). Criticism especially focused on the three main features of the conventional model, as discussed above: sequential method of project realization, procurement through bidding and segmented control.

It has been pointed out (Dupagne 1991) that in the sequential realization

- there are few or no iterations in the design process
- constraints of subsequent phases are not taken into account in the design phase
- unnecessary constraints for subsequent phases are set in the design phase
- there is little feedback for specialists
- there is lack of leadership and responsibility for the total project.

Not unexpectedly, the criticism is similar to that voiced in manufacturing with regard to the sequential approach to product development (treated in Chapter 7). However, unlike the situation in manufacturing, where concurrent engineering has been widely adopted, only a few remedies have been applied to construction[viii]. Among the primary countermeasures are new organizational models of the production system, like design-build, partnering, as well as quality management. The method of constructability – corresponding to the design for X -methods in manufacturing – has been developing since the 1980s (Griffith & Sidwell 1997), but it is still little used in practice. The newest trends are concerned with lean construction and customer-oriented approaches. In the following sections, these new developments are examined in more detail.

8.3.2.2 Design-build and partnering

As one response to the integration problems of construction, the design-build procurement form has grown in popularity. In this case, the client gives, in a single contract, the execution of both design and construction to one company (usually contractor) that has the freedom to integrate design and construction in a suitable way.

The performance of the design-build delivery system in comparison to other major delivery systems has been studied in two recent studies (Bennett et al. 1996, Konchar & Sanvido 1998). The results indicate that statistically, the design-build process outperforms the traditional design-bid-build process in several respects; however, the differences are not great.

Partnering (Godfrey 1996, Baden Hellard 1995, Barlow et al. 1997) dates from mid-1980s, especially in the U.S. and the U.K. Essentially, partnering has been used as a generic term embracing a range of practices designed to promote greater cooperation (Barlow et al. 1997). Achievement of trust and cooperation are essential goals of partnering (McGeorge & Palmer 1997). The wish to avoid the effects of confrontation and litigation has been a major motivation for partnering. Larson (1995) found that partnered projects achieve superior results in controlling costs and technical performance and in satisfying customers compared with other projects[ix].

8.3.2.3 New organizational templates

The traditional way of organizing construction has been found in many countries to hamper performance improvement and innovation. An interesting group of initiatives has resulted from attempts to create a fundamentally new organization for construction, like the sequential procedure in France, open building in the Netherlands or the new building mode in Finland (Lahdenperä 1995).

The main idea of the *sequential procedure*[x] (Bobroff & Campagnac 1987, Cazabat & Melchior 1988, Lenne et al. 1990, Gibert 1991) is to plan the site work as successive realizations of autonomous sequences. A sequence is defined in terms of regrouping of tasks by functions of the building, not in terms of traditional techniques or crafts. During a sequence a firm can operate without interference because it is the only organization on site. After each sequence, there is a quality inspection and change over to the next sequence. The due dates of sequences are strictly controlled. The sequential procedure has been tried out in a large number of projects, and the method has been further refined. However, Chemillier (1993) comments that the method has not had the development it merits.

The *open building system* is an integrated set of rules and agreements concerning the organization of design and building (van der Werf 1990, van Randen 1990, Louwe & van Eck 1991). The distinguishing characteristic is the separation of the “support” (structural) and “infill” (interior work) parts of buildings. The idea is to separate the long-term decisions on the structure of the building from the shorter-term decisions of tenants regarding the interior of the building. This concept, having been developed over a period of 30 years, is now being introduced by a number of contractors and suppliers in the Netherlands.

The goal of *the new construction mode* is to remove the causes of the current inherent problems in construction (Lahdenperä & Pajakkala 1992, Lahdenperä 1998). It combines performance-based design and final product (rather than input resource) oriented construction procurement. On the basis of performance requirements, supplier firms (or company groups) offer their pre-engineered (and often prefabricated) solutions for different subassemblies of the building. A detailed procedure for implementing building projects by means of the new model has been prepared. This model was developed toward the end of 1980s. It has been experimentally applied to the supply of subassemblies to buildings and also to a few whole buildings.

8.3.2.4 Quality management

Recent trends include the introduction of quality management into construction (Sjøholt 1994). The quality issues have received increasing attention since the beginning of the 1980s, and construction-specific interpretations of the general quality methodologies have been published (for example, Shimizu 1979 and 1984, Cornick 1991, Burati et al. 1991, Leach 1991).

However, the results of quality efforts in construction have remained ambiguous. In a study on quality management in three Swedish contracting firms, Rogberg (1995) found that quality management was used as an umbrella for various change programs, rather than as work emanating from the quality concept. Also, he found a clash between the informal culture of construction and the pursuit of formalized organization as evident in quality management implementation. Quality was introduced as a new function to the company. Josephson and Hammarlund (1996) observed several shortcomings in quality implementation: the client does not follow up the realization of his requirements; the contractor's view from headquarters on quality implementation does not match with the situation on site; what is documented is not realized. In general, they found little evidence of benefits from quality implementation between 1987–1995.

8.3.2.5 Lean construction

A small number of pioneering organizations have started to introduce lean production or concurrent engineering. One of the first adopters of time compression was Haka, Ltd in Finland (Lehtomäki 1993). It managed to reduce the average site construction duration of residential construction by 10 %

annually, together with improvement in other respects, like number of defects at handover[xi]. Somewhat later, Skanska in Sweden started a time compression program (Månsson 1994). The British Airport Authority (BAA) provides an example of client-driven pursuit of lean construction. Since 1994, it has launched an extensive array of activities for cutting costs of airport construction (Anon. 1997a, Duncombe 1997). Such initiatives will be examined more closely in Chapter 11.

8.3.2.6 Customer oriented developments

After a long period of maturation, an approach for making the critical first phases of value generation explicit, called the *performance concept,* has been introduced into construction. Becker (1996) says of performance concept:

> Its application in building consists of translating human needs to user requirements (for serviceability, safety, security, comfort and functionality within the building's spaces, and for an adequate life expectancy of the building and its parts); transforming them into technical performance requirements and criteria; implementing them in the various stages of conceptual, preliminary and detailed design, to enable cost-effective construction of buildings that provide long-term satisfactory performance.

The performance concept has increasingly been used in building codes, standards and performance specifications. There have also been experimental building projects where procurement has been structured on the basis of the performance concept: given a performance definition, contractors bid on price as well as design solutions fulfilling the performance expected (Mars 1996, Neerhof 1996). However, so far there is no further penetration of the performance concept into the industry.

Another notable development is the approach to value management put forward by Green (1994), where the emphasis is on clarification and harmonization of the various needs and requirements of project stakeholders.

8.3.2.7 Features of the correctives

The correctives to the mainstream model are explicitly or implicitly based on the F view (regarding design-build, partnering, new organizational models and lean construction) and V view (regarding quality management and customer-oriented approaches). For example, the sequential procedure follows closely, even if implicitly, the suggestions of the F concept. The methods and purposes of the sequential procedure can be interpreted from the point of view of F concept principles as follows:

- Waste reduction. The goal is to reduce non value-added time due to excessive specialization: however, other waste components are not so explicitly attacked.
- Variability reduction. With several strict due dates and quality control points during the project, defects and problems do not easily migrate downstream. Preplanning is facilitated through reduced external uncertainty.
- Cycle time compression. Sequence cycle times (site time of each sequence) are compressed by utilizing better preplanning as well as more prefabrication and preassembly (of course, the total cycle time may be longer than in conventional construction due to preparation and prefabrication)
- Simplification. By establishing strictly sequential work packages, activity interdependencies are reduced and organization and planning of construction is thus simplified.

However, up till now, the initiatives based on the F or V concept have not achieved any major impact on the industry.

8.3.3 Discussion

In summing up, we can state that analogously to manufacturing, construction practice has been influenced first by approaches based on the T concept and more recently by approaches based on the F and V concepts. However, the influence of all these approaches has been largely superficial and has not produced major performance improvement across the industry.

8.4 Theories of construction management

After considering the development of construction practice, we now turn attention to the development of theory. The rise of construction management and economics as a separate academic and scientific subject seems to have happened primarily after the Second World War. It is illuminating that the first European scientific journal on construction management[xii] was founded only in 1983. What conceptualizations have been used in these efforts by researchers and educators? How have the persistent problems of construction been explained?

8.4.1 Construction as project management

Analysis of textbook content[xiii] suggests that the main thrust of construction management education is in project planning and economic analysis. Even a rapid glance at the contents of textbooks on construction management will show that they usually begin with a descriptive account of a construction project and then proceed to specific techniques of management and control. No major conceptual or theoretical analysis of construction is provided at the outset.

In network-based project planning (critical path method networks), a relative newcomer in the historical perspective of construction, the activities needed for producing the various elements of the building are the basic units of analysis.

Engineering economics, by definition, is based on the transformation concept, as discussed earlier. In practice, construction management activities with economic orientation seem to have focused on the very practical issues of cost determination and prediction, rather than on the core problems of economics proper (Ofori 1994).

Thus, essentially, the doctrine of construction management has been based on conceptualizing construction in a similar way to general project management (or economics), as discussed above. This doctrine has certainly had an impact on practical construction activities, even if it has not penetrated them fully[xiv]. The implicit explanation for the problems of construction has been the lack of use of project management methods.

8.4.2 Construction as open systems

Recently, a proper theory of construction (in contrast to applying generic frameworks and methods, like those of project management) has been developed by three British scholars: Bennett, Morris, and Walker. They have taken the open system theory of organization as their starting point.

Bennett (1991) presents a general theory of construction project management. The rationale of a general theory, according to Bennett, is as follows:

> The general theory represents a gross simplification of practice in order to make it understandable. It is intended to help practitioners to make good decisions about their own projects. […] It is in the minds of practitioners that the general theory will make its most important contribution to the efficiency of the construction industry.

The basic elements of the general theory are presented in Figure 10. The central idea is that construction projects need to achieve a balance between the objectives of the customer, the project organization, the nature of the product, and the environment. Models of each of these key elements are needed for managing a project. The mediating entity is days-work[xv]: “The whole point and purpose of construction project management is to create conditions that enable the teams who make up project organizations to carry out days-work efficiently.”

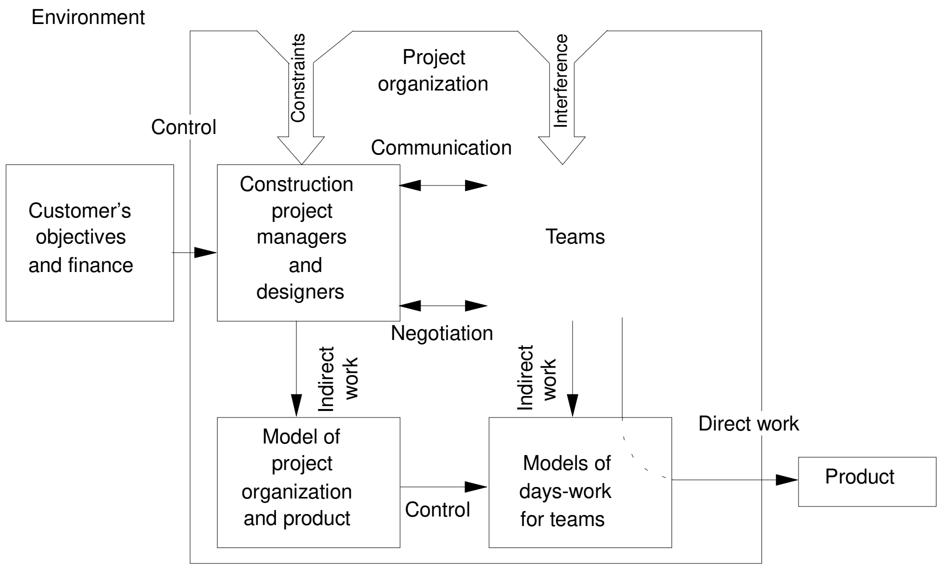

Figure 10. Basic elements of Bennett's general theory of construction (Bennett 1991).

Furthermore, Bennett presents three project forms (ideal forms of project organization): standard, traditional and innovative construction[xvi]. Standard construction is based on predesign and prefabrication, and is suited best to projects that are small, simple and certain. Traditional construction is based on professional roles, and is suited to projects characterized by moderate challenges and medium size. Innovative construction requires a problem-solving organization, and suits large, uncertain and fast projects. As one cause of problems, Bennett presents the inconsistency due to failing to co-ordinate objectives, product, organization and environment.

This typology of Bennett illustrates well the differences in organization and management between traditional construction and, in particular, construction organized according to the mass production template. In innovative construction, features typical of new product development accentuate.

It is interesting to compare Bennett's theory to the TFV theory of production. The value generation concept is presented in his theory only regarding customer's objectives, but not regarding subsequent phases. The transformation concept is, of course, represented by the term "days-work". However, the flow concept is absent[xvii] from this model. We can also note that (construction) design is not decomposed into its constituent parts, but rather treated as a black box.

Morris (1994) presents, based on a detailed analysis of projects, a new model for project management. This model contains four elements: definition (of the project), the external environment, the organization and attitudes. Each of these elements should be in order and developed properly, and there should be a mutual fit between them.

Walker (1996) concentrates on the design of project organizational structures. He models the construction project from the point of view of decision points, defining subsystems of the project. He recognizes two primary decision points in all construction projects, namely, first, that additional real property is required, and second, the nature of the real property to be provided. These decision points divide the project into three stages: project conception, project inception and project realization. For making the decision points and the way different people participate in decisions clear, he proposes the use of linear responsibility charts and their various extensions.

These three approaches all extend the scope of the received view on construction management, and it is easy to accept them. However, all explicitly or implicitly subscribe to the transformation concept[xviii], and leave other concepts aside. Only Morris' approach has been derived from empirical research. The models of Bennett and Walker are based on more general theories of organization, from which the validity of these theories is obviously thought to have followed. Thus, the explanation of problems of construction by these theories suffers from a lack of empirical grounding.

8.4.3 Critical views

Since the 1960s, a small number of voices, critical of the mainstream doctrine of construction management, as presented above, have been heard[xix]. A common feature of this critique is that they question the applicability of centralized and formal management or specific methods for it, as advocated by that doctrine. In Kuhn's sense, anomalies have been detected[xx].

Regarding the critique against centralized and formal management, pioneering work has been carried out by the Tavistock Institute (1966). In their study, characteristics of the structure and functions of the industry were empirically analyzed. The overall approach was to consider building from communication point of view. Interdependence and uncertainty were found to be the two important characteristics of construction.

It was found that the building industry depends to a large extent on the application of an informal system of behaviors and management to work adequately. As the root cause of problems, the disparity of the characteristics of the formal and informal systems in relation to the needs of the real task with which they are concerned is put forward. The formal system (contracts, plans, etc.) does not recognize the uncertainty of and interdependence between the operations of the building process. The informal system of management is geared towards handling uncertainty and interdependence, but it produces a climate of endemic crisis, which becomes self-perpetuating.

Further research on designing organizational forms with less uncertainty and tools for coping with interdependency, especially in design, was suggested (Tavistock 1966). Unfortunately, this research, the results of which have many similarities with the issues considered in this thesis, seems not to have continued.

This presence of informal management has been widely observed in construction. In traditional construction management, the managers are part of the action in the field and are task-oriented[xxi]; in new construction management, the managers are paper oriented (Applebaum 1982). In fact, the result has been dual management: formal management and informal management. These have been aptly described by Applebaum:

> ...we have virtually two separate organizations; one for the management function and one for getting the work done. The two organizations do not coordinate their work, and they are characterized by different goals and viewpoints.

It has also been argued that in project control, "firefighting" ongoing or looming crises consumes management resources and attention so totally that there is little room for planning, let alone improvement activities. "Managers are too occupied with the complexities involved in getting the work done to think about, much less to carry out, organized programs [for productivity improvement]" (Oglesby et al. 1989).

Another anomaly observed is related to cases where unexpected interaction between activities has been observed – in contradiction to the independence principle associated with the transformation concept. The great influence of design on construction and operating costs was first pointed out and analyzed as recently as 1976 (Paulson 1976). Friedrich et al. (1987) strongly criticize the customary notion that large projects can be measured using yardsticks viewed as simple summations of individual yardsticks taken discipline by discipline, system by system, or component by component. They argue that the overall effects of revisions, repairs, and rework on large projects can be very significant, even when the individual effects of specific functions and disciplines appear small and within "normal" acceptable practices.

A third stream of critical research concerns construction planning. Peer (1974) claimed that network analysis methods are incapable of providing a practical construction schedule due to their assumption of unlimited resources, definite activity durations and independence of each activity. Birrell (1980) criticized the CPM/PERT network technique for being not a true model of the construction process. He presented an alternative method for construction planning, which is conceptually based on queueing theory. Laufer and Tucker (1987) found that the role of planning is transformed from initiating and directing action before it takes place (as suggested by theory) to influencing and regulating operations while in progress (as intended in practice) and to follow-up and status reporting (as realized in practice).

8.4.4 Peculiarities of construction

Characteristics or *peculiarities of onstruction* were encountered above as an explanation for the factual organization of construction. There has also been some research that has taken construction peculiarities as a starting point and tried to understand their implications.

8.4.4.1 Peculiarities

An overview on construction peculiarities is presented in Table 7. One of the first to discuss the peculiarities of construction might have been Turin (Groák 1992). He took the view that advances in construction are often related to the elimination of certain peculiarities. Nam and Tatum (1988) come to a similar conclusion in their analysis of the impact of peculiarities on construction innovation. Warszawski (1990) compares construction with manufacturing, and argues that for the sake of efficiency, industrialized construction should be set as a target. Carassus (1998) takes the view that one fundamental specificity, namely that constructed products are located on a site, structures most of the other specific characteristics, as presented by him.

Even if it is easy to find treatments of construction peculiarities, there is little accumulation in understanding in this respect. This is illustrated by the fact that there is no cross-referencing among the sources discussed here. Moreover, related knowledge is qualitative; there have been few, if any attempts to acquire quantitative data on the occurrence or impact of these peculiarities.

Table 7. Views on peculiarities of constructed products and construction.

Source	*Peculiarities*
Turin (from Groák 1992)	Fixity Uniqueness Weight Bulk or volume Complexity of organization and manufacture Long production time High initial and running costs Longevity in use Often sold before built
Nam & Tatum 1988	Immobility Complexity Durability Costliness High level of social responsibility
Warszawski 1990	Work dispersed among many temporary locations Long service life of a typical project Small extent of standardization; each project has distinctive features Large number of tasks requiring a high degree of manual skills necessary to complete a typical construction product Each task performed over large work area with workers moving from one place to another Rugged and harsh work environment High turnover of workers Authority divided between sponsor, designers, local government, contractor, and subcontractors
Carassus 1998	Located on a site Localized orders of extraordinary diversity Production of prototypes Artistic creation A producer not controlling the overall process Itinerant, short-lived, complex and random site work Localized products which can be durably adapted and modernized Rules and conventions playing a considerable role

8.4.4.2 Explaining the prevailing mode of management and organization of construction through peculiarities

The above-cited study by the Tavistock Institute (1966) came to the conclusion that uncertainty and interdependency of construction played a role in the mode of management and organization of construction. The search for such an explanation, based on construction peculiarities, has also been on the agenda of other researchers, from different backgrounds.

In a pioneering paper, Stinchcombe (1959) argues that the lack of bureaucracy in construction can be explained by general instability from causes such as the variability in the volume of work in the course of a business cycle, seasonal variations, limitation of the market to a small geographical radius, and the variability resulting from the organization of work at a site into stages[xxii]. By bureaucracy, Stichcombe refers to features of mass production, especially the fact that both the product and the work process are planned in advance by persons not in the work crew.

One of the most extensive explanations of the organizational arrangements of construction has been presented by Brousseau and Rallet (1995). They prefer to limit the validity of this explanation to France, but it is difficult to discern any elements specific only to that country. Their starting point is the question: How to explain the longevity of a model of coordination characterized by numerous dysfunctionalities? The two organizational principles of construction are decentralization of decisions and informal coordination.

Brousseau and Rallet connect dysfunctionalities directly to this model of coordination. In the absence of a central authority, decentralized decision making prevents whole system optimization. It tends to favor a mode of problem solving where the externalities (negative impacts) are transferred to the next step or the least powerful step in the chain of actions. The informal character of relations encourages opportunistic behavior (negligence, deficiencies and fraud). It is easier not to respect a moral obligation, for which there is no such proof of the nature of the obligation as the written contract.

The first explanation for the longevity of this coordination model is that it corresponds to the techno-economical characteristics of construction and that the parts of it are mutually coherent. For decentralized decision making, there are two causes. Firstly, it would be difficult to direct, in a centralized fashion, the processes of construction. Secondly, decentralization of decisions appears to be a means, among others, for guaranteeing arbitration about the constraints of each player in a project. Similarly, informal relations permit a strong flexibility of the production system with regard to responding to variabilities and complexities of the project. Finally, the compatibility of these two principles of decentralized decision making and informal relations has to be noted. They reinforce each other because each allows limitation of the inconveniences caused by the other.

However, this explanation is not sufficient for understanding why firms of the construction sector have not been able to implement an industrialized process.

The second explanation introduces the concept of fragmentation of the construction sector. Fragmentation refers to the situation where different trades each produce a certain part of the final product. Fragmentation is associated with three factors: very large heterogeneity of demand, the local character of the market, and the impossibility of capital accumulation for the firms. These factors, together with the technical complexity of the production system, which requires cooperation by numerous specialized players, have contributed to the fragmentation of the production system.

However, even this explanation is not sufficient for explaining why it has not been possible for any company to transcend the conventional model by implementing a more efficient organizational model.

The third explanation operates with the concept of organizational lock-in. Two factors seem to play a role. Firstly, regimentation by society tends to codify and separate the roles of different actors. Secondly, the local nature of market and the pressure on the profits prevent firms from extending their competencies.

Clearly, Brousseau and Rallet raise important questions, and their explanation is interesting. However, it is a hypothetical explanation: it is not empirically grounded.

8.4.5 Discussion

A number of conclusions can be arrived at on the basis of this overview of theories on construction management. Firstly, research has not produced an empirically validated, comprehensive theory of construction. This has not gone unobserved by researchers. Laufer and Tucker (1987) suggest an overall re-examination of the philosophy of project management in construction. Sanvido (1988) discusses the lack of a conceptual framework for construction-project organizational design. The calls of Halpin (1993) Fenves (1996) for a theoretical foundation of engineering and construction were mentioned above in Chapter 1.

Secondly, transformation concept oriented approaches have dominated the doctrine of construction management and economics. We do need to acknowledge that there have been some flow-oriented approaches in construction[xxiii]. However, these are exceptions in the otherwise transformation concept oriented mindset of construction.

Thirdly, the discipline of construction management has only to a small extent been directly occupied with the problems of construction[xxiv] as experienced in practice. Rather, prescriptions based on generic theories or methods, originated in other disciplines, have been prioritized.

8.5 Conclusions

The most obvious conclusion from this discussion must be that managerial and other problems have chronically plagued construction, leading to unsatisfactory performance. Why these problems have remained unsolved, in spite of numerous initiatives for finding a solution, is still a puzzle.

Consideration of the evolution of construction practice and theory tends to lead to the conclusion that the transformation concept has been, and still is, a major conceptual underpinning of construction, and thus, theoretically, also one source of its problems. However, it seems that the methods based on the transformation concept have never been a success in construction and have never penetrated construction thoroughly. On the contrary, the informal modes of management and organization, characteristic of craft production, can still be clearly observed today. In addition, there are also alternative explanations for construction problems, and many features of the transformation concept are being rejected in advanced construction practice.

On the basis of this analysis, we can see that the managerial and organizational development of construction has been different in comparison to the general manufacturing scene; however, we have no definitive answer why. Furthermore, in spite of interesting, if tentative, ideas presented by researchers, we have no definite explanation for the problems of construction.

To achieve a clear understanding of the issues at hand, it is necessary to look at what actually happens in construction. Precisely for this reason, the theory of production was explored in the first part of this thesis. From the point of view of the TFV theory of production, it is crucial to understand the problematic mechanisms causing waste and value loss, and the root causes for these mechanisms.

Thus, the following questions are considered in the next chapter, where an empirical body of evidence, both from prior and original research, is consulted: Is there waste and value loss in construction? Which factors cause waste and value loss? Which are the root causes of these problematic factors?

[i] The report was prepared by a committee authorized by the American Engineering Council and appointed by Herbert Hoover, as president of this council.

[ii] The committee that produced the report was chaired by Sir John Egan, Chief Executive of BAA.

[iii] Calculated in roughly the same manner as defined in the Baldridge award procedure.

[iv] The delegation has set up a competition for development of cheaper housing systems.

[v] Barnes and Valdini (1994) comment: “Hurricane Andrew presented us with a rare opportunity to witness a total breakdown in process and the lack of integrity in an industry struggling with a negative quality image.” McGeorge and Palmer (1997) state: “This advice [given by two national bodies to potential purchasers of houses] is, in the authors’ view, indicative of the endemic problem of poor quality in the construction industry.”

[vi] Bröchner (1997) shows that the idea of car production as a model for building construction has had a permanent place in the discussion of advancement in construction.

[vii] Atkin et al. (1996) comment on the use of IT in construction processes: "Worse still, a few companies are using IT tools which have not changed in a decade in an attempt to automate paper-based systems. There is little evidence amongst the majority of companies to indicate that they are determined to break with this tradition**.** *Despite having requested that companies nominate their best sites, we cannot help but wonder what the worst might be: presumably, these would simply have no IT.* Our intention is not to insult individuals and companies facing difficult times. But to pretend that somehow all is about right, would be to fail those very companies." In their study on construction IT in Finland, Enkovaara et al. (1998) found that *for contractors, IT had not produced any benefits, whereas in subcontracting and client procurement activities, IT benefits were negative*, i.e. the benefits accrued have not offset the costs. In many cases, the level of personnel competence or the degree of structured data have not corresponded to those required by an IT application. Also, there are examples of implementation projects that have simply failed.

[viii] McGeorge and Palmer (1997) provide an excellent account of such various remedial approaches.

[ix] However, an American study shows that there appears to be no correlation between the use of alliances (long-term contractual relationships between owners and contractors intended to promote efficiency in capital projects) and project results (The Business Roundtable 1997). The conclusion is that it is not the alliances but the substance of work processes that produces the result.

[x] Note that “sequential procedure” has quite a different meaning to the term “sequential method of project organization” discussed earlier.

[xi] However, these improvements could not prevent this company from going bankrupt in 1994, due to the reduction in value of its real estate, and in connection with major financial difficulties of its main owner.

[xii] Construction Management and Economics.

[xiii] Textbooks consulted: Clough & Sears 1991, Barrie & Paulson 1984, Hendrickson & Au 1989, Pilcher 1992.

[xiv] Morris (1994) notes: "[The WBS] has taken a surprisingly long time to become accepted in project industries: it was entering building and civil engineering in the late 1980s[...]. Bobroff (1994) comments: "*Le bâtiment présente une situation paradoxale: c'est à la fois le secteur où on parle le plus de gestion de projet et néanmoins il apparaît souvent abusif d'utiliser ce terme pour la plupart des opérations*."

[xv] Actually this concept, suggested by Bennett, was an essential part in Taylor's (1913) Scientific Management: "...the average workman will work with the greatest satisfaction, both to himself and to his employer, when he is given each day a definite task which he is to perform in a given time, and which constitutes a proper *day's work* for a good workman. This furnishes the workman with clear-cut standard, by which he can throughout the day measure his progress, and the accomplishment of which affords him the greatest satisfaction."

[xvi] This typology is analogous to the production type model of Hayes & Wheelwright (1984).

[xvii] However, the inclusion of environmental interference is a step towards issues dealt with by the flow concept.

[xviii] Bennett and Walker even present the picture of a transformation process in their books.

[xix] This presentation does not cover the critique voiced in the 1990s by proponents of lean production (Alarcón 1997), concurrent engineering and re-engineering, because it overlaps with the very subject of this research and its themes are thus discussed throughout this thesis.

[xx] As suggested by Kuhn (1970), the deficiencies of the existing paradigm are identified through emergence of anomalies, i.e. cases where the outcome differs from that predicted or assumed on the basis of the paradigm. It has to be acknowledged that the paradigm of construction has not been explicit, neither has it been solid. In spite of this, the, often vivid, descriptions by the finders of an anomaly clearly show that it has been a case of an anomaly in Kuhn's sense.

[xxi] Björklöf (1986) has aptly described the culture of construction by using the terms *papyrophobia*, *viva voce*, *ad hoc* and *in situ*.

[xxii] This explanation has been challenged by Eccles (1981), who argues that Stinchcombe confounded craft socialization with subcontracting. Eccles sees subcontracting as a response to uncertainty, which arises from complexity as well as variability. Eccles takes the view that

construction firms are more bureaucratic than Stinchcombe recognized. However, the argument of Eccles suffers from his lack of recognition of the role of informal management in construction.

[xxiii] Especially in heavy civil engineering practice as well as research, flows of material and equipment have been the framework of analysis. In addition, discrete event simulation of site activities has addressed flow characteristics (Halpin & Riggs 1992, Bernold 1989, Tommelein 1998).

[xxiv] Of course, the same can be said of operations/production management in general.

9. Causes of construction performance problems

How can the chronic performance problems of construction be explained by the TFV theory of production? This is the theme of this chapter. First an investigation is carried out as to what extent there is waste and value loss in construction. Next, the factors producing waste and value loss are explored. Finally, the root causes of these factors are sought.

9.1 Introduction

The primary aim of this chapter is to add to the understanding of the performance problems – as perceived from the operations management viewpoint – in construction. The TFV theory of production is used as a framework for analysis and explanation. Regarding contemporary construction, the more specific research questions are as follows (Figure 11):

- What kind of waste and value loss is there in construction and to what extent?
- Which factors causing waste and value loss exist in construction?
- Which are the root causes of these factors? In particular do the managerial concepts and practices in use cause problems, and consequently waste and value loss? Alternatively, do construction peculiarities cause waste and value loss?

In prior research, the causes of waste and value loss have not been considered to any large extent. Eisenhardt (1989) states that building theory from case study research is most appropriate in the early stages of research on a topic or to provide freshness in perspective to an already researched topic. Such is the situation here: the various types of wastes occurring in construction are well known, but a convincing explanation of their cause is still lacking. Thus, the results of the case study, where the mechanisms of waste and value loss formation could be studied in detail, are taken as a starting point for explanation. By means of the results provided by prior research, the results from the analysis of case observations are validated and extended.

The material in this case study has been analyzed in a number of conference papers (Huovila, Koskela, Lautanala, Pietiläinen & Tanhuanpää 1997a, Koskela, Lahdenperä & Tanhuanpää 1996, Lahdenperä, Koskela & Tanhuanpää 1997) and in a booklet (Tanhuanpää, Koskela & Lahdenperä 1999).

Figure 11. Framework of formation of waste and value loss as used in the case study.

9.2 Materials and methods

9.2.1 Materials

In this chapter, three bodies of research material are utilized: data from the case study project, prior research on waste and value loss in construction, and prior empirical research on the problems and management methods of contemporary construction.

9.2.1.1 Case study materials

Figure 12. The completed office building (photo: Veli-Pekka Tanhuanpää).

The office building in question (Figure 12) was realized in the design-build mode, where the briefing phase was started first in 1991 but interrupted due to the recession, and re-started in December 1994. The design of the 7 100 m^2 and 25 700 m^3 building, comprising five floors, was started at the beginning of January 1995 and the construction at the end of the same month. Subsequently, a floor was handed over monthly, starting from the fourth floor at the end of July. All the floors had been finished and handed over by the mid-November 1995.

The design time of the building was 9 months, which is quite a standard design time for this kind of building. The construction time was slightly under 10 months and due to overlapping of design and construction the whole project was thus realized in 11 months.

Many players in the construction project had already worked together in the same area, so they had some feeling about the expected quality level and mode of action. The tenant of the building was a growing high tech company. The project was considered as averagely successful, and no major objections were voiced by any party. Technically, the constructed building in itself is representative of Finnish state-of-the-art of commercial construction.

9.2.1.2 Prior research

Prior empirical research on construction management from Finland, Sweden, United Kingdom, United States and other countries is consulted.

9.2.2 Methods

9.2.2.1 Data gathering

In data gathering for the case project, the principle of triangulation of information sources was used. Firstly, a researcher collected all the relevant documents (also generally confidential, like final account books) of the project. Secondly, he observed and documented ongoing tasks during both design and construction: information flows between actors, task dependencies, duration of tasks, and problems occurring. He was present at most design and site meetings. Thirdly, gathered information was completed and checked by interviewing designers and construction parties.

The results of the collection of empirical data were composed into a descriptive construction process model (Tanhuanpää & Lahdenperä 1996) which consists of over 1000 design and building tasks, about 850 task dependencies and 450 information flows. In addition, one part of the project, inner walls, was monitored systematically in more detail. The results were then compiled into a case study data base report (Tanhuanpää 1995).

The method of data gathering focused especially on the issues of interaction between tasks. Internal problems within tasks that did not surface at the meetings could be observed only haphazardly. Moreover, data gathering was more focused on waste than on value loss, due to better observability of the former.

The researchers had access to the final contractor accounts for the project. However, so as not to disclose sensitive information, publicly available cost information is used in cost analyses, especially regarding the total costs. Care was taken to ensure that the results are not misleading.

9.2.2.2 Data analysis

Several tactics were used in data analysis:

- Pattern matching – the observed processes were compared to the theory-derived processes
- Time series analysis – the interactions of tasks across timelines were analyzed
- Explanation building – the starting point was provided by a mini case study on one work package, namely the construction of partition walls, where the mechanisms in action could be studied in detail. The findings of the mini case study were then compared to other project data, and actually a high degree of generalizability could be observed. Moreover, the findings were compared to existing literature.
- Analytical methods – the design process was modeled as a design structure matrix, and the construction process as a critical path network. The analytical power of these methods was used for gaining further insights about the respective processes.

9.2.2.3 Shaping hypotheses

The theoretical framework provided by the TFV concept of production was initially used for organizing data. However, it was attempted to be as sensitive as possible to findings not fitting into this framework. After a series of iterations, a framework of hypotheses emerged that seemed to be capable of covering the phenomena observed in construction. Thus, the case study led to a number of hypotheses not associated with the initial set of concepts. For all hypotheses, a careful investigation was carried out to check that relationships between constructs agreed with the evidence in this case and other cases presented in the literature.

9.2.2.4 Comparison to prior research

In order to ensure the generalizability of the results of the case study, they were compared (and to some extent augmented) with findings in prior research.

9.3 Results from the case study[i]

9.3.1 Waste and value loss

What kind of waste and value loss is there in construction and to what extent? Even if waste and value loss were monitored qualitatively and selectively only, a number of observations could be done, especially regarding site construction. Firstly, well-known waste types, like rework, waiting of materials (material buffers) and lost production occur generally in construction: *presence of waste is pervasive*. Secondly, there is a type of waste specific to construction, namely reduced productivity due to *suboptimal conditions*. These conditions are often caused by interference between tasks and lack of prerequisites of a task.

Regarding the construction design phase, the observations on waste were largely similar. The phenomenon of suboptimal conditions was also found in design, where it was primarily caused by lack of input information.

Regarding value loss, the functional performance of the building from the user point of view was not examined in the case study. However, an anecdotal example of the loss of a requirement was observed. Furthermore, it was found that situations where designers worked under suboptimal conditions were prone to lead to some value loss.

9.3.2 Factors causing waste and value loss

The analysis of the causes of waste was started by considering the partition wall work package. Investigation revealed that the direct causes of waste (and value loss) were distributed throughout the project phases prior to its occurrence. *Waste primarily originated from prior phases* of the project rather than from the phase of its occurrence. Waste was caused by problems of client decision-making, design management, supply chain management and site production management. Characteristically, these problems were not dissimilar to Kendall's (1912) description of problems of unsystematized production (Chapter 3). Particularly, client decision-making and design management[ii] suffered from lack of planning, with frequent change orders as a result. Site production and procurement of materials were systematically planned[iii] and prepared, but these efforts were thwarted by the frequent change orders, and in the end, production management as realized was informal and decentralized rather than facilitated by a plan and centralized management. As a result, there was rework, working in suboptimal conditions, physical waste (of damaged or surplus materials), double handling, and other waste types in the building of partition walls.

When the other parts of the project were analyzed in the light of these findings, it was realized that these same factors, which can be characterized as bad control[iv], were consistently present across the whole project.

However, there was a second group of factors, relating to production system design. The production system had in many respects an unfavorable design: inherently high variability, high complexity and low transparency. Thus, deliveries were often erratic, even if the order had been correct and there was overcapacity in the supplier industry. The organization of work packages was sometimes overly complex, leading to constant coordination problems. Weather caused rework in inner works. In construction design, the responsibilities of different parties were not always clear.

Thus, due to bad control and unfavorable design of the production system, a cascade of waste and value loss formation was created, as depicted in Figure 13. Different causes of waste seemed often to act jointly, and they accumulated towards the end of the project.

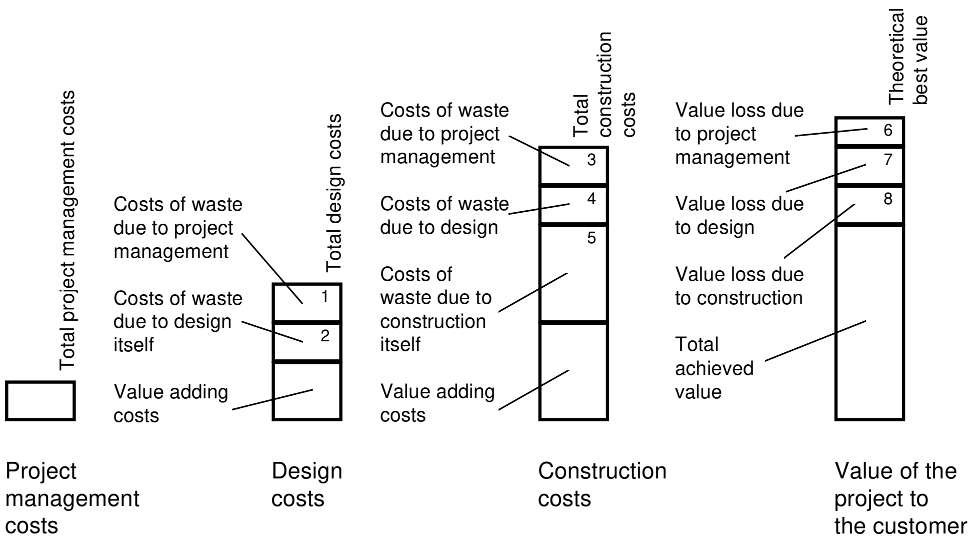

Figure 13. Formation of waste and value loss in construction projects (this figure is schematic and does not indicate relative quantities of different costs or values).

9.3.3 Root causes of waste and value loss

In order to find the root causes of waste and value loss, the case project is interpreted from the point of view of the TFV theory of production. The discussion is focused on task management, flow management and value management as defined in Section 6.1.2. To what extent does waste and value loss result from lack of systematized and articulated management in these three areas? What is the role of peculiarities in the formation of waste and value loss?

9.3.3.1 Task management

The *system design* of the project followed the work breakdown model. Thus, the project was decomposed into tasks, and responsibility for each task was given through contract or assignment. The primary criterion of selecting sub-contractors and suppliers was the price.

At the level of *control*, extensive planning of construction followed the template set by the methods of project management, and was thus task-oriented. Likewise, formal control was focused on the fulfillment of tasks in time and the accumulation of costs. However, the task management was not implemented consequently and to the extent possible. This was especially evident in construction design, where there was no effort to identify individual tasks. Also, in construction, the intended systematic task management became corrupted as construction progressed and became informal management, characterized by mutual adjustment[v] of teams and neglect of formal rules.

Regarding *improvement*, very little explicit action could be perceived. There seems not to be any systematic consideration of the achievements in improvement of the organizations selected for the project. However, this being a repetitive project, different players could use the work and experiences from the previous building, even if there was no systematic, joint utilization of feedback.

9.3.3.2 Flow management

There were traces of articulated flow management in both the design and the control of the project production system, even if, in general, flow design and control were primarily realized as a by-product of task management.

Regarding *system design*, the procurement method selected, design-build, is in principle instrumental for ensuring the coordination between design and construction. Similarly, the design-build contract of the HVAC-systems was in principle instrumental in this regard. However, from the flow management viewpoint, two types of structural problems could be distinguished: poor mutual integration between phases (client decision-making, design, and construction), and poor internal structure of each phase.

Regarding the first type, the problems of integration between client decision making and the other phases were accentuated. The tenant was not well integrated into the project team, and delays of related requirement clarification and decision making resulted.

Regarding the second type, various problems could be observed. In construction, great effort was put into finding the least cost for every material order and work package. Construction work was to a large part subcontracted out. Thus, the costs for the main contractor were practically determined in proportion as orders were placed or subcontracts were agreed on. After that, the motivation of the contractor to manage work, except where the master schedule seemed to be jeopardized, was logically low.

Other problems included the complexity of organizational arrangements, due to an urge to ensure that the minimum price is found for every input resource. Another issue concerns variability: when the selection criterion was solely price, the variability of deliveries or work probably grew[vi].

Regarding *control*, both lack of control against waste and control principles contributing to waste were observable. Lack of control against waste was due to ignorance, lack of tools or lack of commitment. There was no effective effort to influence the disruptive decision-making pattern of the tenant. There was no effort to find the minimal duration through critical path methodology. The realization of the schedule was not effectively enforced, which allowed propagation of variability.

Some control principles used contribute directly to waste. Unnecessary buffers in material flows provide an example of this. On the other hand, lack of buffer between consecutive trade crews contributed to reduced productivity and thus waste.

In general, all phases of the project were characterized by a high level of variability. There was practically no effort to stem the accumulation of variability or to minimize its impacts.

Very little structured *improvement* was directly observable. Also, judging from the high level of deviations stemming from the internal operations of participating firms, there was little amount of previous improvement. No measurement from the flow point of view was observable.

9.3.3.3 Value management

There was almost no effort to explicitly address the value issues. Requirements by the tenant were not formally presented; rather the brief was formed on the fly during the design process.

Regarding the *system design*, several shortcomings could be observed. The designers did not form a collaborating team (lack of unity). There was no effort to structure the design process suitably for explicitness from the point of view of value management (as suggested by the performance concept).

Similarly, regarding *control*, little explicit action was found. Requirements were not mapped up-front in an orderly manner; there was no follow-up of requirement realization. No tools for modeling value generation were used. There were no explicit targets, say, for maintenance costs. There was little joint optimization by different disciplines during design.

Regarding *improvement*, the situation was analogous. As far as it is known, there was no *a posteriori* evaluation of the building. Neither were lessons learned in earlier, similar projects systematically used.

9.3.3.4 Peculiarities

Another root cause to waste and value loss seemed to be made up by the *construction peculiarities*, like one-of-a-kindness, site production and temporary organization. These peculiarities lead to complexity, variability and lack of transparency, which, if not mitigated, cause waste. However, the number of occurrences of waste where construction peculiarities are clearly involved as the primary cause was much less than those where managerial concepts and practices were involved. On the other hand, these peculiarities were often a secondary, contributing cause for waste.

9.3.3.5 Discussion

On the basis of the case study, root causes of construction performance problems are primarily related *to the managerial principles used or their implementation.*

However, the causal mechanisms vary in different phases of a construction project.

Management of the project was primarily conceived as task management. The design and control of the production system were largely determined by the decomposition and cost minimization principles. However, *these managerial principles directly led to violation of principles related to flow and value management*. When the primary selection criterion was price, inherent variability or capability of the production system remained unconsidered. The interdependencies between decomposed tasks were not orderly addressed. Indeed, it could be observed that the principles adopted lead often to complexity and lack of transparency. Thus, *unfavorable design* of the production system resulted. On the other hand, also construction peculiarities contributed to unfavorable design.

However, it is noteworthy that regarding site production, the principles adopted were implemented only to the level of subcontract or material order: control of production was effected through contract control. Even if tasks included in subcontracts were planned in greater detail, they were not controlled (that is, assigned and monitored) in greater detail, leading to a lack of systematized management in practice. Similarly, supply-chain management was not pursued beyond a search for minimum price transaction. Regarding then client project management and design management, there were only traces of intended task management, leading again to a lack of systematized management in practice. Thus, the managerial principles in use effectively led to the endemic management problems, *bad control*, in all phases of a construction project.

There was little systematized improvement. Lack of prior improvement can be seen as one contributory factor for bad control and unfavorable design.

The strong interaction between task management, flow management and value management is noteworthy. Both the (one-sided) implementation of task management and the deficiencies in it led to problems from the point of view of flow management. Particularly in construction design, deficiencies of task management and flow management led to problems from the point of view of value management (this is analyzed in more detail in Chapter 10).

9.3.4 Summary of the explanation of construction performance problems derived from case study

A simplified presentation of the findings of the case study is provided by Figure 14.

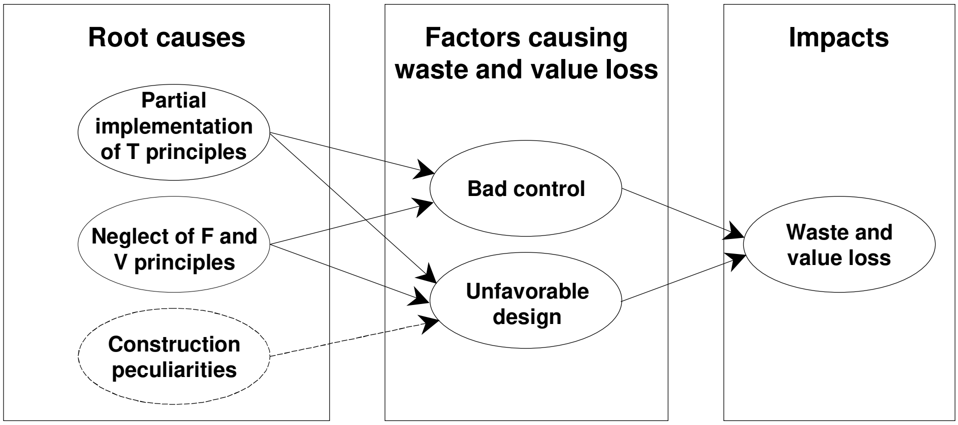

Figure 14. Explanation of waste and value loss formation as found in the case study.

9.3.4.1 Waste and value loss

Well-known waste types, like rework, waiting of materials (material buffers) and lost production are *widely observable*. In addition, there is a waste type specific to construction, namely reduced productivity due to *suboptimal conditions*. Regarding value loss, it is not possible to draw general conclusions on the basis of the case study material only.

9.3.4.2 Factors causing waste and value loss

Waste primarily *originates in prior phases* of the production process rather than in the phase of its occurrence. Waste is caused by problems of client decision-making, design management, supply chain management and site production management. There are two factors that directly cause waste in each phase: *bad control* and *unfavorable design* of the production system. Value loss seems to be caused rather similarly.

9.3.4.3 Root causes

Construction is predominantly managed according to the transformation concept, and principles related to the flow and value generation concepts are largely neglected. Management efforts are centered on task management and based on principles of the transformation concept. However, task management is not implemented systematically across all phases, resulting in added variability. Even where there is an intention to implement systematic task management, it corrupts, due to the high level of variability, to unsystematized management. Thus, *bad control* (i.e. deficient attention in control to the principles of production) across all phases results. The goal of not using resources unnecessarily is realized by minimizing the costs of each task and each task input. However, in doing so, complexity and variability increase, leading to *unfavorable design* of the production system (i.e. production system design where the principles of production have been deficiently realized).

There is a second issue playing a role, namely *construction peculiarities* (one-of-a-kindness, site production, temporary production). Because of these, flows are more variable and complex than otherwise, and also value generation is hindered. However, to which extent they are root causes for waste and value loss is an open question: if there is no alternatives for these peculiarities, obviously they do not cause *avoidable* waste or value loss.

9.4 Results from prior research

9.4.1 Waste and value loss

As far as it is known, there has never been any systematic attempt to observe all waste in a construction process. However, partial studies from various countries can be used to indicate the order of magnitude of waste in construction. The same applies for value loss. In the following, results on waste and value loss from prior research are presented and compared with the corresponding findings from the case study. Waste and value loss types employed in prior research are used for structuring the presentation.

9.4.1.1 Waste

Poor quality

Quality costs are perhaps the best-researched area. In numerous studies from different countries, the cost of poor quality (non-conformance), as measured on site, has turned out to be 10–20 % of total project costs (Cnudde 1991). In an American study of several industrial projects, deviation costs averaged 12.4 % of the total installed project cost; however, "this value is only the tip of the iceberg" (Burati et al. 1992). The causes of these quality problems are attributed to design, 78 %, and to construction, 17 %.

In a very detailed Swedish study on a design-construct project in 1987, the costs of quality failures (during the site work, defect correction after hand-over not included) for construction companies were found to be 5.4 % of the production costs (Hammarlund & Josephson 1991, Josephson 1994). A corresponding study, comprising seven projects, was repeated in 1995 (Josephson & Hammarlund 1996). On average, the cost of defects was 4.4 % of the production costs. Of the total working time of construction workers, 7.1 % was allocated to rectifying defects. Of the costs of defects, 1/4 were due to design and production planning, respectively, and 1/5 were due to work execution and material deliveries, respectively.

Lack of constructability

Constructability is the capability of a design to be constructed (The Construction Management Committee 1991). Constructability of a design depends on the consideration of construction constraints and possibilities. Projects where constructability has been specifically addressed have reported 6–10 % savings of construction costs (Constructability 1986). It has been argued that better collaboration in design between the consulting engineer and the specialist engineering contractor could produce a cost saving of 20 % (Latham 1994).

Poor materials management

It has been estimated that 10–12 % savings in labor costs could be produced by materials-management systems (Bell & Stukhart 1987). Further, a reduction of the bulk material surplus from 5–10 % to 1–3 % would result. Savings of 10 % in material costs are reported from vendor cooperation in streamlining the material flow in Sweden (Asplund & Danielsson 1991). This potential of 10 % saving is confirmed in Jarnbring's (1994) study.

Material waste

Based on extensive studies, Skoyles and Skoyles (1987) state that about 10 % of all material delivered to a site in the United Kingdom end up as material waste. According to a Swedish study, excess consumption of materials on site (scrap, wastage and surplus) is on average 10 %, varying in the range of 5–30 % for different materials (Bättre materialhandling på bygget 1990). A Dutch case study (Bossink & Brouwers 1996) came to the conclusion that 9 % of the total purchased materials ended up as waste (by weight).

Nonproductive work

As for work processes, the average share of working time used in value-adding activities is estimated to be 36 % (Oglesby et al. 1989) or 31.9 % (Levy 1990) in the United States. There are similar figures from other countries (for example, National Contractors Group 1990).

Working in suboptimal conditions

Thomas and Oloufa (1995) found that for reasonably good projects, the average weekly labor performance is reduced by about 9 percent for every disrupted[vii] workday. For abnormal projects with many disruptions, the cumulative labor performance is reduced[viii] by an average of 60 %. In HVAC installation, interferences are so common that a 5–10 % cost increase is quite usual (Gunnarsson et al. 1994). O'Brien (1998) found that subcontractors increase their bids up to 10 % based on expectation of poor general contractor performance on site. It was found that productivity in elevated areas was almost 20 % higher than normal, because foremen tended to plan and prepare those works more carefully, and because the worker was less likely to be interrupted and shifted to other work (Hester et al. 1991).

Lack of safety

Another waste factor is lack of safety. In the United States, safety-related costs have been estimated to be 6 percent of total project costs (Levitt & Samelson 1987). A recent investigation (Everett & Frank 1996) concluded that the total costs of accidents has risen to somewhere between 7.9 % and 15 % of the total costs in nonresidential construction in the United States. A case study on a particular construction site in UK showed that accident costs represented 8.5 % of the tender price (Dester & Blockley 1995).

9.4.1.2 Value loss

Failure to reach cost and schedule targets

In a British study on commercial building projects in 1984–1986 (NEDO 1988), it was found that about one-third of projects were completed on time (as specified in the contract) or early, another third overran by up to one month and the rest had overruns in excess of one month. In the same study, customers were also asked how they viewed the success of their project. Dissatisfaction was most forcible linked to long overruns.

An Australian study on building projects completed in 1988–1993 found that 14 % of projects had a cost[ix] overrun and 67 % a time overrun (CIDA 1993). Furthermore, it was found that 73 % of projects had variations in scope, representing 9 % of the total value of all projects studied[x]. 22 % of projects had variations in scope of greater than 10 %, and all of these projects had time overruns.

A recent study in the United States (Konchar, Sanvido & Moore 1997) showed that 38–51 % of 304 projects considered, depending on the project delivery type, ended up above budget by more than 5 %. A corresponding British study (Bennett et al. 1996) found that 21–32 % of projects ended up above budget by more than 5 %.

Failure to reach the best functional performance

As for the failure to attain the best possible performance, little systematic data has been collected. However, on the basis of existing indirect and partial data, it is possible to have at least a rough picture of the situation. In the following, two examples are presented.

Figure 15 presents the energy consumption of residential multi story buildings in Finland as a function of the construction year. An increase in the average energy consumption can be observed up till the early sixties. From 1970 on, the effect of the energy crisis is visible, leading to decreasing energy consumption. However, the decrease levels off in the eighties, and changes to a slight increase in the beginning of the nineties.

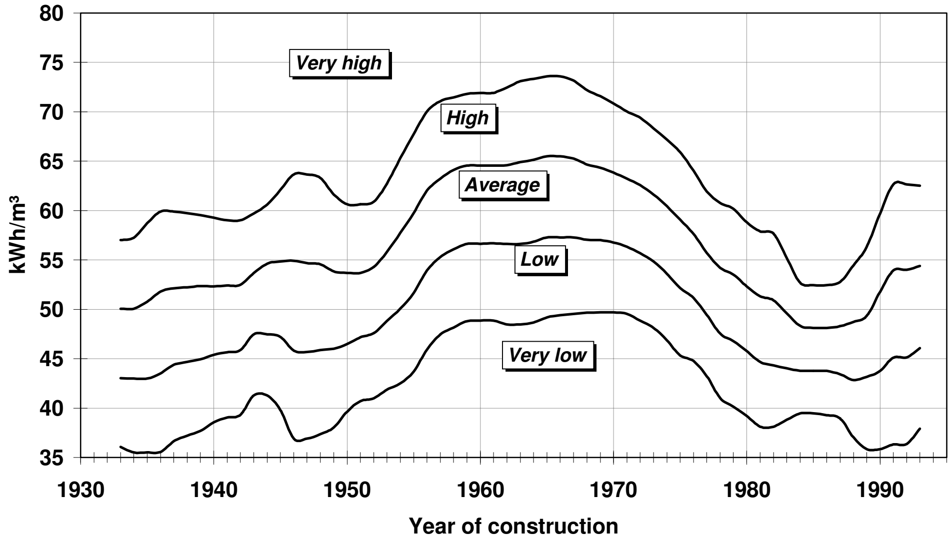

Figure 15. Energy consumption in residential multi-story buildings by construction year in Finland (Aho et al. 1996).

Energy consumption has been in the societal focus since 1970, first due to the energy crisis and later due to growing awareness of the need for sustainable development. Energy is the largest single item – roughly a quarter – in the operating costs of a residential building, and thus it is of interest both for the owner of buildings with rented flats and owners of condominiums.

There certainly is a clear reduction – roughly 25 % – in energy consumption when buildings from the sixties are compared to those of late eighties. However, this reduction seems to be largely due to changes in building regulations[xi], as pointed out by the flattening out of average consumption in the eighties. On the other hand, energy consumption in buildings from the eighties is not essentially different from that of buildings from the thirties (admittedly, new buildings have functionalities that were not common in the thirties, such as mechanical air ventilation).

In addition, it is of interest that the variation of energy consumption has only slightly decreased. Of the buildings constructed in 1960, 86 % have energy consumption within 19 % of the average, for buildings constructed in 1985 the corresponding statistic is 15 %.

The energy consumption of a building is influenced both by the design solution and its realization, and the level of operation and maintenance. In a long-term analysis, the development of materials and components also plays a role. The big variation of energy consumption in newer buildings indicates that the cause for variation is in the characteristics of the production system rather than in lack of maintenance.

Simply, the building industry has not advanced much in the fulfillment of this customer requirement, except when compelled by regulations to use solutions leading to better energy economy. Another argument is that it is the lack of innovation in materials and components that has resulted in slow progress. However, experimental projects (Kaitamaa et al. 1993, Nieminen 1994, Laine & Saari 1998) show, that a much lower level is achievable based on existing components and materials, thus indicating that the fault is not attributable to product innovation, but rather to deficiencies in production systems of construction. In fact, energy consumption has rarely been presented as a target in building projects, and even if it has been presented, there usually is no attempt to verify whether it has been realized.

A lack of achievement regarding energy consumption in buildings becomes visible if we compare the development of energy consumption of buildings to that of cars. According to studies (Anon. 1997b), the gasoline consumption of new cars[xii] diminished by 14–26 % (depending on whether one drives in cities or on highways) during the period 1975–1996. This is roughly the same as in residential buildings. However, *this has been achieved when functionalities have been simultaneously added*: cars weigh more, have bigger engines, and the exhaust gases are considerably less polluting than twenty years ago.

Another example concerns ventilation systems, which have a direct impact on the indoor air quality in buildings. Swedish data on ventilation systems in existing buildings (Engdahl 1998) shows that only 34 % of them have a performance that conforms to the regulations that applied when the system was brought into operation. According to the study, deficiencies in the maintenance, cleaning and balancing of those systems are the direct reason for this phenomenon[xiii]. However, such indirect causes as lack of operation and maintenance instructions, lack of robustness, maintainability and operability as well as mismatch between system complexity and the potential of the maintenance organization operated in the background.

Surely it is the responsibility of the production system to design a ventilation system that is robust[xiv] and easy to maintain, and to provide instruction on how to operate and maintain it. Thus, this example shows a failure to consider life-cycle requirements for a building system.

Thus, these examples give some evidence that the failure to reach the best functional performance is a systematic and significant feature in construction.

Latent defects leading to exceptional maintenance

Exceptional maintenance carried out by owners during facility use has been studied in several countries. In Sweden and Germany these external quality costs are estimated to be 3 % of the value of annual construction production (Hammarlund & Josephson 1991). For Norway, the corresponding figure is 5 % (Ingvaldsen 1994). When the average costs for exceptional maintenance are traced back to the time of the actual construction, the loss of value is found to be 4 % of the production cost in the case of Sweden (Hammarlund & Josephson 1991). 51 % of these costs are associated with design problems, 36 % with construction problems, and 9 % with use problems.

9.4.1.3 Comparison

These prior findings on waste and value loss are now summarized and compared with the findings from the case study.

Our knowledge on waste and value loss in construction is fragmentary. In existing empirical studies, the definitions of each waste type vary considerably. A wide variation due to local conditions, project types, construction methods etc. may also be anticipated. However, there is enough empirical evidence to conclude *that a considerable amount of waste and value loss normally exists in construction*[xv]. Available figures tend to be conservative, because the motivation to estimate and share them is greatest in leading companies, which may use methods close to the best practices. Furthermore, even an energetic effort to observe, say, all quality problems does not reach all of them. Thus, high levels of waste and value loss, as observed in the case project, are a normal phenomenon in construction.

Prior research gives also support to the case study finding on waste caused by work in suboptimal conditions, even if it has not been widely addressed. Likewise, findings on the causes of rework and deviations give support to the case finding of waste origination in prior phases. Furthermore, the findings of prior research on the wide occurrence of value loss in construction augment the results gained from the case study, where value loss was not systematically monitored.

9.4.2 Factors causing waste and value loss

9.4.2.1 Bad control

The case study findings were compared to the results of contemporary (interpreted to mean the 1990s) research and observation with empirical backing. It turned out that the case findings are consistently supported by empirical studies or expert observations concerning recent construction in different countries, as summarized in Table 8. Representative samples of findings of prior research are presented next.

Table 8. Observed problems of construction management according to recent research.

Source	*Problems of client decision making*	*Problems of design management*	*Problems of supply chain management*	*Problems of on site production management*
Arnell et al. 1996		x		
Barton 1996	x			
Gardiner 1994		x		
Jarnbring 1994			x	
Jonsson 1996			x	x
Josephson & Hammarlund 1996	x	x	x	x
Koskela & Leikas 1997			x	
Lindkvist 1996	x			
Lyrén & Sundgren 1993	x	x		
Proverbs & Olomolaiye 1995			x	
Sverlinger 1996	x	x		
Walker 1996				x
Vrijhoef 1998			x	

Regarding client project management, Lindkvist's (1996) study is illustrative. A group of construction professionals, balanced in regard of their role in projects, were asked about problems in the early phases of projects. The five most important problems were as follows:

- decision makers initiate the project too late and prescribe a too short duration for it
- to persuade the decision makers to understand the importance of defining what they want
- there is often such a hurry that there is no time for producing several alternative proposals
- having room for methodical programming in the project
- it is difficult for the client to be organized so that various requirements are transparently transferred to the project.

In a thorough study on design management (Arnell et al. 1996), the central problems found were defined as follows:

> The involved persons perceive uncertainty on what has to be done, who has to do it and when it has to be ready.
>
> The actors in the design project organization have no common and clear understanding on what should be designed.

Regarding supply chain management, Proverbs and Olomolaiye (1995) describe the current stock control practice on site:

> Stocks were replenished when they were seen by managers to be diminishing, or sometimes when competent workers would bring it to their attention. This ad-hoc system invariably led to short-term delays and the need to redirect workers or slow down activities, thereby reducing productivity.

As for site management, Jonsson (1996) found, when trying to compare actual and scheduled time use, that the work of subcontractors was in many cases just drawn as one long line in the schedule, with only a start and finishing date. Furthermore:

> [T]he time schedules were so coarse that it was sometimes impossible to transfer the hours from budgets (or estimates) to the activities on the time schedule. However, after much work we finally managed to create time schedules containing more than a few lines.

Paradoxically, these findings regarding endemic management problems of construction can be seen as both non-surprising and puzzling. In fact, this state of affairs can be seen as a continuation of historical conditions, and thus as no surprise: many of these problems were recognized already in 1965 by Higgin & Jessop (1965), quoted in Chapter 8. Thus, initiatives like quality management, computerization, and others have contributed little to the amelioration of construction. On the other hand, there is a puzzle: why does practically all management in construction seem to be problematic, by all parties, in every phase? Is there some underlying reason for this?

9.4.2.2 Unfavorable design

As found in the case study, unfavorable production system design may be caused by the managerial approach or by the inherent peculiarities of construction. The fact that the inherent peculiarities of construction have an unfavorable impact has long since been recognized. For example, Bennett (1991) analyzes, based on empirical data, the impact of weather, a feature of site construction, on project delays. Another peculiar feature that causes variability is the high interdependence between teams, also associated with site construction (Bennett 1991).

The impact of managerial approaches on production system design has also been considered to some extent in prior research. Le Gall (1993) has pinpointed the negative impact of the lack of (prior) improvement on the production system. Also, it has been noticed that even seemingly insignificant decisions on system design may lead to more complex and variable arrangements, as illustrated by the following quote (Thomas et al. 1999):

> There were a number of fabrication errors with steel members. This may have been because the fabricator subcontracted the detailing of the shop drawings, and the quality of these drawings seemed subpar.

Thus, prior research supports the findings of the case study regarding the role of unfavorable design in waste and value loss formation.

9.4.3 Root causes of waste and value loss

In order to clarify to what extent the case study results can be generalized regarding the root causes of waste and value loss, it is requisite to compare the method of management of construction typically found in prior research to that found in the case study. – Views of prior research on peculiarities as root causes were shortly treated above.

9.4.3.1 Analysis of root causes by project phase

Client project management

As discussed above, client project management is generally only to a small extent systematized, except by the large professional clients. No major guiding principles can thus be recognized.

Construction design

According to the observations by Barber et al. (1998), planning of design consists of estimating the time it takes to produce the required number of drawings plus associated specifications. A "release schedule" is used to monitor the performance of the process. Thus, management is focused on the tangible outputs of design, rather than on design tasks.

Supply chain

In a study into the logistics of construction in Finland, it was found that buying price is the dominating criterion for supplier selection (Wegelius–Lehtonen et al. 1996). Jarnbring (1994) found that it is customary to use material inventories as buffers against disturbances.

Site production

Särkilahti (1993) found that in Finland subcontractors are selected on the basis of price. Bennett and Ferry (1990) found that "...the specialists [contractors] are just thrown together and told to sort things out between themselves". Ballard and Howell (1998) argue that production control equates to contract control:

> The construction model of control is actually a model of project control, not production control. Direct control of production itself occurs only within the production unit, and is not addressed by the disciplines of project or construction management. In other words, how the contractor, subcontractor, or department gets the job done is their own business and is irrelevant as long as they meet their "contractual" commitments. Construction can thus be said to have no theory of production control proper.

In a similar vein, Allen (1996) describes the impact of increased subcontracting on production control:

> Suddenly there was a contract between the manager and the production process and yet we still acted as if we directly controlled the work face. The contractual problems that inevitably arose required a fix, and we started down the road to managing contractors, not production.

9.4.3.2 Analysis of root causes by management level

Design

Barber et al. (1998) observed that operational relationships on projects using new forms of procurement, like DBFO (design-build-finance-operate) or DB (design-build) act against the strategic aims of the project. Despite working in a seemingly integrated relationship, the actual practices are conventional and fragmented.

Control

Laufer and Tucker (1987) describe how the intended centralized task control becomes downgraded to mutual adjustment. They claim that the role of planning is transformed from initiating and directing action before it takes place (as suggested by theory) to influencing and regulating operations while in progress (as intended in practice) and to follow-up and status reporting (as realized in practice). Applebaum (1982) and others have described the resultant dual management, consisting of formal and informal management systems. Josephson and Hammarlund (1996) find several shortcomings in quality implementation which can be interpreted as having been caused by the neglect of formal systems, i.e. client does not follow up the realization of requirements; contractor's headquarter view on quality implementation does not match with the situation on sites; what is documented is not realized.

Improvement

Jouini and Midler (1996) observe, in their case studies, the weakness of improvement by feedback in construction. This is corroborated by Fischer (1997).

9.4.3.3 Conclusions

Thus, prior research has found that construction is primarily managed based on the principles of the transformation concept, especially decomposition of tasks and costs minimization. However, the intended systematized task management corrupts to unsystematized management. One significant reason for this is that task management is effectively implemented only to the level of subcontract, but not in greater detail. In client project management and design management, task management is only weakly applied. Thus, the primary principles used in the management of the case project seem to be in wide use. What happened in the case project corresponds to the customary method of operation in the construction industry. It can be assumed that *similarly as in the case study project, the managerial principles in use in the construction industry in general lead to bad control and unfavorable design, leading in turn to waste and value loss*.

9.5 Validity

According to Yin (1989), a case study has to be evaluated on the basis of its reliability and validity. Validity is comprised of construct validity, internal validity and external validity.

The reliability of the results depends on the extensive, published case-study database, which has been the starting point of later analyses and interpretations of the project. Construct validity was enhanced by using several types of information, like site observation, documents and interviews. Internal validity was ensured by using a series of techniques: pattern matching, time series analysis and explanation building. Pattern matching consisted of comparing the observed processes to theory-derived processes. Time series analysis was focused on observing the interaction of tasks across the project timeline. Explanation building was based on a mini case study where the mechanisms in action could be observed in detail. The findings of the mini case study were then compared to other data, and actually, a high degree of generalizability could be observed.

Regarding external validity, it can be argued that the case project is representative for current Finnish mainstream construction. The organizations involved form a cross section of typical firms operating as customers and suppliers in the construction industry: an established major construction company, an institutional investor, a rapidly expanding high tech firm and a number of design practices, subcontractors and prefabricators. The design solutions and the construction methods selected are in wide use. Also when measured by cost, the project is in the normal range. Only regarding the duration, the project is fast in comparison to the historical standard, but not exceptional.

The similarity of the problems found in this project and recent construction projects across other countries suggest that, on the whole, the findings can be generalized to international level.

Among the limitations of the case study, there are the following:
- Due to interruption in the course of the project, the initial phases of the project could not be observed.
- Value management was emphasized less than task management and flow management.
- The number of cases is only one, which may lead one to think that the empirical grounding of findings is unconvincing. However, comparison with other projects revealed a great number of similar problems and mechanisms.

In spite of these limitations, the overall results of the case study can be evaluated as having good validity. However, this one case study did not necessarily reveal the whole range of mechanisms through which bad control and unfavorable design emerge and lead to waste and value loss.

9.6 Discussion

Only a few studies on construction extend into the domain of explanation of construction performance problems. However, many provide prescription based on description, and thus implicitly contain also explanation. What is the position of the explanation in this study compared to explanation in prior research?

The prior explanations can be categorized as follows:

- Lacking capability or motivation of individuals. Josephson and Hammarlund (1996) claim that half of the costs of defects and 60 % of defects are caused by deficient engagement of individuals, the rest by deficient knowledge, deficient information, risk-taking, and stress. Thus, they suggest emphasizing the significance of the individual in the project.

- Lacking implementation of existing principles, methods, tools etc. The report of the Business Roundtable (1983) holds that the problem is in the sluggish introduction of modern management systems. These methods comprise critical path network and tools of engineering economics. This is the position also implicitly held in the doctrine of construction management, as represented in textbooks.

- Deficiencies in the theoretical foundations of principles and methods. This explanation has been one underlying theme in Laufer's work, for example (1997). He has especially pointed out the lack of consideration of uncertainty in project planning. The theoretical frameworks of Bennett, Walker, and Morris are largely in this category. One of their main arguments is that the environment should be taken into account when configuring a project.

- Structural deficiencies. Barton (1996) is among the few who claim that most practical problems in construction are related to systemic or structural problems with the way projects were conceptualized and initiated. Similarly, Higgin & Jessop (1965) say that any lack of coordination is more the result of forces beyond the control of any individual or group. Moreover, Barton attributes the problems of client decision making to the fuzzy, ill-defined problem situations in the early phases of projects.

- Peculiarities of construction. Brousseau and Rallet (1995) argue – as discussed in Chapter 8 – that the two organizational principles of construction, decentralization of decisions and informal coordination, correspond to the techno-economical characteristics of construction and that they are mutually coherent and thus reinforce each other. However, these principles lead to such dysfunctionalities as lack of whole system optimization and opportunistic behavior.

- Uncertainty and interdependency lead to informal management, which leads to endemic crisis. In the study of the Tavistock Institute (1966), the disparity of the characteristics of the formal and informal systems in relation to the needs of the real task with which they are concerned is pointed out as the root cause of problems. The formal system (contracts, plans, etc.) does not recognize the uncertainty of and interdependence between the operations of the building process. The informal system of management is geared towards handling uncertainty and interdependence, but it produces a climate of endemic crisis, which becomes self-perpetuating. (This explanation is roughly similar to that presented by Brousseau and Rallet, but adds the phenomenon of self-inflicted problems.)

It is easy to agree with the prior views presented; most of them converge with the findings in this case study, and thus add to its validity. However, they all are either partial or unspecific. For example, it is true that most problems are caused by individuals; however, we must ask why work routines have not been installed where the possibility of error is minimized. It is true, that the lack of the implementation of "modern methods" may be one cause of problems; however, it is these same methods in themselves that are a source of problems. It is true that the lack of consideration regarding uncertainty leads to problems. However, uncertainty – or variability – is just one aspect of a wider neglected concept, namely flow. It is true that there are structural deficiencies but there are also problems related to control and improvement.

Regarding the explanation by Brousseau and Rallet, it must be said that the case study shows that a great share of variability is self-inflicted, by the very principles that they see as a response to variability (as the result of construction peculiarities). On the other hand, their approach is conceptually somewhat problematic. For example, it can be questioned whether whole system optimization needs centralized decision-making, as they claim, or whether aligned, decentralized decision-making[xvi] would do the job.

The Tavistock explanation encompasses many core mechanisms, and is apt in the light of the case study.

Finally, there is one significant difference between the explanation created in this study and prior explanations. Explanations like those presented by Tavistock, or by Brousseau and Rallet, do not directly lead to prescription, usable in practice. In contrast, the explanation created here is anchored to an existing body of principles and methods, which potentially can be used for the amelioration of construction management.

9.7 Conclusions

On the basis of the analysis performed, it can be conceived as a grounded hypothesis that the situation in construction may be briefly characterized as follows:

- The conceptual basis of construction management is transformation concept oriented.
- The managerial methods in use are counterproductive by neglecting or violating principles of flow management and value management (and to some extent also principles of task management).
- As a consequence, there is considerable waste and value loss in construction.

However, in many instances, a contributing factor to waste seemed to be made up by such construction peculiarities as one-of-a-kindness, site production and temporary organization. How should these peculiarities be addressed in construction management? This question is explored in Chapter 10.

It was concluded that the chronic problems of construction are mainly due to the neglect of principles of the F and V concepts; however, there is no proof yet that the application of the TFV concept would actually provide the solution. This issue will be addressed in Chapter 11.

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[i] The full documentation of the findings and the data on which they are based are presented in an unpublished case study report (Koskela 1999).

[ii] The major factor influencing waste formation in design was the tardiness and instability of layout requirements as voiced by the tenant. Calculations show that without these problems, the design phase could have been compressed by 40 % from its realized duration of nine months (Tanhuanpää et al. 1999).

[iii] However, analysis showed that construction management decisions were often based on too narrow a consideration, and thus cost and time were added by *non-optimal choices* (Tanhuanpää et al. 1999).

[iv] This term is used by Hopp and Spearman (1996) for referring to non-optimal control.

[v] Note that the organizational form relying on mutual adjustment, *adhocracy*, is simply not an efficient structure (Mintzberg 1983).

[vi] Here it is possible to present a counterargument: a subcontracting company having reached high internal and external quality should be price-competitive. However, in practice, at least in this case, it was difficult to point out examples of such subcontractors in the marketplace.

[vii] The management disruptions meant are congestion, sequencing, rework, and lack of supervision, information, equipment, tools, and materials. Note that weather was not defined as a disruption here.

[viii] Thomas and Oloufa (1995) indicate that performance can be affected by an average of 1:2.5. Thus, the normal performance of 100 % is reduced to 40 %, equalling a reduction of 60 %.

[ix] However, in this case costs have been adjusted to account for authorized variations and extensions of time.

[x] This matches well with the results of Choy and Sidwell (1991), who found an average cost escalation of 7.8 % of the fixed contract sum in Australian construction projects. This escalation was primarily due to changes initiated by designers and the client.

[xi] Thicker insulation, triple-glazed windows, heat recovery etc.

[xii] This applies to the most popular car models in Finland in this period.

[xiii] As a countermeasure, checking the performance of the ventilation system has been made compulsory in Sweden in 1993 (Engdahl 1998).

[xiv] Robust in the sense of Taguchi (1993), especially in this case: the design of new products is best for customers' varying operating conditions.

[xv] Of course this is not surprising in view of the widely held opinions on construction. Schonberger (1990) comments that construction does not fit the usual categories of industries: "One industry, construction, is so fouled up as to be in a class by itself. Delay, lack of coordination, and mishaps (especially return trips from the site to get something forgotten) are normal, everyday events for the average company."

[xvi] For example, Warnecke (1993) suggests such decentralized management.

10. Interpretation of construction from the point of view of the TFV theory

As found in the preceding chapter, one source of waste and value loss in construction is provided by the peculiarities of construction, which, for example, may directly contribute to variability or indirectly amplify the impact of variability. Is it possible to eliminate or mitigate such peculiarities? For clarifying this issue, it is necessary to interpret the production situation typically occurring in construction from the point of view of the TFV theory. Such an interpretation will be discussed in this chapter based on observations from the case study (described in Chapter 9) and findings from prior research.

10.1 Introduction

From the point of view of operations management, it is convenient to group the significant peculiarities of construction, as presented in Chapter 8, into three major categories[i]: one-of-a-kind nature of projects, site production and temporary organization.

One-of-a-kind production is not a unique feature of construction. Even if manufacturing is largely understood as mass production, a major share of manufacturing output consists actually of one-of-a-kind products[ii], mostly in the capital goods sector (hence also the term project industries).

The one-of-a-kind nature of construction output is caused by differing needs and priorities of the client, by differing sites and surroundings, and by differing views of designers on the best design solutions (Warszawski 1990). This one-of-a-kind nature, which varies along a continuum, covers most often the overall form of the building or facility, and the interfaces between different subsystems. The materials, components and skills needed are usually the same or similar. From the point of view of contractors and design offices, there is often continuity and repetition: roughly similar projects and tasks recur[iii]. Thus, it has to be stressed that the problems associated with one-of-a-kindness affect only certain aspects in any project. In comparison to many other industries, like software programming, the degree of one-of-a-kindness in construction is not extreme.

One-of-a-kind production is characterized by two issues (Wortmann 1992a, Riis et al. 1992). Firstly, product design is an integral part of production (that is, product design or development beyond mere selection of options or configuration design). Secondly, there is uncertainty, which is critical especially in regard to customer order acceptance.

Construction production is typically carried out at the final site of the product to be constructed. Thus, construction is characterized by *site production*, a feature shared by only a few other industries, like mining and agriculture. In construction, the concept of site production refers actually to a bundle of features:

- Site as a resource: the site is a necessary input resource for production.
- Lack of shelter: there is usually little protection against elements or intrusion, rendering operations prone to interruptions.
- Local resources and conditions: local material and labor input often has to be used, potentially adding to uncertainty; other areas of uncertainty include site geology and other environmental factors.
- Creating the production infrastructure: the production infrastructure (machines, manpower, etc.) has to be planned, procured and set up on site.
- Space needed by production (workstations move on the product): the spatial flow of workstations (teams) has to be coordinated (in contrast to a factory, where only material flow through workstations is planned).

It is evident that these characteristics of site production add to uncertainty and complexity of construction in comparison to stationary production.

A construction project organization is usually *a temporary organization*[iv] designed and assembled for the purpose of the particular project. It is made up of different companies and design practices, which have not necessarily worked together before, and which are tied to the project by means of varying contractual arrangements. The temporary nature of the organization extends to the work force, which may be employed for a particular project, rather than permanently. This feature reflects the one-of-a-kind nature of a constructed product: several alternative materials may be used, each requiring specialist expertise in design and installation. On the other hand, as mentioned above, the economic necessity of using local labor or subcontractors is one cause of temporary organization.

Of course, temporary organization is not unusual; it is being advanced as a future production mode in the framework of agile manufacturing and virtual production.

10.2 The impact of construction peculiarities on management of construction from the T point of view

The goal of the discussion is to identify and define the problem and to review existing solutions as well as to point out research and developments needs. The discussion is confined to the decomposition feature of the transformation concept; thus, for example, mechanization – historically attached to the transformation concept – is not considered.

10.2.1 Transformations in construction production

The fundamental difficulty in the utilization of the T concept and related principles in construction is how to deal with uncertainty and interdependence due to construction peculiarities, as noted already by the Tavistock Institute (1966). The difficulty is caused by the incompatibility of uncertainty and interdependency with the inherent simplifying assumptions of the transformation concept: decomposed subtransformations of production are considered as independent and certain. Problems surface especially at two instances: procurement of work by the client or the general contractor, and production control by the general contractor.

10.2.1.1 Procurement of work

Let us consider the case where a general contractor bids on the basis of drawings and other usual documentation. In addition to the general causes of uncertainty there is the fact that drawings seldom describe comprehensively what should be done (Tommelein & Ballard 1997). As a direct reaction, the contractor puts a risk premium on top of the bidding price. During the work, ambiguities or unexpected developments may lead to various coping strategies on the part of the contractor, like informal management, excessive documentation, and litigation as a last resort. Note that the situation is problematic from the point of view of the both parties. After the contract has been made, the contractor has a monopoly situation regarding the pricing of changes, and thus there is a danger of opportunistic behavior by him, as viewed from the client's perspective. The constructed facility will contain a number of latent defects, the costs of which the client cannot foresee. In addition, it is clear that it is the client who will finally carry the burden of all transaction costs like the bidding costs of contractors and subcontractors[v].

Actually, this is a situation considered by the transaction cost theory (Milgrom & Roberts 1992). According to it, when uncertainty and complexity make it hard to predict what performance will be needed, contracting becomes more complex, specifying rights, obligations, and procedures rather than the actual performance standards. Another alternative is that parties establish a long, close relationship, where it is possible to reward a faithful partner and to punish an unfaithful. Thus, the need for formal, detailed agreements is reduced. The difficulty of performance measurement tends to lead to arranging affairs to make measurement easier or to reduce the importance of accurate measurements.

Practical developments seem to justify the predictions of transaction theory. The standard contract format, oriented towards the T concept, is increasingly criticized[vi]. An example of a more complex contract is provided by the New Engineering Contract (NEC) where the responsibilities of parties and the procedures for conflict mitigation are determined in much more detail than in conventional contracts (Perry 1995, Broome & Perry 1995). The need for long-term cooperation is exemplified by Dorée (1996), who showed that the Dutch municipalities only use the open tendering procedure infrequently, but rather use selective or limited tendering[vii]. The main reason for this policy is the concern over contractors' opportunistic behavior, especially in the situation where the contract specifications have to be changed. Of course, long-term partnering[viii] in general is based on the same premises.

There are also other radical alternatives that reject the transformation model in procurement. There are at least two options: the procurement may be structured according to flows, or according to value generation. In the former case, one procures outputs from self-contained flows; in the latter, one structures the procurement on the basis of the value generation model. These alternatives will be explained in the sections below.

10.2.1.2 Production control

In the transactions between the general contractor and subcontractors, similar problems occur as between the client and the general contractor. Nevertheless, what is characteristic of these transactions is that the general contractor creates by its production control the conditions for the work of the subcontractors. On the other hand, the behavior of the subcontractor impacts on the realization of the intended production control. Thus, mutual interdependency accentuates: in the augmented transaction cost theory, this feature is called connectedness (Milgrom & Roberts 1992).

In practice, the subcontractors are left on their own as long as the due date of the project is not endangered (as exemplified by the case study and corroborated by prior research). One frequent result is the rejection of formal planning and the rise of informal management (as discussed in Chapter 8).

Again, according to the transaction cost theory, more complex contracting or increased frequency or enhanced coordination can be used. Practice seems to support the predictions of the transaction theory. On more complex contracting, the NEC model, mentioned above, gives an example also in this case. Enhanced coordination has been realized, say, through detailed specification of the interfaces between various subcontracts (Club Construction et Qualité de l'Isère 1993).

However, when work is decomposed further into days-work of crews, the transformation performance can be explained only by viewing construction from the flow point of view. These issues are further treated in section 10.3.1.1.

10.2.2 Transformations in construction design

Due to the inherent characteristics of design (as discussed in Chapter 7), uncertainty and interdependency of tasks is even more accentuated in construction design than in construction production. Thus, it is no wonder that it is difficult to find indications of serious application of the transformation concept in construction design (as evident from the case study and prior research considered). The finding of Arnell et al. (1996) that designers perceive uncertainty about what has to be done, who has to do it and when it has to be ready is quite understandable from this viewpoint.

There have been attempts to alleviate this problem through the description of good practice in each discipline and even generic process models of the whole design project (for example Karhu et al. 1997), but the implementation of such guidelines or models in a specific project has remained as a challenge.

Again, as in the case of production, only by taking recourse to the F concept and the V concept can the mechanisms of transformation performance in design be understood. This will be discussed below.

10.3 The impact of construction peculiarities on construction management from the F point of view

As evident already from the discussion above in this chapter, construction peculiarities have a dramatic impact on the characteristics of flows in construction. The feature of one-of-a-kindness necessitates the inclusion of product design as an integral part into the system of production. The feature of site construction affects the nature of production flows. The feature of temporary organization adds the task of set up of inter-organizational interfaces. However, it is only by detailed analysis of the resultant flows that we can discern the peculiarity implications and possible countermeasures.

10.3.1 Flows in construction production

The production in construction is of assembly-type, where different material flows are connected to the end product. In Table 9, the material flows of construction are depicted and contrasted with those of car production. In car production, the material flows can be divided into two types, the flow of components to the assembly line, and the (main) flow of the car body through the assembly line. In construction, there are three flows. The material flow of components to the site is comparable to that of car production. However, due to the size of the product, there is an intermediate flow where all installation locations proceed through the installation workstation (Birrell 1980). In car production, this phenomenon also exists (several seats have to be installed in different places of the car body), but due to the compactness of (ordinary) cars, all seats can be installed as one operation at one workstation. Lastly, the building frame proceeds through the different assembly phases (processing of all locations by a particular type of workstation(s)) like a car body proceeds through different workstations. However, a building is immobile, unlike a car body.

Table 9. Material flows in car production and site construction. The components of seat and window are used as illustration. The concept of task (not a flow) is presented for clarity.

	Car production	*Site construction*
Material flow (supply chain)	A seat is assembled in the seat factory, transported to the car assembly factory, transferred to the workstation and installed.	A window is assembled in the window factory, transported to the site, transferred to the place of installation and installed.
Task (elementary)	*The seat installer installs the seats at his workstation to one car.*	*The window installation team installs one window (sometimes two or more) to one window opening.*
Location flow	The same as above (the seats of one car are installed as one task at one workstation)	All window openings proceed through the installation workstation (in practice, the team moves throughout the building).
Assembly flow	The car body moves through all workstations of the assembly line.	The building proceeds through all assembly phases (like window installation, partition wall construction, etc.).

Let us illustrate the cost significance of each flow through data from the office building project described in Chapter 9 (Tanhuanpää et al. 1999). The costs of materials bought and transported to the site[ix], corresponding to the material flow, were 45 % of the total construction costs (design costs included). The cost share of work on site, caused by the location flow, was 35 %. The time-dependent building costs, essentially caused by the assembly flow duration, were 6 % of the total construction costs. However, when the opportunity and other costs for the owner are taken into account, the time-dependent costs were 12 % in comparison to the total construction costs. Note that all these costs have a cost share due to waste, which provides a potential for improvement.

Let us analyze the interaction between these three flows and tasks in construction. We focus especially on the elementary construction task. A task equates to processing of designated locations, and it is thus a part of the location flow. A work order (or assignment) consists of a certain number of tasks to be carried out in certain locations in a certain time window. It is appropriate to start from the location flow, where all other flows and tasks are intertwined. Also, due to the central position of the location flow, findings on the possibilities for stemming the formation of waste in construction are discussed in connection to it.

10.3.1.1 Location flow

Construction tasks are of assembly-type

Let us consider the elementary construction task, as it repeats from location to location and from trade to trade. Firstly, it has to be noted that this task is (usually) an assembly operation. If an assembly operation involves multiple purchased parts, the reliability of deliveries is extremely important, because the probability of having them all at time is the product of the individual on-time probabilities (Hopp and Spearman 1996).

In Figure 16, the preconditions for the execution of a construction task, like a day's work[x], are presented. There are at least seven resource flows (or conditions) that unite to generate the task result (usually even more, if more than one material is used in the task). Many of these resource flows are of relatively high variability (due to construction peculiarities), and thus the probability of a missing input is considerable. For example, it is not uncommon that detailed drawings are still lacking at the intended start of the work. Latent errors in drawings or prefabricated parts will surface as problems of realization on site. External conditions (extreme temperature, rain, snow, and wind) form one specific source of variability. Also, the productivity of manual labor is inherently variable, and the availability of space and connecting works is dependent on the progress of tasks of previous trades, thus bound to be variable. Thus, in contrast to typical manufacturing[xi], there are more sources of variability.

Let us assume that the probability of a deviation in any of the resource flows to a construction task over one week (5 workdays) is 5 %. The probability that there is no deviation in any input flow is thus (Hopp & Spearman 1996)

Prob{no deviation in any input flow} = $(0.95)^7 = 0.70$.

In fact, empirical observations of the realization of planned construction assignments[xii] during one week give the result that a value less than 60 % of plan realization is quite normal (Ballard & Howell 1998).

Thus, the first insight gained is that *construction consists of assembly tasks involving a high number of input flows*. Planning and controlling production so that the workstations do not starve due to lack of inputs is an inherently difficult task. This is the very reason why tasks and flows have to be considered in parallel in production management: *realization of tasks heavily depends on flows, and progress of flows in turn is dependent on realization of tasks*.

This insight is reflected in the observation on high levels of non-productive time as typically found in construction (discussed in Chapter 8). However, one often tries to cope without all preconditions, if possible; this will be discussed below.

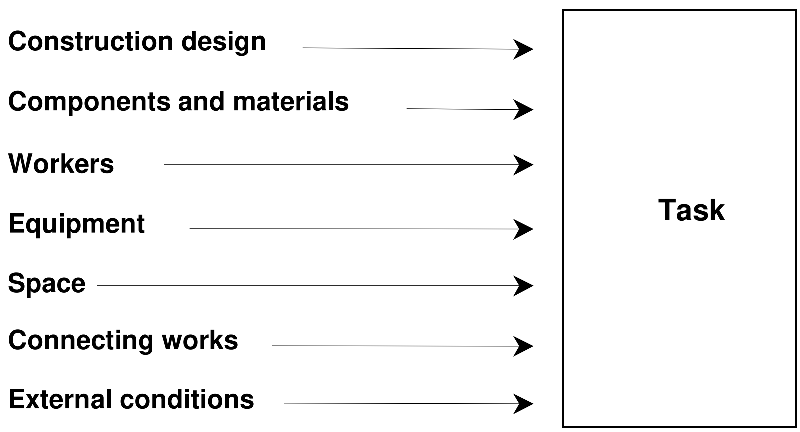

Figure 16. The preconditions for a construction task.

Construction is prototype production

The second insight concerns defects. *Construction can be conceived as prototype production*, which normally is carried out for debugging errors in design and production plans (Methodik… 1986). Presumably, due to the prototype nature of construction, drawings and production instructions are a most frequent cause of construction defects. The resulting rework is, of course, a source of further variability.

The empirical investigations into the causes of construction defects are convincing in this regard. In his study of construction defects, Josephson and Hammarlund (1996) found that when measured by cost, design-caused defects are the biggest category. Of the design-caused defects, those originating from missing coordination between disciplines were the largest category. Deficient construction planning was the largest cause of defects, when measured by occurrence. The three largest deficiencies in the framework of planning were deficient production planning, deficient work preparation and deficient materials management.

There is part congestion and workstation congestion in construction

Thirdly, in construction actually it is the installation team that moves from location to location. This leads to another important feature of construction. In factory production, one part can physically be only at one workstation at any one time. However, in construction, *one part (say, a room) can be worked on by several workstations at the same time,* usually with lessened productivity due to interference. Thus, the phenomenon of congestion has a more dramatic influence on construction productivity than in manufacturing: in addition to part congestion, common in manufacturing, workstation congestion may occur in construction.

Jensen et al. (1997) cite studies showing that oversizing crew from the optimal crew size leads to a considerable productivity loss, due to congestion. Rad (1980) estimated the impact of congestion on productivity on power plant sites to be an average weekly loss of between 4.36 and 5.93 hours per man.

Work is done in suboptimal conditions

However, congestion is just one facet of a wider phenomenon. It is natural that when a workstation is on site, work that happens to be available is carried out. Thus, tasks are routinely commenced or continued without all preconditions realized. The fourth insight gained is that *work is often done in suboptimal conditions, with lessened productivity*. This is a type of waste characteristic to construction, not present in the classical list of seven wastes (presented in Chapter 4), originating from manufacturing.

These suboptimal conditions include, in particular, the following (Ballard & Howell 1998, Jensen et al. 1997, Josephson 1994): congestion, out-of-sequence work, multiple stops and starts, inability to do detailed planning in advance, obstruction due to stocks of materials, trying to cope without the most suitable equipment for the task (due lack of planning and preparation), interruptions due to lack of materials, tools or instruction, overtime, oversizing of the crew.

One specific source of non-optimal conditions is rework due to a change order or a defect found. Changed and unchanged work may be required to be carried out in parallel, leading to dilution of supervision, congestion and other problems (Hester et al. 1991, Finke 1998).

It can be argued that the consequences of working in suboptimal conditions include decreased productivity and quality, increased material wastage**,** ergonomic problems and increased risk of accidents. However, at present clear empirical evidence exists only regarding the productivity impact (as presented in Chapter 9).

Stemming the formation of waste

Up until now, we have found several interesting features in the location flow of construction; however, they all are potentially prone to cause or amplify waste. What can be done to stem the formation of waste?

The most basic solution to these problems is at the level of system *design*. The basic goal is to avoid features of the production system design with high inherent variability. The site problems can be alleviated by configuring the production system so that a minimum number of activities are carried out on site. The rationale of prefabrication, modularization and preassembly is partly based on this principle. The problems stemming from the one-of-a-kind features can be alleviated by using standard parts, solutions, etc. Interference between flows and tasks, which is difficult to handle in a temporary organization, can be reduced through procurement strategies such as the French sequential procedure (Chapter 8), where there is always only one company working on site.

The next option is to mitigate the inherent variability on the level of *control*. There are three requirements to be set for optimal control. First, we want to avoid the cascade of pointwise deviations to other tasks, i.e. variability propagation (Lindau & Lumsden 1995). Of course, the same applies for self-infliction of variability by control. Secondly, we want to avoid unnecessary penalties for variability. As discussed above, regarding production control for a given variability level, there are three optional penalties: buffering of flows, lower utilization of resources or lost production (due to starvation or, particularly in construction, due to suboptimal conditions) (Hopp & Spearman 1996). Thirdly, out of the necessary penalties, ones should be selected that minimize the disadvantages in view of overall objectives.

A new method, often called Last Planner, to cope with the situation met in construction production control, has been developed by Ballard and Howell (1998) since 1992[xiii]. There are five basic principles in this method. Let us analyze them from the point of view of the requirements for production control just mentioned.

The first principle is that the assignments should be sound regarding their prerequisites. This principle has also been called the Complete Kit by Ronen (Ronen 1992). The Complete Kit suggests that work should not start until all the items required for completion of a job are available. Thus, this principle attempts to minimize work in suboptimal conditions.

The second principle is that the realization of assignments is measured and monitored. The related metric, Percent Plan Complete (PPC) is the number of planned activities completed, divided by the total number of planned activities, and expressed as a percentage. This focus on plan realization diminishes the risk of variability propagation to downstream flows and tasks.

Thirdly, causes for non-realization are investigated and those causes are removed. Thus, in fact, continuous, in-process improvement is realized.

The fourth principle is to maintain a buffer of tasks which are sound for each crew. Thus, if the assigned task turns out to be impossible to carry out, the crew can switch to another task. This principle is instrumental in avoiding lost production (due to starving or suboptimal conditions).

The fifth principle suggests that in lookahead planning (with a time horizon of 3-4 weeks), the prerequisites of upcoming assignments are actively made ready. This, in fact, is a pull system (Ballard 1999) that is instrumental in ensuring that all the prerequisites are available for the assignments. On the other hand, it ensures that too big material buffers do not emerge on site.

Thus, the method of Last Planner facilitates avoiding both variability propagation and unnecessary penalties[xiv] of variability. It does not directly address the trade-off between penalties. However, it can be argued that because it is a structured methodology with metrics as an inherent part, it will facilitate the experimental search for an optimal trade-off between penalties in practice.

Regarding *improvement*, we want to locate the source of variability, to launch corrective action, if feasible, and to monitor to what extent the corrective action has succeeded. In fact, the method of Last Planner is instrumental for these purposes, as evident from the description above: it effectively combines control and improvement to fight back against variability and the waste caused by it. However, it is also otherwise possible to aim at increased reliability of deliveries, added conformance to schedule and other such targets in collaboration with all parties.

10.3.1.2 Material flow

The material flow – or supply chain – in construction can be of varying complexity: from transport of sand to a complex supply chain of, say, elevator fabrication. Generally viewed, construction material flows are not different from other material flows in production. The value-adding time in construction material flows is typically 0.3–0.6 % (Jarnbring 1994). Research has shown that in traditionally managed material and supply flows, there is much waste due to excessive variability and bad control (Wegelius-Lehtonen et al. 1996, Jarnbring 1994). However, there seems to be two common properties in them due to construction peculiarities. Firstly, the order is often incomplete or unstable (Koskela & Leikas 1997). Secondly, the delivery is to a temporary location, without permanent facilities for handling material.

Supply chain management can play three major roles in construction. Firstly, the focus may be on the supply chain itself, with the goal of reducing costs (especially logistical costs), lead time and inventory. In view of the large share of the cost taken up by supply in construction, this focus is often wholly appropriate.

Secondly, the focus may be on the impact of the supply chain on site tasks, as discussed above. The goal is to reduce site costs and duration. In this case, the primary consideration is to ensure dependable material (and labor) flows to the site for the sake of avoiding disturbances to the location flow. This may be achieved by just focusing on the interface between site and direct suppliers or on the whole supply chain.

Thirdly, as discussed above, the focus may be on transferring activities from the site to upstream stages of the supply chain. The rationale may simply be to avoid the intrinsically inferior conditions of the site, or to achieve wider concurrency between tasks, not possible in site construction with its many technical dependencies. Here, the goal is again to reduce the total costs and duration of construction.

10.3.1.3 Assembly flow

In the assembly flow, the building frame proceeds through the different assembly phases. This kind of production situation is addressed by the line-of-balance method (Lumsden 1968). Ideally, the location flows (which are usually called tasks in the parlance of line-of-balance) are planned to progress at the same speed[xv], and time buffers between consecutive workstations are planned as a countermeasure to variability of progress, as illustrated schematically in Figure 17. Note, that in practice tasks have different durations and the time buffers between tasks vary. In addition, not all tasks may have start-to-start dependencies.

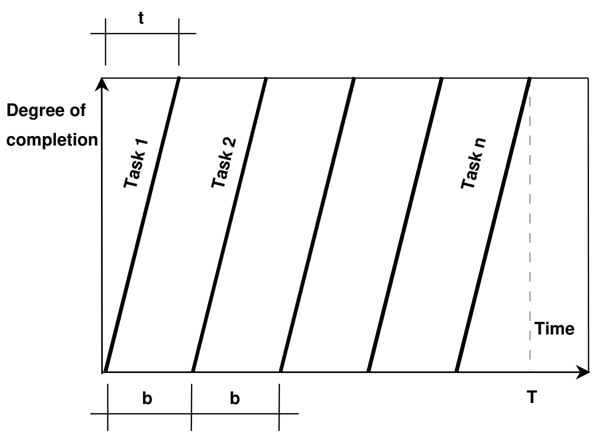

Figure 17. Formation of construction duration (Koskela et al. 1997b).

The total construction time is determined by the characteristics of the assembly flow. Considering a simple example, the total construction time can be described as follows (Peer 1974):

$$T = b(n - 1) + t$$

in which T = total construction time; n = number of tasks; b = time buffer between the start of consecutive tasks; t = duration of a task.

This analysis suggest that the total time is mostly dependent on the number of tasks and the buffer time[xvi] between tasks, needed due to the variability of the progress of these tasks (as analyzed above). The number of tasks can be reduced by prefabrication[xvii] or by using multifunctional teams. Reduction of variability allows reducing buffer times and thus shortening the construction time.

According to Burbidge and Falster (1993), the key to an improvement in productivity and profitability in the production of one-of-a-kind products is in the reduction of product delivery times. In construction, there has always been attention to the overall lead time, i.e. the duration of construction. This is because of client needs, and the fact that there are time-dependent costs, which grow more or less linearly as time passes, and the temporary factory, site, exists. Fast Tracking is an approach aiming at shorter project duration, having already been practiced in construction projects. However, Kwakye (1991) argues that Fast Tracking costs more by definition:

> Fast tracking costs more because the accelerated production rate is above the optimum level of production (the level at which the marginal productivity becomes disproportionately expensive).

Should we interpret this so that, in construction, time reduction does not lead to waste reduction? However, the same situation rules in a factory regarding expediting one order in a job shop: time reduction of one order leads to chaos in other orders, and increased overall costs. It is the contractor's *capability to construct all projects in a shorter time that leads to improved efficiency*, rather than the acceleration of an individual project. Indeed, a major characteristic of Fast Tracking, understood as mere overlapping of activities, is that uncertainty is increased in comparison to the conventional (sequential) method. In consequence, often the total construction costs increase and the value of the end product decreases. Thus, other objectives are more or less sacrificed for faster production[xviii]. This is correctly reflected in the conventional view of the costs of Fast Tracking (Figure 18). According to it, there is an optimal rate of work; a more rapid rate leads to acceleration costs, a slower rate leads to the increase of time-dependent costs (Kwakye 1991). However, through variability reduction and other measures, the location of the time-cost curve can be changed downwards.

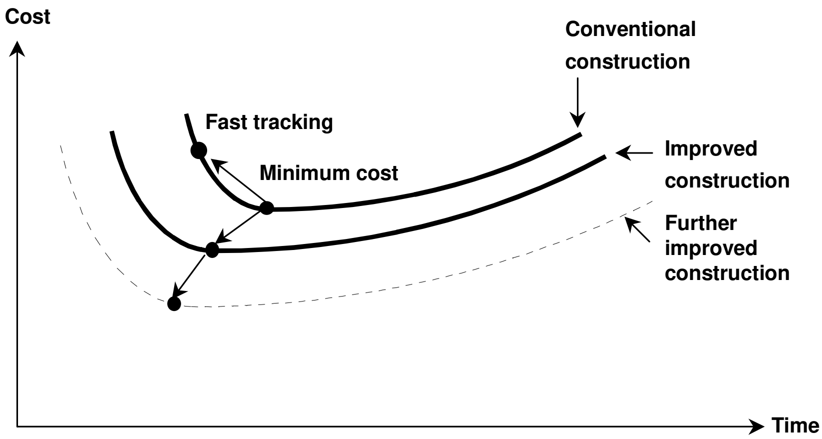

Figure 18. In improvement of construction from the F concept point of view, the aim is to transfer incrementally the time-cost curve downwards, whereas in Fast Tracking, a point on the existing curve is selected.

10.3.1.4 Conclusions

The peculiarities of construction heavily influence the structure and behavior of material flows in this industry. There are three flow types in action on site, in contrast to two types in a factory. Production in construction is of the assembly type, which is inherently vulnerable to input flow variability. Construction is by nature prototype production, normally carried out for debugging errors in designs or production plans. In construction, a part (a location) can be simultaneously at several workstations, leading to working in congested conditions. Also otherwise, work in suboptimal conditions is common; this is a waste-type characteristic of construction. Thus, a high degree of inherent variability and complexity is associated with the flows.

It is suggested that wastes due to peculiarities be eliminated from all of these three flows in an integral way. Generally, there are the following alternatives. Firstly, the production system can be designed so that problems due peculiarities (and associated variability) are reduced or eliminated. Secondly, production can be controlled so that variability is cut down and the disadvantages of penalties of variability are minimized. Thirdly, production and its control can be improved; in particular, variability can be reduced.

For optimal production control given a particular variability level, there are three options: buffering of flows, lower utilization of resources or lost production (due to starvation or suboptimal conditions). From these penalties, the ones should be selected that minimize the disadvantages in view of overall objectives.

10.3.2 Flows in construction design

The case study (Chapter 9) showed that the many technological dependencies between different elements of the building accentuate the significance of correct ordering of design tasks for reducing rework. On the other hand, Coles (1990) found lack of confidence in pre-planning for design work among practicing designers. Is it in general possible to plan and control construction design work flows? This central question will be analyzed in more detail below.

10.3.2.1 Analysis of construction design by means of the Design Structure Matrix method

The Design Structure Matrix (DSM), shortly introduced in Chapter 7, was originally developed by Steward (1981). It is a method suitable for representing information flows in design. In this matrix, design tasks are first organized in their intended chronological order as matrix rows and columns. An input to a task from another task is pointed out as a mark. If there is a mark over the diagonal of the matrix, it indicates that a task gives input to an earlier task. This may be due to poor ordering of tasks, or it reflects an iteration (circuit) in the logic of the design process. By means of certain algorithms (called partitioning algorithms), the tasks in the matrix can be reorganized so that only marks belonging to genuine circuits, called *blocks* (of coupled tasks), remain above the diagonal. This is the optimal order of tasks in the sense that iterations are minimized.

This reorganized matrix provides a starting point for scheduling: the tasks in a block have to be carried out simultaneously, sequential tasks (a mark just below diagonal) in sequence and parallel tasks (no marks linking them) can be carried out in arbitrary order in reference to each other (Figure 19).

In addition to the case study project (Chapter 9), the DSM method has been tried out *ex post* in one other construction project by VTT Building Technology (Huovila & Koskela 1996). In both cases, *there has been one large block (of coupled tasks) in the early phases of the design*; the other blocks are minor. This preliminary finding, which has to be substantiated by other cases, stresses the importance of the planned collaboration of concerned design disciplines in the early phases of design.

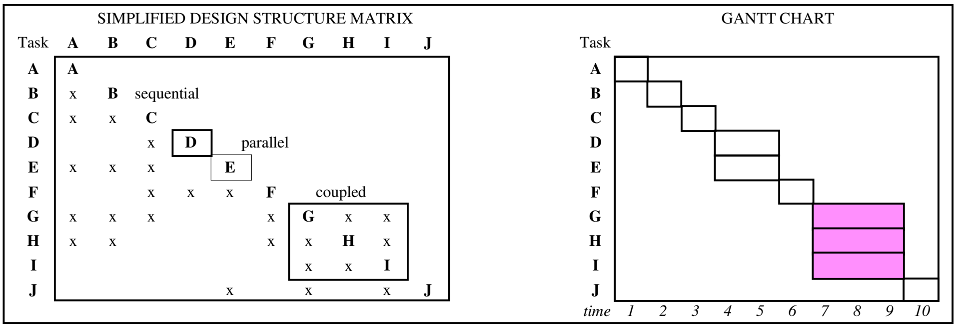

Figure 19. Sequential, parallel and coupled (interdependent) tasks in a Design Structure Matrix and in a schedule.

From the case study analysis by means of the DSM, a somewhat surprising conclusion can be drawn: *construction design is predominantly an assembly type of operation*. If the detail design is decomposed into 27 tasks, so on average, for each task 3–4 inputs from other tasks are needed. Thus, the insights about the significance of reliable input flows, as observed above regarding production, are valid also for design.

10.3.2.2 To what extent can the optimal order of design tasks be predicted in practice?

While the initial results from the DSM method are promising (Huovila et al. 1997a, Austin et al. 1994, Austin et al. 1997), this method is still in the research phase. Only after sufficient testing and launching of commercial software can this systematic tool for finding the optimal order be implemented in practice. Thus, at the moment, no commercial-grade software tools for DSM analysis are available.

However, the principle of optimizing the sequence can be – and actually is – also approached informally. If the building (or other facility) type is familiar, the designers will have a good feel for the optimal sequence of the tasks. In design meetings, designers actively present their input information needs regarding other designers, and the order of making design decisions is thus implicitly agreed on.

Often, especially in the early phases of a design project, there is an inherent restriction on determining the optimal order of tasks. This is because the optimal order may be dependent on a design decision to be made: for example, *in situ* construction requires different order to prefabrication. On the other hand, what is important is that the optimal (or near optimal) order of short-term (next 2–4 weeks) tasks is known, and this should be possible both through a DSM analysis and also through pooled experience in the design group.

10.3.2.3 There are factors tending to push the design process away from the optimal sequence

However, in practice there are several factors tending to push the design process away from the optimal track. One major issue is that, unfortunately, building design cannot be scheduled solely on the basis of the internal logic of the design. Rather, there are three other parties, the needs of which influence the order of design tasks: construction (order of site tasks), prefabrication (lead time of prefabrication) and controlling authorities (documents needed for authority approvals).

Beyond this, in the case study the following factors were observed as problematic:

- blocks of coupled tasks; obviously, the iteration needed has to be started with incomplete information
- lacking or delayed input from the client (requirements, decisions)
- changes in design objectives or criteria
- unbalanced design resources (especially in a block of coupled tasks, some discipline may be a bottleneck)
- late engagement of a design party
- earlier decisions or intentions not being taken into account in a later task
- variability due to internal affairs of design offices.

Interestingly, Sverlinger (1996) found that half of the disturbances in design are due to design organizations themselves, rather than the design process in question. A similar order of magnitude for this factor was found by Koskela et al. (1997a).

Thus, even if the optimal order of tasks is more or less well known, problems emerge due to the high level of associated uncertainty and the half-heartedness of efforts to control the design process. In addition, the weaknesses of the internal management processes in design firms play a major role here.

10.3.2.4 Out-of-sequence design process leads to low performance

The case study revealed that there are several methods for allowing the design to progress in spite of lacking input. However, almost every method brings about additional costs or an added risk of these, or reduced functionality. These solutions and their implications are exemplified in Table 10.

Table 10. Solutions used for making the design to progress in spite of lacking input.

Solution	*Implications*
Assumptions are made and checked later.	Leads to redoing if assumptions have to be corrected after checking. On the other hand, checking is easily forgotten or there is no time for it, and a discrepancy between different designs might emerge.
Design input is actively sought in design meetings and per telephone.	Tends to make design work of other designers fragmented, preventing concentration.
Design iteration is eliminated through an alternative construction method.	Usually more expensive.
Interface between design tasks is prearranged.	The solution might turn out to be sub-optimal.
Design solution is overdimensioned to absorb all possible future decisions.	Sub-optimal solution.
Design solution is selected based primarily on the consideration of design progress (i.e., it prevents the progress of other design tasks as little as possible).	The selected solution might be inferior in other considerations, like functionality and cost.

Thus, out-of-sequence design tasks deteriorate the performance in the design phase itself as well as in the construction phase and eventually decrease the value provided for the customer.

10.3.2.5 Enforcing the realization of the optimal sequence

Koskela et al. (1997a) describe an experiment, in which the optimal sequence of design tasks was analyzed by means of the design structure matrix and a schedule was prepared on the basis of the ordered tasks. The execution of tasks was controlled by means of the Last Planner method (presented above in this chapter). The resulting design process was definitively more disciplined in comparison to a process managed in the conventional style[xix].

There are two major benefits associated with the use of the method just described in design management. Firstly, the design process is made transparent through both the schedule (and the underlying design structure matrix) and the metric of PPC. The impact of, for instance, a design change to the schedule can be analyzed more easily in advance. The impact of erratic decision making behavior by the client can be made visible through PPC graphs. It is presumably the lack of transparency that, for its part, has made disruptive decisions and practices possible in design.

Secondly, a metric (PPC) for design management is provided, making it possible to benchmark, to set targets and to monitor progress across projects. The lack of metrics has up until now been one factor that has effectively hindered improvement of design management.

Thus, the results – which are corroborated in the experiment reported by Miles (1998) – suggest that the realization of an optimal or near optimal sequence of tasks can be enforced through planning and control.

10.3.2.6 Summary

The following hypotheses with regard to design management were discussed: (1) There is an optimal sequence of design tasks. (2) Internal and external uncertainties tend to push the design process away from the optimal sequence. (3) Out-of-sequence design process leads to low productivity, prolonged duration and decreased value of the design solution. (4) It is possible and worthwhile to enforce the realization of the optimal or near optimal sequence. Initial empirical evidence in support of these hypotheses exists. – This analysis focused on control of construction design only; the potential of advancing construction design at the level of system design and improvement has to be charted in future research.

10.4 The impact of construction peculiarities on management of construction from the V point of view

How do the peculiarities of construction influence the value generation processes? It has to be admitted that the value formation process of construction is still poorly understood. A more detailed analysis of the impact of the peculiarities on various phases of value generation is a task for future research. However, it is appropriate to make a few general remarks on this issue.

10.4.1 Value generation in construction design

There are four characteristics that have to be analyzed: (1) customer-driven process; (2) varied group of customers; (3) temporary organization; (4) prototype nature of construction. In addition, the generic issue of cross-concept impacts merits a comment.

10.4.1.1 Customer-driven process

The traditional method of construction assumes that it is the client who initiates the construction process, and this is still one typical approach. Due to the long use time of constructed facilities, the client often has no prior expertise in construction. Requirements capture and brief formulation are important parts of the initiation of any construction project. If the client is a layman regarding construction, the situation is such that requirements capture is the responsibility of the weakest link in the chain. It is not probable that an architect or a construction company would reject a project order from a client due to incomplete or insufficient brief.

The need for a systematic requirements capture and a complete brief is a relatively new insight in construction. The seminal paper on programming by Peña and Caudill dates from 1959. In Europe, Blachère (1988) has been an early proponent of similar ideas.

In principle, requirements capture and brief formulation is a part of the task of the architect. However, as stated by Peña et al. (1987), programming and designing are two distinct processes, requiring different attitudes and different capabilities. Moreover, as they say, "most designers love to draw", and thus there is a push also from architects to start designing before the brief is complete.

Another principle that easily is violated due to the customer-driven process is measurement of value. A one-off client has little interest in measuring the value realized, because no immediate future use for this information is perceived. The situation is different regarding professional clients, like governmental agencies responsible for construction. Usually they have systematized ways of requirements capture and brief formulation, and often at least attempt[xx] to make post-occupation evaluations or lessons-learnt studies.

10.4.1.2 Varied group of customers

One major problem from the point of view of value generation is that the number of customers is large. There are many different roles vis-a-vis a building (occupant, maintenance organization, owner, etc.). Another dimension is added by the fact that buildings are long lasting, and thus the needs of future occupants, etc. should be taken into account. In practice, this situation has led to an involvement of public authorities in the building process through building codes, planning, etc. Buildings should not fulfill only functional requirements, but also esthetic and symbolic. This, in turn, is one reason for the situation that there are no appropriate measures, related to buildings, which would measure the total effectiveness of design.

Thus, the principle "Ensure that customer requirements have a bearing on all deliverables for all *roles* of the customer" is easily violated. One example of this is provided by the common preoccupation with the procurement cost, in contrast to operation costs.

10.4.1.3 Temporary organization

A process manned by organizations with no prior collaboration is by definition less efficient: the set up of collaboration adds more steps; results of continuous improvement are not at hand, and the goals of different parties may not be congruent.

The temporary nature of the design organization presents a problem both for flowdown of requirements and cross-disciplinary optimization. It has been observed in empirical investigations that design teams that have worked together previously are more effective than newly formed teams (Josephson & Hammarlund 1996).

10.4.1.4 Prototype nature of construction

For obvious reasons, it is not possible to construct a prototype building[xxi] for verifying that all the intended requirements have been realized. Rather, the realized building *is* the prototype. This, of course, prevents the carrying out of iterations based on prototypes.

10.4.1.5 Impacts of the deficiencies of design as seen from the point of view of T and F concepts

The fact cannot be ignored that the endemic design deficiencies discussed above, when viewing design from the T and F points of view, presumably impact on value generation. It is not probable that a designer, who does not know his role or division of work, would contribute to value as much as when the situation is clear regarding these issues. Likewise, it is not probable that a designer, who has to struggle with insufficient or unstable input data, would contribute to value as much as he would were the provision of input data smooth.

The case study contained anecdotal evidence on these impacts. The strength and causal mechanisms of these impacts provide a topic for future research.

10.4.2 Value generation in construction production

The basic role of construction production in value generation is the realization of the product as specified. Beyond that, the production phase can contribute to the maintenance of the building through as-built drawings and operation manuals.

Again, it has to be noted that the endemic deficiencies of production management, as discussed above, are a hindrance to value generation.

10.4.3 Solutions

An analysis of the industrial scene reveals that there have been attempts to mitigate the effect of difficulties described both at the level of design of the production system (in this case, project delivery system), control of that system and improvement of that system.

Regarding *design* of the system, there are several recent developments. As explained above (Chapter 8) the performance concept is a method where the procurement is structured on the basis of value generation process, namely, the product is procured on the basis of requirements (rather than drawings or prescribed solutions). This method intrinsically highlights, on the one hand, the preparation of the brief including the performance required, and on the other hand, the realization of those requirements in production. Another recently developed procurement method is Build-Operate-Transfer (Walker & Smith 1995), where goal congruence between various functions should be easier to achieve[xxii].

A totally different solution is to eliminate peculiarities that are difficult to handle. Thus, in projects involving pre-designed buildings, the majority of design has been done in advance, and the solutions have been realized and evaluated. The approach of open building, for its part, decouples, by means of a modular product system, certain design tasks so that user-oriented decisions can be postponed[xxiii] to near completion, when the users are known.

Regarding then *control*, many methods exist. For programming, systematic methods can be used (Peña et al. 1987). There can be an effort to rapidly form a functioning team of persons who do not know each other (Gray & Suchowski 1996). Quality function deployment can be used for making the value generation process visible (Huovila et al. 1997b). Methods rooted in value engineering can be used for the sake of requirement clarification and systematic search for the best solution in each task (Kelly & Male 1993). Incentives and targets can be used for focusing the team efforts. The lack of repetition and thus feedback cycles can be remedied by creating artificial feedback cycles (Chew et al. 1991): simulation in its various forms and physical models.

For *improvement*, post-occupancy evaluations (Preiser et al. 1988) are instrumental, especially if the results can be compared with a larger set of projects. Even in the case of a one-off client, it might be possible to find a designer who routinely allows such evaluation for his projects.

10.5 Conclusions

This chapter endeavored to investigate the implications of the peculiarities of construction for the management of construction from the viewpoint of the three production concepts.

Regarding the T concept, the overwhelming difficulty in construction is the uncertainty and mutual interdependency of its transformations. There are at least two instances where methods based on the T concept are indispensable, i.e. contracting (including subcontracting) and production control.

Analysis shows that in contracting, either the problems can be avoided by using other concepts for buying services and products or they can be mitigated through special types of control. Regarding the latter case, there is a prior theory regarding this kind of situation, namely the transaction cost model of economics. In subcontracting, the situation is similar, except that there is also mutual interdependence between the buyer (contractor) and the seller (subcontractor) of a service or product.

In production control, the purpose is to get all work, decomposed in manageable pieces, efficiently done. Analysis shows that the T concept is inadequate as such for a sole foundation of production control in construction: the T and F concepts have to be used in parallel.

The T concept provides both a problem and an opportunity for construction. The use of the T concept solely as a foundation to manage construction seems to have been a major source of inefficiency. On the other hand, principles and methods based on the T concept are needed in production management as a part of the total approach. In this respect there still seems to be many possibilities for improvement.

In prior research, construction has been interpreted only to a small extent from the point of view of the F concept. However, analysis shows that the peculiarities of construction have a large impact on the structure and behavior of material flows:

- There are three flow types in action on site, in contrast to two types in a factory.
- There is a high degree of inherent variability, due to construction peculiarities, associated with these flows.
- Production in construction is of assembly type, which is inherently vulnerable to input flow variability.
- Construction is by nature prototype production, normally carried out for debugging errors in designs or production plans.
- Unlike the situation in a factory, a part can be simultaneously at several workstations, leading to work in suboptimal conditions: this is a waste type characteristic of construction.

Thus it is suggested that waste be eliminated from all of these three flows in an integrated way. The production system can be designed so that problems due to peculiarities are eliminated. Secondly, production should be controlled so that variability propagation is cut back and the disadvantages of penalties of variability are minimized. Thirdly, production and its control should be improved, in particular variability should be reduced.

Regarding construction design, it turns out somewhat surprisingly that it is of the assembly type. The following hypotheses were formed on the basis of the evidence at hand:

- There is an optimal sequence of design tasks.

- Internal and external uncertainties tend to push the design process away from the optimal sequence.
- Out-of-sequence design process leads to low productivity, prolonged duration and decreased value of the design solution.
- It is possible and worthwhile to enforce the realization of the optimal or near optimal sequence.

Initial evidence indicates that the principles emanating from the F concept provide a major opportunity for improvement in construction, both in the design and construction stages.

Regarding construction from the point of view of the V concept, it has to be stated that the realization of every principle is made difficult by some peculiarity:

- Requirements capture is in a vulnerable position because it is the one-off client, having scarce understanding of the significance of requirements capture, who is in control of the project in the initiation phase.
- Requirement flowdown is made difficult by temporary organization.
- Coverage of all customer roles is made difficult by the great number of such roles, and the organizational complexity in each role.
- Ensuring the capability of the production system is made difficult by the temporary nature of its organization.
- For measurement, there is little interest by the one-off client.

Again, there are various means to solve these problems:

- The problem may be eliminated in system design, like the problem of goal congruence through the BOT approach.
- The problem may be mitigated in system control through intensive use of suitable methods, like QFD or value engineering.
- The problem may be mitigated in system improvement by tapping an external pool of improvement, like industry-wide benchmarking data.

The analysis made in this chapter suggests that it is imperative that the peculiarities of construction are understood and taken into account in construction management both from the point of view of the T, F, and V concepts. In contrast to prior research, suggesting either acceptance or elimination of peculiarities, it is concluded here that peculiarities can be either eliminated or reduced at the level of system design and/or mitigated at the level of control or improvement. This issue will be revisited in the next chapter where additional industrial evidence is considered.

All in all, the peculiarities of construction are an ill-understood area, having attracted very little research hitherto. However, as already this explorative examination indicates, this is a core area for developing construction-specific methods and tools for production management.

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[i] For example, from peculiarities listed by Carassus (1998), "localized orders of extraordinary diversity", "production of prototypes", "artistic creation" and "localized products which can be durably adapted and modernized" represent the *one-of-a-kind* feature. "Located on a site" and "itinerant, short-lived, complex and random site work" represent the *site* feature, and "a producer not controlling the overall process" represents the *temporary organization* feature. Only the peculiarity "rules and conventions playing a considerable role" is not covered by this grouping, but this peculiarity is not very significant from the operations management point of view.

[ii] However, statistical analyses show that one-of-a-kind industries have systematically underperformed mass production industries with regard to profitability (Eloranta & Nikkola 1992). This has been interpreted to suggest that the production management methods are more geared towards mass production (Ranta 1993).

[iii] It is often argued that construction projects are unique, and essentially different from manufacturing in this aspect. However, claims of uniqueness of particular plants abound in manufacturing as well (Plossl 1991, Chew et al. 1990). It seems that there is a psychological urge to see one's own system as unique. In addition, Raftery (1994) has emphasized the large extent of repetition in construction.

[iv] However, these characteristics are often not caused by objective conditions, but rather are a result of managerial policy aimed at sequential execution and shopping for the realization of various parts of the building at the apparently lowest cost.

[v] Glimskär (1998) estimates, based on case studies in Sweden, that the share of transaction costs is 5–10 % of total construction costs.

[vi] Pietroforte (1997) argues that the U.S standard contracts for construction, like those issued by the American Institute of Architects, are based on the following assumptions: certainty and formal nature of information, divisibility and measurability of performance, clear definition of responsibility, and the control of the process through administrative provisions such as written rules etc. According to Pietroforte, these assumptions are not valid in present construction.

[vii] Dorée states that in an open tender procedure there are an average of 16.2 contenders and in a selective tender an average of 3.8 contenders. In limited tendering, the contract is negotiated with one company.

[viii] On the other hand, there are also examples of project-wise partnering (Loraine 1994), where trust is built among parties in order to avoid opportunistic behavior. This does not fit nicely into the transaction cost framework.

[ix] Note that the installation cost is excluded here.

[x] As suggested by Taylor (1913) and Bennett (1991).

[xi] In the case of manufacturing, Lindau and Lumsden (1995) identify five different kinds of disturbances: material shortage, absenteeism, machine breakdown, tool shortage, and technical documentation shortage. This would indicate that in stationary production, external variability arrives through five inflows into an operation, as opposed to (at least) seven, as in the case of site construction.

[xii] Note that in practice, the probabilities of various inflows probably differ greatly to each other.

[xiii] More on the evolution of this method can be found from (Ballard 1997, Ballard & Howell 1997, Howell & Ballard 1997a and 1997b).

[xiv] Utilization of resources is not directly addressed by the Last Planner method, but in construction, unnecessarily low utilization of resources is rarely planned.

[xv] Of course, this is just the *Takt* method applied to construction.

[xvi] In conventional building construction projects, a buffer of 10–15 workdays is suggested (Kankainen & Sandvik 1993).

[xvii] Warszawski (1990) says that the critical path of a construction process could be reduced from 15–20 activities, with the conventional method, to 10–12 activities, with an industrialized system.

[xviii] Actually, speeding may be sacrificed in fast tracking, too. Fazio et al. (1988) report on a fast tracking case where the planned project duration was extended by 40 % due to problems inflicted by the Fast Tracking procedure itself.

[xix] This even if only part of the Last Planner features was used (performance feedback and impacting on causes were not used).

[xx] In practice, professional owners also seem to have difficulties in improvement (Fisher 1997).

[xxi] However, there are situations where this is possible. For example, in hotel design, it is customary to build mock-up rooms in the design phase.

[xxii] Walker and Smith (1995) comment: "The transfer element in the BOT formula allows the receiving authority to spell out exactly what is expected at the end of the period but it is the low maintenance regime during the concession period that is uppermost in the

concessionaire's mind. These factors combine at the design stage when durability coefficients form a key part of the input."

[xxiii] This corresponds to the principle of postponement in the supply chain literature (for example Lee 1993).

11. What can be learned from the implementation of approaches containing elements from the TFV theory?

The TFV theory of production, as it has been presented in this study, has not been implemented in construction as such. However, there are a small number of instances where some core parts of it have initially been implemented. Methodologically, such instances of actual implementation are treated here as cases in case research. These cases, as well as other evidence found in prior research, will be used for validation of three key contributions of this study. In addition, the cases are analyzed for other findings.

11.1 Key contributions to current knowledge

For the purpose of validation by means of case research, the three key contributions are defined in the following as hypotheses along with the corresponding views from current knowledge.

11.1.1 Concept of production

This contribution is related to the central theme of this study, namely to the question of an appropriate foundation for managing production. The current view and the new view put forward in this study can be presented as the following pair of hypotheses.

Hypothesis 1 A *Methods founded on the T concept are sufficient for efficient management of construction.*

Hypothesis 1 B *Methods founded on the TFV concept are necessary for efficient management of construction.*

The hypothesis 1 A represents the received view that can be found in textbooks on construction management, as discussed in Chapter 8. Also the current mainstream production paradigm of construction is oriented towards this hypothesis, as found in the case study (Chapter 9). The characterizing principles are as follows. Production is a transformation of inputs into outputs, and can be decomposed into smaller transformations or tasks. By minimizing the costs of each task, the total production costs can be minimized. Outputs of greater value can be achieved by using inputs of greater value.

The hypothesis 1 B represents the theoretical foundation proposed in this study. According to it, production should simultaneously be seen as transformation, flow and value generation. The principles related to these three concepts should be used in a balanced way, taking the various trade-offs and synergies into consideration.

How can the validity of these hypotheses be investigated? Actually, we can monitor practical experiments, where, starting from practice founded solely on the T concept, an attempt is made to extend management to the principles included in the F and V concepts. If these experiments produce clear benefits, the validity of the hypothesis 1 B is strengthened.

11.1.2 Level of implementation

This pair of hypotheses is related to the comprehensiveness required in the implementation of principles of production in construction.

Hypothesis 2 A *It is sufficient that new principles of production are implemented at the key level of production, namely in the design of the production system.*

Hypothesis 2 B *It is necessary that the TFV principles of production are implemented in the design, control, and improvement of the production system.*

The prevailing view among proponents of a renewal in construction is that there is a single level in the production system, change of which would make a revolution in the whole production system. Even if there are differing views as to what this single level is[i], mostly it is a question of system design. According to the re-engineering movement, the solution is in the redesign of processes (Hammer & Champy 1993). Another, popular view holds that the mode of procurement is the key aspect. Especially, it is suggested that an integrated design-build contract is superior to the conventional, separated design-bid-build procurement (Bennett et al. 1996). A third view is that advancing partnering is a solution to the problems of construction (Baden Hellard 1995).

The view adopted in this study is that the TFV principles should be implemented at all three levels: design, control and improvement of the production system. The central argument, supported by case study findings (Chapter 9) is that there are three different causes of waste, and for waste elimination all three causes have to be tackled. In practice, this means just design, control and improvement. An analogous argument can be presented regarding value loss.

The validity of these hypotheses can be considered by monitoring practical experiments where either the single-level approach or the multi level approach has been adopted, and by comparing respective results.

11.1.3 Treatment of peculiarities of construction

This pair of hypothesis deals with the peculiarities of construction: one-of-a-kind production, site production and temporary organization.

Hypothesis 3 A *Construction peculiarities are a barrier to the advancement of construction, and thus they should be eliminated by suitable solutions.*

Hypothesis 3 B *Construction peculiarities contribute to waste and value loss, and it is necessary to eliminate or reduce those peculiarities and/or to mitigate their impacts at the level of control and improvement.*

The hypothesis 3 A has been put forward in particular in studies on innovation in construction (Nam & Tatum 1988, Groák 1992). This hypothesis is also implicitly behind the efforts towards industrialization of construction (Warszawski 1990) or behind such slogans as "Construction as manufacturing".

The hypothesis 3 B reflects the observations made in the case study (Chapter 9) and the discussion in Chapter 10. Construction peculiarities are a cause of complexity and variability, and thus waste, and they hinder value generation. It is possible – but not necessarily worthwhile – to eliminate or reduce peculiarities through structural solutions, but beyond that it is necessary to mitigate the impact of peculiarities through control and improvement.

The validity of these hypotheses can be considered by comparing practical experiments where either the peculiarity elimination approach is realized or the multi level mitigation approach is adopted.

11.2 Implementation cases

The basic criterion for the selection of implementation cases, to be presented below, was that principles related to the F and V concepts of production have been implemented. Based on the considerations in Chapter 8, it is justified to assume that in each case, principles related to the T concept have been followed before, and thus actually it is a question of augmenting the T principles with F and/or V principles. Secondly, a wide variety of situations were pursued. In particular, it was intended to cover all the major parties in construction: client, designer, contractor, and subcontractor. Thirdly, the selection was constrained by information availability. Actually, beyond the cases presented, there are very few known major implementations. Fourthly, familiarity of the author with the cases played a role. There are three cases visited personally by the author.

11.2.1 Sekisui Chemical

11.2.1.1 Description[ii]

The company

Sekisui Chemical, with an annual output of c. 35 000 homes, is the fourth or fifth largest manufacturer of prefabricated housing in Japan. There are six factories in Japan.

Measures implemented

The Sekisui homes are built from modules, rather than parts. Each house typically consists of 12 to 15 modules. One house requires about 5000 unique parts; in total, there are 300 000 parts in use. The dimensional tolerance of parts is generally +/- 1mm.

The methods of lean production[iii], automation and information technology have been aggressively implemented. Regarding lean production, the range of methods includes quality, flow-oriented layout, kanban, supplier development, continuous improvement, visual control and others.

Regarding technology, there are robotized systems for welding steel frames, for example. In ordering, CAD is used for customer-wise design. This is transformed to a material list by means of an artificial intelligence based system. Before the implementation of this system, there used to be an error rate of 5 % in parts selection, causing further problems in factories. Just after the introduction of a new model, the error rate could rise to 30 % during the first six months.

Buyer options relate to visible features such as color, type of finish, and to some extent layout. Parts not seen by the customer are standardized by their specification.

The company gives a 10-year guarantee for such performances as durability of principal elements and water-tightness. All customers are asked about their degree of satisfaction with their house when they have lived in it for one year.

Outcomes

The delivery time of a house is 40 days. The factory assembly of modules for a house takes three and a half hours. The actual productivity rise has been 10 % per year.

11.2.1.2 Within-case analysis

This company[iv] has achieved a superior rate of improvement, not generally found in the construction industry. The striking feature of this case is that the construction peculiarities have been to a large extent been eliminated. The houses are one-of-a-kind, but they are configured from existing design options. The site work has been minimized. The supplying organization is stable, rather than temporary. On the whole, construction has largely been given over to mass-customized manufacturing, and all the improvement possibilities of this type of production can be utilized. Thus, regarding the T view, there are aggressive investments in mechanization and automation. Regarding the F view, continuous development of flow design and control as well as flow variability reduction have been instituted. Regarding the V view, long term customer-oriented development of the product has become possible[v].

It is interesting to note that the dimensional tolerances are much tighter than usually occurs in house building: tight tolerances are instrumental for prefabrication and assembly. Noteworthy also is the development of computerized methods for error reduction. Thus, technological means and operations management principles are effectively and synergistically used.

Another interesting observation is that the elimination of construction peculiarities is not without cost. In spite of the great variety of product models and options in them, there is the problem that the offered products fall short of the needs and wishes of some of the customers[vi]. The great volume of production, making product and process development possible, has been achieved through a wide network of sales agencies. Thus, the costs of marketing and customer service at least partly consume the productivity benefit created in the physical production process[vii].

There seems to be a definite difference between car production and industrialized house production (Gann 1996). Housing producers need to cope with higher degrees of flexibility relating to customer's choice than in car production. The total number of parts and permutation of assembly options is higher in housing than in car production. Whereas a car is assembled from around 20 000 different parts, a house may be constructed from as many as 200 000–300 000 different parts[viii].

11.2.2 Skanska

11.2.2.1 Description[ix]

The company

The Sweden based Skanska is one of Europe's biggest contractor companies.

Measures implemented

Since 1991, Skanska has implemented a program called 3T (abbreviation for Total Time Thinking), where the goal is to make the construction process more efficient through time compression.

The program consists of structural, operational and support actions. The structural action consists of specialization of functions and products, and changes in project organization. Instead of geographical division, the business activities have been grouped according to products. Instead of the traditional approach of site manager, a system of project engineer (responsible for production preparation, planning and progress control) and production manager (responsible for overall result) was introduced.

Operational action consists of action programs by different units in the company. These are revised continuously and thus make up a form of continuous improvement.

Support action consists of training, associated with action programs, 3T consultants who support implementation in cooperation with line management, tools and back-up (like quality systems), and information material.

Outcomes

In 1996, the management announced that the goal of a 30 % time reduction in projects was reached. In residential construction, the number of defects at handover had declined from 13/100 sq.m (1991) to 3.8/100 sq.m (1995). The time to rectify defects after handover had been reduced by 70 %.

11.2.2.2 Within-case analysis

In this case, the main thrust is in implementing principles from the T, F and V views in site construction; there is no effort to eliminate peculiarities. The case presents several important insights. Firstly, it shows that time compression indeed is an effective way of improvement in construction, and good results can be obtained already in the short term. Secondly, it points out the typical difficulties to be encountered in an endeavor to change the way of operating in a large organization.

Lund University of Technology has evaluated the 3T program as it was implemented in Skanska Syd, a regional company of Skanska (Borgbrant & Hansson 1995, 1996). It is concluded that the implementation has, largely, given good results and the personnel mostly has accepted the message. However, there is lack of understanding vis-a-vis 3T philosophy, especially among the production personnel. It is also indicated that the company culture contains barriers regarding improvement (for example, shortcomings in internal communication). In reply to an inquiry 80% of subcontractors spontaneously indicated that participating in Skanska's pilot projects had increased stress. This might indicate[x] that the inclusion of subcontractors in the program has not been sufficient.

Ekstedt and Wirdenius (1994) have compared the 3T program with a corresponding program in manufacturing. They found that builders with their project culture have a greater receiver competence regarding renewal efforts. However, at the same time this means that a fundamental mental change was hardly needed in implementing the 3T program, and thus its cultural and mental influence has been limited.

11.2.3 Arcona

11.2.3.1 Description[xi]

The company

Arcona is a Swedish project management organization with 60 employees. It operates with two subsidiaries, the other architectural design firm, and the other electrical, water and HVAC engineering design firm. The design firms have 125 employees in total.

Arcona handles mostly turnkey projects, with full responsibility for costs, quality and time. All construction work is carried out by subcontractors under Arcona's supervision. Between 20 and 25 % of the operations of the design subsidiaries are related to turnkey projects within Arcona, the remainder are for outside customers.

Measures implemented

Arcona has already started process improvement in the 1980s, first for the most part by means of information technology. The primary goal has been to strive for a high level of precision in work processes, allowing for JIT deliveries of materials and schedule compression. In the 1990s, Arcona has subscribed to the lean construction principles, especially time compression as the driving force.

Arcona, its design subsidiaries and three outside installation contractors have formed a fixed team operating on all turnkey projects. There are a number of working groups aiming at continuous improvement in cooperative work. Installation contractors have been selected as strategic suppliers because installations represent the most complex part of a building.

The design process typically starts through a workshop for all stakeholders, where requirements and wishes are charted and discussed.

Incentives are extensively used in subcontracts. Typically, part of the incentive is related to the own work of the subcontractor and part is related to the success of the overall project.

Methods applied include reducing the number of parts to be assembled (through preassembly), reducing the number of fasteners (especially for HVAC installations), and continuous flow in assembly (small time buffers between consecutive crews).

Outcomes

An example of the results of the approach is provided by the Nacka Police Building, which was constructed in 10.5 months[xii] and under budget. In comparison to Finnish data (Tanhuanpää et al. 1999), this duration is 30 % shorter than the historical average, 15 months, for this size of office building constructed with the same technique.

11.2.3.2 Within-case analysis

This concept is comprehensive. It covers design and control of processes and related improvement in a balanced way. Also, both task, flow and value management are addressed. There are several interesting features in this concept. Because design is done in-house, designers usually have worked earlier together and know each other's way of operating. It is also easier to improve the design process, both flow-wise and value-wise. Constructability improvements are relatively easy to make. The preference for co-operation with installation contractors is justified: waste-causing complexities are found in this area. The aggressive investment in CAD systems produces benefits regarding the construction phase of the project. Finally, the tight control of work on site contributes to productivity and fast schedule.

11.2.4 Doyle Wilson

11.2.4.1 Description[xiii]

The company

Doyle Wilson Homebuilders is a company in Texas, building over 400 homes a year.

Measures implemented

The company launched an initiative for quality and lean production in 1991. The initiative initially consisted of teaching TQM to the whole workforce, collecting and analyzing data on operations, eliminating individual sales commissions, and requiring subcontractors to attend monthly quality seminars.

The company has a centralized scheduling system, where the "Daily Build Schedule" has a key role. This schedule details the work to be completed the following day. The goal is to have the same type and amount of work every day, even if at a different house. The schedule is non-negotiable, and its realization is monitored by Daily Tracking Reports. The completion of each task is ensured through Job Ready Check Sheets. Reports (Daily Tracking Report and Supplier Scorecard) and Daily Build Schedule are sent to suppliers by fax each evening.

The supplier base has been cut from more than 100 to about 40, with whom the company works closely.

Throughout the company office, a flag system (or andon system) has been implemented. Professionals (architects, etc.) hoist a flag as they deal with a specific step, a red flag for delay and a green one for a step that is going smoothly.

There is a formal Opportunity for Improvement (OFI) program. The firm aggressively seeks feedback from buyers, contractors and suppliers, and the ideas received are assigned within 48 hours to an OFI improvement team.

Monthly goal measures cover customer satisfaction, cycle time, supplier scorecard and some other issues.

Outcomes

The costs of building typical houses have been reduced by 12–13 %. The construction period of a house has been shortened from 165 days to 71 days (1998). The customer satisfaction rate was 95.70 % in April 1998. In cooperation with the city of Austin, the permit issue time has been reduced from 7–21 days to 24–48 hours. In 1995, the company won a National Housing Quality Award.

11.2.4.2 Within-case analysis

Interestingly, task management has been strengthened in this case. The centralized scheduling system[xiv], which has a pivotal role in improvements, follows largely the doctrine of scientific management and mass production. Regarding flow management, time compression, variability reduction and transparency accentuate. Value management, especially, has been improved through better value measurement.

This company operates in the same market as Sekisui, building of family houses, but in a very different way. However, the case shows that also in site-oriented construction, it is possible to create a competitive benefit by introducing principles related to the TFV concept (mediated here through approaches of lean production and quality management). Obviously, an indispensable role is played here by the champion of this organizational transformation, the owner of the company.

Whether some practices from manufacturing, like the flag system, have been adopted too uncritically is a matter worth debating.

11.2.5 T40 project

11.2.5.1 Description[xv]

The study

Contrary to the other cases, this is not a concept in use, but rather a proposed concept, resulting from a study of a group of Australian companies, led by Fletcher Construction Australia. The intention was to produce a redesigned process, allowing for a construction project time reduction of 40 %, and a series of new, related practices. The study was based on three workshops: (1) flowcharting the as-is process, (2) redesigning the should-be process, and (3) developing aspects of the solution.

Measures proposed

The proposed concept is characterized by following features:

- Single point accountability for the client by a “solution team”, a collaborative group of up to nine organizations: all parties are involved from the start of the project and they address directly the client’s needs (rather than have them filtered through the architect and filtered again through the general contractor).
- Elimination of traditional tendering: the project contract with the client would be closed on the basis of agreed and third party certified cost as being close to the industry’s most competitive, agreed facility performance and significantly advantageous time performance.
- Financial incentives and penalties for the whole group.
- Business practices based on trust and fair dealing.
- Reorganization of work packages to eliminate multi visits to site by operatives; sharing of resources rather than duplicating functions.

- Teaming between management and work force.
- Partnering with local government for approvals.

The study report outlines the structure, control methods and improvement prerequisites for the proposed concept.

Outcomes

There was an attempt to trial one aspect of the solution (Ireland 1997). A project was put out to subcontractors on two bases, the traditional use of 50–100 subcontractors or suppliers and the suggested method of 6–8 packages. The traditional method was 5–10 % cheaper than the T40 solution. On investigation, it was found that it was impossible for the subcontractors to abandon the traditional division of work among operatives or divisions without added costs. In the end, it was impossible to find anyone who was willing to pay more for the project being completed under the T40 structure.

11.2.5.2 Within-case analysis

The main emphasis in this case is on system redesign for the benefit of flow and value management. Even though the concept proposed was not implemented, the T40 study adds to the validity of a number of points of this thesis.

The exercise of preparing an as-is process description, identifying non-value-adding steps and redesigning the process to eliminate these steps was carried out by industry representatives. The high share of non-value-adding steps, inherent in the traditional project organization, became clearly apparent.

The redesigned process contains a high number of innovative features (the study report lists 32 innovations), proving that the new conceptual framework leads to innovation, that is fulfills one function of a theory, namely providing direction for further progress.

From a critical standpoint, this study exemplifies some of the limitations of the re-engineering approach. It turned out that it is impossible just to jump into the new process. Thus, it is questionable whether a mere process redesign, without supporting action at the level of control and improvement, is practicable. Another drawback of the study is that there was no attempt to prove, say by means of hypothetical schedules or simulation, the fulfillment of the 40 % time compression target.

11.2.6 Plano 100

11.2.6.1 Description[xvi]

The company

Plano 100 is a concept of Rossi Residencial in São Paulo, Brazil. It is focused on providing residential multi-story buildings.

Measures implemented

The concept contains innovations regarding delivery channels, product design, production, and organization.

The flats are sold directly to families, based on 100 fixed monthly payments to the constructor. External financial institutions are thus excluded. Client satisfaction is continuously measured.

Design solutions and materials are standardized. Various technical solutions have been developed for raising the productivity of site work. Operational procedures are standardized. Each job is started only when all necessary resources are available on site. A new design language has been developed for simplifying drawings and thus reducing drawing interpretation errors and the time needed for interpretation on site. Partnerships with main suppliers have been organized pursuing joint development.

Continuous improvement is achieved through weekly meetings of site engineer, foremen, support teams and leaders of production teams. Teams are rewarded on the basis of duration, productivity and quality. The foremen's training is extensive.

For reducing the turnover of workers, there are various benefits like free medical and dental services and classes for reading, writing and construction techniques.

Outcomes

It is claimed that construction costs have decreased by 35 % from 1992 to 1997. Material losses have decreased, for example in the case of masonry, to 1.5 %. From the average 30 % share of productive time out of the total working time, the level of 45 % has been reached. A quarter of sales are made through referral by existing clients.

11.2.6.2 Within-case analysis

This is an interesting and successful implementation of TFV principles in construction. It is balanced in several respects. Both task, flow and value management are addressed. New principles have been implemented at the levels of system design, control and improvement. Again, this case clearly shows that it is possible to gain significant benefits during the initial five-year implementation of TFV principles.

11.2.7 BAA

11.2.7.1 Description[xvii]

The company

An example of client-driven improvement in construction is provided by the British Airport Authority (BAA). It owns and operates seven airports in the United Kingdom of which Heathrow is the largest.

Measures implemented

Since 1994, BAA has launched an extensive array of activities for cutting the costs of airport construction. The program started with defining and implementing current best practice. This phase included the introduction of design standards and standard components, a common vocabulary, emphasis on greater predictability of cost, and generally a disciplined approach to projects, with clear project gateways.

A number of policies were adopted to provide a basis for continuous improvement:

- Preplanning: to complete the design and to thoroughly pre-plan the fabrication and construction process before starting construction
- Concurrent engineering: to work with suppliers as an integrated team
- Framework agreements: to work closely with a small number of carefully selected suppliers.

The standardization work has produced 29 standards and 12 draft standards on various components or aspects of airport design (like airfield pavements, public area seating, acoustics, and energy efficiency).

The project process of BAA has been described in “Project Process Guidelines”, consisting of eight volumes. The goal of these is to increase the transparency and predictability of projects. One area where improvements are specially targeted is product definition and briefing. The process maps, first prepared as paper-based, are being transformed into interactive, digital versions.

Projects are measured, regarding both process and outcome, by means of a comprehensive system.

In framework agreements, BAA and the respective supplier agree on the delivery of specified products or services over a number of years. For example, in the areas of cost consultancy or architectural design, there are 7–8 framework partners. The suppliers were originally clustered into dedicated airport teams.

In 1999, there is a plan to further reduce the number of frameworks from the existing 90 to around half this figure. The share of project activities covered by frameworks, currently 30–50 %, is targeted to grow to 70–80%.

The reduced number of framework suppliers will be clustered to form four delivery teams: shell & core, fit-out, baggage and infrastructure. It is the aim that these teams concentrate on developing generic solutions based on BAA product standards, whereas the airport project teams concentrate on needs definition and concept design phases.

Outcomes

The accident frequency rate (per 100,000 hours construction) has decreased from 0.86 (1995–96) to 0.66 (1998–99). In comparison, the industry average is currently 1.26. The nominal costs of office building have decreased by approximately 30 % from 1993 to 1999 in spite of the fact that the average building costs have risen by 43 % in this period. Predictability of project cost and duration has increased. For example, regarding predicted and realized costs of construction projects in the financial year 1998–99, 71 % were below target, 19 % on target and 10 % above target. Correspondingly, regarding construction time, 23 % of the projects were below target, 64 % were on target and 23 % above target.

11.2.7.2 Within-case analysis

This case provides proof of the claim that a client with sufficient market power can influence supply in order to make construction efficient. It is worth noting that both system design (through frameworks), control (through process maps and defined managerial procedures) and improvement (targets, measurement) have been covered. Similarly, where different concepts of production are concerned, there is progress towards more articulate management based on the T concept (definition of activities and roles), F concept (emphasis on predictability) and V concept (improvement of the briefing process).

11.2.8 TDIndustries

11.2.8.1 Description[xviii]

Company

TDIndustries (TDI), Texas, installs and services air-conditioning and plumbing systems. All stock is in the hands of employees, with no one owning more than 9 %. The work force numbers c. 1000.

Measures implemented

In 1996 an improvement program was started, where one part was to experiment with the Last Planner method (presented in Chapter 10). The goal was to help foremen gain control over their crews by teaching them how to more effectively plan the work that each crew will do based on the work that is available to them and the actual project conditions. Actual work completed was measured against work planned, and reasons for variances were identified. Once reasons for variances were identified, improvements were made to correct the problems found.

A binder with blank forms was issued to foremen and superintendents to support the implementation. The forms deal with one-week plans, five-week plans, safety plans, pre-project hazard analysis, etc.

Outcomes

Productivity in projects where the measures were implemented was compared to that in other projects happening simultaneously during a period of 26 weeks. Analysis showed that the projects where the measures had been implemented were about 10% more productive than other projects. The difference was statistically significant.

11.2.8.2 Within-case analysis

This case shows that even a subcontractor can effectively implement principles of the TFV model. Initially, implementation of new control methods in task and flow management brought about a 10 % improvement of productivity. In contrast to data on performance improvement in most other cases, this result has been scientifically validated.

11.3 Analysis of case and other evidence

11.3.1 T concept versus TFV concept

11.3.1.1 Evidence from case studies

An overview of the principles and methods implemented in different cases is presented in Table 11. In most cases, both F and V principles have been used. However, it should be noted that T principles have also been implemented as an integral part of the total implementation strategy.

In comparison to current state-of-the-art in manufacturing, many cases present a modest maturity level, partly even tentative attempts, except for the Sekisui case (that essentially is manufacturing). This was anticipated, taking into account the very recent implementation and the still incomplete methodology regarding the application of advanced operations management in construction.

Remarkably, *in all seven cases where principles of the TFV concepts have been practically implemented, clear productivity, cost, duration, quality or other improvements have been realized*. These cases convincingly show that in construction, it is possible and worthwhile to reduce waste and to increase value for the client. Thus, it seems that the situation is as it was in manufacturing a few years ago: the sole use of the T concept as a foundation of manufacturing had rendered it so inefficient, that even initial attempts to introduce principles based on F and V concepts contributed considerable benefits.

Another interesting observation is the simultaneous strengthening of the methods and principles based on the T concept in connection with the introduction of principles related to the F and V concepts. This indicates support for the hypothesis that balance is needed between the implementations of principles of different concepts (as elaborated in Chapter 6). Moreover, this observation matches well with the finding (Chapter 9) that the primary T principles are in current practice only partially implemented, which leads to problems.

Table 11. Implementations of principles and methods based on different concepts of production. (Regarding transformation oriented principles, only those implemented as a part of renewal have been presented.)

	Transformation	*Flow*	*Value generation*
Sekisui	Computerized bills-of-materials, automation of production	Time compression, variability reduction, transparency	Systematic measurement of value and product development based on this
Skanska	Improved task planning	Time compression	Reduction of defects Reduction of the time to rectify defects
Arcona	Improved task definition and planning	Time compression, simplification, transparency	Improved requirements capture and flowdown and design optimization
T40	Improved task planning, clearer responsibilities of parties	Time compression, variability reduction, simplification	Improved requirement flowdown and design optimization
Doyle Wilson	Centralized task planning and control	Time compression, variability reduction, transparency	Improved feedback from buyers
Plano 100	Improved task planning	Variability reduction, transparency, simplification	Systematic measurement of value
BAA	Improved task definition, planning and control	Variability reduction, time compression, transparency, simplification	Improved needs capture and requirement flowdown
TDIndustries	Improved task planning and control	Variability reduction	

11.3.1.2 Other evidence

The significance of the TFV principles in capital projects is illuminated by a recent study of The Business Roundtable (1997), which defines the universal characteristics of best capital project systems, based on benchmarking a great number of projects. Interestingly, half[xix] of the characteristics are primarily concerned with flow management, the other half being related to value management (Table 12). Whether these characteristics are used or not has a definite impact on the profitability of the project. The best company transforms a 15% return on investment (ROI) project, based on average performance, into a 22.5% ROI project, while the poorest performers correspondingly end up at a 9% ROI. Thus the study shows that methods based on the F and V concepts are used by the best companies, and that they create a significant competitive advantage[xx].

Table 12. Universal characteristics of best capital project systems (The Business Roundtable 1997). The classification of the characteristics has been added by the author.

Primary aspect of management	*Characteristics*
Flow management	Cross-functional teams to develop projects Continuous improvement systems Systematic performance measurement
Value management	Active and project knowledgeable business leadership, especially on the front-end Engineering and project functions report to the businesses, not to plant management The in-house resources develop and shape projects until the projects are ready for detailed design

11.3.1.3 Conclusion

On the basis of the case studies and other evidence, it can be concluded that we should accept as valid the hypothesis 1 B: *Methods founded on the TFV concept are necessary for efficient management of construction.* Correspondingly, we should reject the hypothesis 1A.

11.3.2 Structural implementation versus multi level implementation

11.3.2.1 Evidence from case studies

The level of implementation in different cases is presented in Table 13. Out of 8 cases, in 6 there is substantial development at all three levels. The exceptions are Skanska[xxi] and TDIndustries, where the focus has been on control and improvement. Moreover, in the case of T40, experimental implementation focusing on the design level was planned but it could not be realized.

Thus the cases support the hypothesis that implementation should be comprehensive. In particular, implementation should cover design, control and improvement of processes. Secondly, two cases show that implementations that concentrate on control (and improvement) are also feasible and effective.

Table 13. Level of implementation of TFV principles and methods in different cases (the primary view of principles and methods implemented – or to be implemented – in parentheses).

	Design	*Control*	*Improvement*
Sekisui	Factory layout, prefabrication, supply chain development (TFV)	JIT control (TF)	Effectively improved (TFV)
Skanska	Organizational specialization (T)	Controlled in a more effective way (T)	Improvement stimulated by time compression, measurements and specialization (TFV)
Arcona	Supply chain cooperation, design-build contracting (TFV)	Controlled in a more effective way (detailed schedules) (TF)	Improvement stimulated by time compression and joint product development (FV)
T40	New organizational structure, process redesign (FV)	Controlled in a more effective way (T)	Enhanced improve-ment through measurements (TF)
Doyle Wilson	Supplier base reduction. partnering with suppliers (F)	Controlled in a more effective way (centralized control) (TF)	Targeting, system-atic collection of improvement ideas, measurements (TFV)
Plano 100	Stable supplier networks, streamlined delivery channel (FV)	Controlled in a more effective way (F)	Joint improvement with suppliers, improvement of on site processes, measurements (TFV)
BAA	Stable supplier networks, redesigned project delivery processes (TFV)	Systematized control (TF)	Targeting, measurements (TFV)
TDIndustries		Controlled in a more effective way (short term planning and monitoring) (TF)	Measurements (TF)

11.3.2.2 Other evidence

The separation of design and construction has long since been presented as the root problem of construction (Chapter 8). Thus it is no wonder that great expectations have been attached to design-build (DB) procurement of construction projects, where these two stages are organizationally integrated from the outset.

The performance of the DB delivery system in comparison to other major delivery systems has been studied in two recent studies (Bennett et al. 1996, Konchar & Sanvido 1998). The results indicate that, statistically, DB outperforms the traditional design-bid-build (DBB) process in several respects[xxii]. Both studies conclude, based on statistical analyses, that the construction speed of DB is 12 % faster than the speed of DBB, and the total delivery speed is 30–33 % faster. In the UK, the share of projects ending up above budget by more than 5 % was 21 % in DB projects in contrast to 32 % in DBB projects. In the United States, the corresponding figures were 38 % for DB projects and 51 % for DBB projects.

However, in critical analysis, it has to be stated that the differences found are small and partly explainable through factors other than increased efficiency due to improved integration. The construction time of DB is shorter, because the contractor has a greater possibility of taking care of constructability, and there is more time for production planning. The total delivery speed of DB is naturally faster for three reasons: the bidding period does not prolong the delivery; it is relatively easy to overlap design and construction; and the construction period may be somewhat shorter, for reasons discussed above. The increase of cost and schedule certainty is minor when changing from DBB to DB delivery.

Thus, these studies show statistically that through design-build, definite, but minor improvements have been reached. The potential of amelioration by only making changes in system design, as implied by design-build, is limited[xxiii].

11.3.2.3 Conclusions

The cases that relied on comprehensive implementation are all demonstrably effective. On the other hand, prior research indicates that the potential of improvement through system design, as in the case of design-build procurement, is limited[xxiv]. Thus, on the basis of the case studies and other evidence, it can be concluded that we should accept as valid the hypothesis 2 B: *It is necessary that the principles of production are implemented in the design, control, and improvement of the production system.* However, the reservation must be made that it seems feasible and effective to center the implementation on control, at least initially.

11.3.3 Peculiarity elimination versus multi level peculiarity reduction and mitigation

11.3.3.1 Evidence from case studies

The treatment of different peculiarities in the cases is presented in Table 14. A number of interesting observations can be made. Firstly, in most cases, one or more of the construction peculiarities have been eliminated or reduced. This suggests that such peculiarity elimination contributes to the overall implementation of principles of production – *it tends to be beneficial to eliminate peculiarities*.

Table 14. Treatment of construction peculiarities in cases.

	One-of-a-kindness	*Site work*	*Temporary organization*
Sekisui	Largely reduced through standard parts and mitigated through flexible manufacturing	Largely reduced through prefabrication	Eliminated through stable supplier network
Skanska	Allowed	Allowed, mitigated through more effective control	Allowed
Arcona	Allowed, to some extent reduced through standard details	Reduced through prefabrication and preassembly, mitigated through more effective control	Largely reduced through stable supplier network, mitigated through incentives
T40	Allowed	Allowed, mitigated through more effective control	Eliminated through stable supplier network
Doyle Wilson	To some extent reduced through standard design solutions	Allowed, mitigated through more effective control	Largely reduced through stable supplier network
Plano 100	Largely reduced through standard design solutions	Allowed, mitigated through more effective control and improvement	To considerable degree reduced through stable supplier networks
BAA	To considerable extent reduced through standard design solutions	Allowed, to some extent reduced through prefabrication	To considerable degree reduced through stable supplier network
TDIndustries	Allowed	Allowed, mitigated through more effective control	Allowed

On the other hand, there is usually a reason for the peculiarity, and it is costly to eliminate it. The case of Sekisui demonstrates that even if major efficiency benefits in production are achieved through standardization, industrialization and permanent supply chain, some of these benefits are offset by a heavy sales organization, without which the traditional way of construction operates.

Secondly, in two cases, Skanska and TDIndustries, where the implementation apparently has been successful, the peculiarities are more or less accepted. Thus, *performance can also be increased without elimination of peculiarities: unique site work by a temporary organization can be controlled better and improved further*. However, it is wasteful to accept peculiarities unnecessarily.

11.3.3.2 Other evidence: Industrialization of construction

Industrialization can be seen as a structural means for eliminating or at least drastically reducing on-site activities in construction. The intended benefits of industrialization of construction (Warszawski 1990) include the following: saving in manual labor on site, faster construction process, and higher quality of components.

Since the Second World War, the idea of industrialization has received much attention both in Europe, North America and elsewhere. In spite of a great number of attempts, there has been a relative lack of success[xxv] resulting from industrialized building methods (Warszawski 1990). According to Warszawski, the main problem of prefabrication of today is the lack of a system approach to its employment on the part of the various parties involved.

However, it can be argued that an even greater cause for the lack of success of industrialization has been the lack of consideration of industrialization from the point of view of the F (and V) concept. It is not enough to change construction to a manufacturing process: even in conventionally managed manufacturing there is much waste and value loss. But there is another significant point: when analyzed as flow processes, industrialized construction shows widely different characteristics in comparison to site construction.

Firstly, the flow is longer (both in the sense of containing more steps and in the sense of distance) due to two (or even more) production locations: factory and site. This, of course, means that the total variability is greater than in a shorter flow with similar elements. The requirements for co-operation and coordination within the design, planning, and installation processes are higher.

Secondly, the amount of design required is larger (Paus, n.a.), and it has to be done earlier than design for on-site construction, due to prefabrication lead times. This is in contrast to the typically tardy determination of stable design solutions in construction design. In practice, this leads to the phenomenon of incomplete and changing orders.

Thirdly, the error correction cycle is longer: for example, dimensional errors of prefabricated components are detected only on site, while for *in situ* construction, dimensional errors in drawings are often detected in production preparation and can be rectified without large costs (Paus, n.a.).

Fourthly, requirements for dimensional accuracy are usually higher[xxvi] (in on-site construction activities, it is usually possible to compensate for dimensional variations between adjacent components through sizing of the later components). This requirement causes problems especially when prefabricated components are assembled beside *in situ* constructed parts of the building – this is always the case when installing components adjacent to the foundation, but this situation also often occurs elsewhere.

Thus, the total process of industrialized construction tends to become more complex and vulnerable in comparison to site construction. Consequently, it seems plausible that in badly controlled (or poorly improved) design, prefabrication[xxvii], and site processes of industrialized construction, the increase of costs due to non-value-adding activities has often consumed the theoretical benefits to be gained from industrialization. This, in turn, among other factors, has presumably led to the relative lack of success of industrialized building methods.

The lesson learned is thus that the elimination of a construction peculiarity has a price: the characteristics of the production system may change so that new problems emerge, even if the problems related to the peculiarity are alleviated or eliminated. If the new problems are not tackled adequately, the intended benefits of the elimination of the peculiarity will not be realized.

11.3.3.3 Conclusions

Thus, on the basis of the case studies and other evidence, it can be concluded that we should accept as valid the hypothesis 3 B: *Construction peculiarities contribute to waste and value loss, and it is necessary to eliminate and/or reduce them or to mitigate their impacts on the level of control and improvement.* In view of the case findings, the situation seems often to be such that a peculiarity has to be mastered at the level of both design and control/improvement. This is because it is seldom possible to eliminate a peculiarity totally.

11.3.4 Evaluation of the validity of the case study

Admittedly, the evidence of this case study is thin. The available information on each case is limited, and thus the validity and the generalizability of results are modest. However, at this stage the goal is not to present a definitive proof of the new production concept, but rather to collect initial proof – or proof of concept – on the basis of which progressive parties of construction can decide on their own experimentation and implementation strategies. The same reasoning applies to directing research and development carried out by research institutes and academic researchers. From this viewpoint, it can be held that this case study successfully provided a proof of concept for the hypotheses presented.

11.4 Conclusions

Consideration of the implementation cases of TFV principles of production gives support to a number of conclusions.

Firstly, it is justified to state that the principles based on the TFV concept are effective also in construction. Major improvements can be created immediately by the basic implementation of some principles, which reflects the poor starting point of construction – in other words, the high levels of waste and value loss.

Secondly, the comprehensiveness of the implementation of TFV principles of production is a crucial factor. Partial approaches, like those addressing solely system design, have produced only limited results. Rather, evidence suggests implementing this method in the design, control and improvement processes of the production system.

Thirdly, the treatment of construction peculiarities seems to be a critical issue, requiring further clarification and differentiating construction from other types of production from the point of view of operations management. Indeed, a specific theory of construction should address, among other issues, how to cope with these peculiarities. Based on evidence at hand, it is necessary to eliminate or reduce peculiarities by design and/or to mitigate their impacts at the level of control and improvement.

Fourthly, it has to be stressed that the practices and methods based on the TFV concept and specific to construction are still in their initial state. Further development of construction-specific methods and practices based on high level theories is needed. However, the very framework of the TFV theory gives direction to this endeavor.

Fifthly, evidence suggests that the TFV principles are indeed generic, and can be used in widely different contexts, by clients, contractors, design firms and subcontractors, and both in developed and developing countries.

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[i] In literature on production control, design and improvement aspects tend to get less attention. In turn, the proponents of continuous improvement tend to forget the role of design and control of production.

[ii] This case description is based on personal visitation (Koskela 1985) and a number of both inside and outside descriptions (Hall & Yamada n.a., Irino & Tamura 1995, Engelmore 1993, Gann 1996, Sekisui Chemical Co. 1997).

[iii] Actually, cases from the Japanese prefabricated house industry have not infrequently been presented as exemplars of advanced production thinking (Hall & Yamada n.a.).

[iv] This statement would apparently be valid also for many other Japanese producers of prefabricated housing; for an overview, see (Gann 1996). Interestingly, Toyota has also recently entered this market.

[v] According to Gann (1996), in this kind of business there is usually a guarantee of ten years on structural works and water-tightness and two years on services and finishes. Furthermore, many companies inspect houses at regular periods after completion to obtain feedback on their products. This is the case also at Sekisui Chemical.

[vi] Gann (1996) notes that in the modular method the flexibility is lower than in the panel types of prefabrication.

[vii] When asked, "How do the costs of your prefabricated houses compare with the costs of traditional housing construction in Japan?", Dr Ishimoto from Sekisui House (note that this is a competitor of Sekisui Chemical, even if partly owned by the latter) replied as follows (Ishimoto 1995): "They amount to more or less the same price, although we have to distinguish between cost and price. The cost is much lower than that of wooden housing, but of course the type of steel frame prefabricated housing I have been describing has rather high overheads compared to wooden houses. Therefore, although the cost is lower the price would be more or less the same as traditional housing." "With any industrialized products the cost is usually about 40 % of the final price but we cannot really adopt this principle in housing. The profit is about 30 %."

[viii] The figure of 200,000 is from Gann (1996), the figure of 300,000 from the Sekisui Chemical case.

[ix] Sources: (Månsson 1994, Borgbrant & Hansson 1995, Borgbrant & Hansson 1996, Andersson 1995, Hindersson 1996, Ekstedt & Wirdenius 1994).

[x] This is a comment by the writer, rather than by Borgbrant and Hansson.

[xi] Sources: personal visitation, news bulletins of Arcona 1996–1998, (Birke et al. 1997, Hindersson 1995).

[xii] The construction duration announced by Arcona is 9.5 months. However, when including one month of holidays, the duration is 10.5 calendar months.

[xiii] Sources: (Wilson 1998, Womack & Jones 1996, Novicki 1996, BuilderOnline 1996, Caldeira 1997).

[xiv] This kind of centralized dispatching system is very rare in construction. The only other known occurrence of it is in the former Soviet Union, where in construction corporations (called construction trusts) a military style management system called the "dispatcher system" was used. The technical director could have simultaneous telephone connections to all units so that in case of any problem, he could take immediate action (Sebestyén 1998). Thus the main benefit seems to have been trouble-shooting, whereas at Doyle Wilson, the benefits of repetition and leveled production are primarily sought.

[xv] Sources: personal participation in the project in the framework of the CSIRO team, (Ireland et al. 1994, Ireland 1995 and 1997, McGeorge & Palmer 1997).

[xvi] Based on (Conte & Martinelli 1997, de Vasconcellos 1998).

[xvii] Based on (Anon. 1997a, Duncombe 1997), the issues 1–11 of the magazine In Context and the Construction Report 1998/99 issued by BAA.

[xviii] Sources: (Teston 1998, Lieber 1998).

[xix] This classification is subjective. For example, cross-functional teams are also instrumental in value management. Systematic performance measurement may be related to any type of management, but because this theme has generally been advanced mostly in the framework of flow management, it is classified correspondingly.

[xx] Interestingly, information technology was not among the characteristics, in spite of the great attention usually given to this theme. In other words, it seems that it has not been possible to create competitive advantages through IT utilization.

[xxi] The feature implemented by Skanska at the design level, organizational specialization, can be judged to have a minor role in the total implementation strategy.

[xxii] Cost, too, is analyzed in both studies. The US study finds DB to be 6 percent less costly than DBB. The UK study estimates that DB is 13–32 percent less costly than DBB. However, these figures have been calculated in incompatible ways and it is difficult to draw general conclusions from them. In the US study, the contract unit cost is one explaining variable for the (final) unit cost (that is usually higher than the contract unit cost through cost growth). Thus, the other variables explain the difference between the final unit cost and the contract unit cost. The result has to be interpreted so that in DB projects, the average difference between final unit cost and the contract unit cost is 6 percentage units less than in DBB projects. This result is sensible because those projects where the client wants to influence the design during the project (rather than through the brief) tend to be realized rather as DBB than as DB projects. Instead, the UK study uses absolute costs, and concludes that DB is between 13% and 32% cheaper than DBB. However, there are three factors that reduce the plausibility of these results. Firstly, the explanatory model explains only 51% of the variation. Secondly, clients themselves assessed the quality of buildings, rather than external assessors. As the study finds, the clients tend to have lower quality expectations from DB projects, but it remains unclear whether the whole quality difference between DB and DBB projects has been captured, because of the lack of a standardized assessment method. Thirdly, the existence of interacting variables, like quality and procurement form, renders the interpretation of the results more difficult.

[xxiii] This should not be interpreted so that the potential of design-build in general is limited. Rather, design-build, in allowing long-term product development as well as supply chain development, provides considerable possibilities for realizing superior control and improvement; however, these possibilities seem generally not to have been utilized in practice.

[xxiv] In other words, no support could be find for the hypothesis that implementation solely through design is effective. On the other hand, that hypothesis could not either be disproved by evidence derived from the cases or from prior research on design-build, because it can be argued that all possibilities for implementation through design have not been studied or tried out yet.

[xxv] However, the situation varies greatly from country to country. The share of prefabrication is high in such countries as France, Finland and the Netherlands but it is lower in Germany.

[xxvi] As exemplified in the case of Sekisui.

[xxvii] In a research project participated in by the author, it was found that through applying lean production principles, the production costs could be rapidly reduced by 5–10 % in a prefabrication plant (Koskela & Leikas 1997).

12. Discussion

In this chapter, the results of the research as well as their practical implications are discussed. First, the contribution and the methodology of the research are reviewed. Next, needs for further research are considered. Finally, the implications of the findings for construction management are analyzed.

12.1 Contribution

12.1.1 Contribution to operations management theory

The main contribution of this study to the operations/production management doctrine is the formulation of a theory of production, which, when applied to a particular production situation, provides new understanding. In prior research, either the existence of a theory of production has been denied or partial theories have been put forward.

The transformation view of production has been dominant during the 20th century. The conventional template of production has been based on it, as well as the doctrine of operations management. The transformation view has its intellectual origins in economics, where it has remained unchallenged up to this day. The popular value-chain theory, proposed by Porter (1985), is another approach embodying the transformation view. A production theory based directly on the original view on production in economics has been proposed by a group of scholars led by Wortmann (1992a).

The flow view of production, first proposed by the Gilbreths (1922), has provided the basis for JIT and lean production. In a breakthrough book, Hopp and Spearman (1996) show that by means of queueing theory, various insights, which have been used as heuristics in the framework of JIT, can be mathematically proven.

The value generation view was initiated by Shewhart (1931) and further refined primarily in the framework of the quality movement. Cook (1997) has recently presented a synthesis of a production theory based on this view.

However, nobody has up till now suggested that the three views are all necessary for production management and should be used simultaneously, in an integrated and balanced manner.

The second main contribution is related to an analogous clarification of the foundation of concurrent engineering. It is shown that the various methods, tools and practices of concurrent engineering can be directly explained by the TFV theory. Before, there has not been any commonly accepted view on the theoretical foundation of concurrent engineering.

A third contribution concerns the intellectual history of the discipline of operations/production management. It is shown that all three views mentioned can be traced back at least to the beginning of the 20th century. However, this is a discipline without memory. In particular, the flow view was misunderstood and practically forgotten for decades, with the result that it has recently been promoted as a novel approach.

12.1.2 Contribution to construction management theory

Even if the doctrine of construction management is not coherent, it is shown that it, too, is largely based on the idea of production (and other operations) as transformations. This foundation has led to anomalies in the form of various performance problems. The new conceptualization, based on the TFV theory of production, explains these anomalies and provides for a new improvement potential. Thus, a new theory of construction is proposed. This is the major contribution regarding construction management.

In the interpretation of construction from the TFV theory point of view, there are two specific contributions. Firstly, it is argued that the TFV principles have to be applied in the design, control and improvement of production systems of construction. Secondly, it is argued that it is advantageous, but not necessary, to eliminate such construction peculiarities as one-of-a-kind products, site construction and temporary project organization. If they are not eliminated by production system design, they can be mitigated by control or by improvement. In practice, confusion has prevailed regarding these issues: implementation of new principles has been partial, focusing only, say, on production system design, or it has been viewed that construction has to be transformed into manufacturing (by eliminating peculiarities) before performance improvement can be attained.

12.2 Methodology

The study is related to the most fundamental concepts and principles of production (paradigm-generating theories). It is not possible to fully validate them directly; rather, their justification is earned if the more operational methods, tools and practices, based on them, can be proven empirically valid and useful in practice.

The validity of the TFV theory of production is proved in three ways. Firstly, there is historical justification. It is shown that each of the three constituent concepts has been the dominating idea of a major production template. Each template has brought about performance gains in comparison to its predecessor. Thus there are grounds for believing that all three concepts are necessary to a theory of production.

Secondly, this theory is compared to prior theories of production. Comparison reveals that the TFV concept of production can be argued to be deeper than prior theories on production.

Thirdly, as the most severe test, it is asked whether the theory contributes to new understanding and improved performance when applied to a specific production situation, construction. Methodologically, this question is first approached by means of a case study on a construction project, where the observations are structured and explained by using the theoretical framework created. It turns out that a new explanation for the persistent performance problems of construction can be found, based on the TFV theory. Comparison with prior research adds to the validity of the explanation. Second, through short case studies of actual implementation of novel methods of construction management, it is verified that the new theory, when applied practically, leads to improved performance.

However, even if an initial validation of the new theory exists, it is still shallow, and the hypotheses in question should be further refined and tested in subsequent research. On the other hand, the new theory currently gives the best explanation of phenomena in construction, and should thus be used in practice, rather than its rivals.

12.3 Further research

12.3.1 Further research in operations management

As stated above, it is intrinsic to the nature of the contribution that it leads to further research. As for the operations management theory in general, let us here just mention some directions for future research.

After all, empirical knowledge and theoretical understanding of production is still in an embryonic state, resembling the situation in medicine, say, in the 19th century. At that time many phenomena, like blood circulation, were known in outline, but not well enough for avoiding counter-productive prescriptions, like bloodletting. This relative underdevelopment of the science of production is in stark contrast to the significance of production for the well being of the mankind, as pointed out by Hopp and Spearman (1996).

Thus, the theory of production requires further clarification, development, formalization and testing. In particular, research should focus on formulating a unified production theory. Commonly agreed definitions of key concepts (value, process, operations, etc.) are sorely needed.

For historians of science, the issue of the long and haphazard formation of production theory provides an invitation for research. Why did the efforts of industrial engineering in the 1920s to advance the flow view of production wither away?

12.3.2 Further research in construction management

Regarding the construction management theory, there is an abundance of fruitful research questions. Actually, the issues to be considered broach several current interests regarding development of construction management.

The theoretical foundation, as outlined in this study, should be further refined, strengthened and validated. Especially, further empirical clarification of the value view (in contrast to the flow view) and its problems in construction is required. The full range of mechanisms causing waste in conventional construction should be explored and explained. The relation between operations management and innovation in construction needs clarification.

Of course, there is a need for further development of construction-oriented practices and methods based on the TFV principles. How could the TFV theory be effectively applied for furthering specific goals, like safety, sustainability etc. in construction? How could operations management principles and information technology initiatives in construction be better aligned? How could practical efforts directed at forming a production template based on the TFV theory be assisted?

One special point of view is related to the options of the client in construction. What are the possibilities for a client to stimulate performance improvement, from the demand side, in his projects? How should offers made by companies at different stages of implementation of TFV principles be evaluated?

Peculiarities of construction provide for another topic of fruitful research. Empirical studies on the nature of construction peculiarities and their impacts are sorely needed.

12.4 Implications for construction management

12.4.1 Introduction

In the first part of this thesis, it has been argued that a theoretical foundation of production can be defined. In the second part, evidence has been presented for the view that this foundation is applicable also for construction. This is a totally new situation for construction management, where no coherent theoretical foundation has up till now been recognized. What are the implications of this finding for construction management, understood both as a scientific discipline and professional practice?

Note that in manufacturing, such advances as mass production and lean production have diffused as practice-based methodology, and theory formation has lagged behind actual practice. Could construction benefit from a more rapid and coherent theory-based evolution and diffusion of methods and practices based on the TFV concept of production?

12.4.2 Implications for the discipline of construction management: reintegration to operations management

Operations management for construction, called "construction management and engineering" or "construction management and economics" is the only subfield of operations management that has its own department in universities, in contrast to the department of production/operations management. Content analysis of scientific papers shows that the discipline of construction management and engineering is largely inward looking[i] (Betts & Lansley 1993). It is not unfair to say that construction management and engineering has developed in relative isolation from the trends in operations management in general.

There are four issues that make this isolation problematic. Firstly, construction, especially manufacturing of construction components, has incrementally developed towards manufacturing (Sebestyén 1998). Secondly, in manufacturing, features typical of construction have become more common. One-of-a-kind production is increasingly studied in the framework of operations management (Hirsch & Thoben 1992, Wortmann 1992b). Due to the short life cycle of products, the manufacturing of a product can increasingly be seen as a project (Goldman et al. 1995). These two trends lead to the difference between construction and manufacturing becoming increasingly diluted.

The third issue is related to the theme of this study: the theoretical foundation of construction management is the same as for operations management in general. As in any other particular field of production, the theoretical foundation has to be applied to the specific features of construction. However, having progressed in isolation[ii], construction management has largely failed in the task of clarifying the peculiarities of construction, as discussed in Chapter 8. This failure is the fourth problematic issue.

This suggests that the discipline of construction management and engineering, now progressing in relative isolation, has to be reintegrated[iii] with the generic discipline of operations management and its related sub-fields, like design science and project management.

12.4.3 Redirecting major development efforts in construction

In many countries, major resources have been and are currently channeled to such development themes as industrialization, construction safety, computer integrated construction and sustainable construction. It is of prime importance that they are redefined in terms of the foundation, especially as some of them, like computer integrated construction, are perceived, rightly or wrongly, as a competing paradigm with those approaches that, at least partially, are based on the TFV concept, like lean production. Thus, the following considerations exemplify especially the power to direct of the emergent foundation.

12.4.3.1 Industrialization

Industrialization has already been discussed in Chapter 11 as a structural means for eliminating on-site activities. It was concluded that the lack of consideration of the F and V concepts has been a major cause for the rather modest success of industrialized construction. Indeed, the early misunderstanding of the model of Ford's mass production, discussed in Chapter 4, may be seen as the historical root cause for the problems of industrialized construction.

Industrialization is attractive due to the elimination of construction peculiarities, and it is still relevant as a source of future productivity improvements. In addition, the development of information and automation technologies would seem to enlarge the area of feasibility of industrialization. Thus, what is required is design, control and improvement of the production system of industrialized construction from the point of view of the F and V concepts. However, conceptual understanding and empirical coverage of these issues are still embryonic.

12.4.3.2 Safety

Lack of safety is one of the chronic problems in construction, as is evident from the high safety costs, discussed in Chapter 8. What would be the contribution of the TFV concept to construction safety?

Earlier approaches often viewed safety as a separate subject (Shillito 1995), which could be improved in isolation from other issues in production. Of course, this corresponds to the general view on improvement in the production model based on the T concept.

It has been argued that a production system that progresses towards less waste and variability also improves its safety conditions. Womack and Jones (1996) claim that after the introduction of lean production, the accident rate has halved[iv]. Indeed, standardized, systematized and regularized production can be expected to lead to better safety as a side effect (Kobayashi 1990). There are several mechanisms for this:

- There is less material in the work area.
- The workplace is orderly and clean.
- The work flows are more systematized and transparent, so there is less confusion.
- There are fewer disturbances (which are prone to cause injuries and accidents[v]).
- There is less firefighting, and attention can thus be directed to careful planning and preparation of activities.

It can be also argued that there is an opposite causal effect: safety contributes to overall improvement of production. In fact, many world-class companies have also raised the priority of safety due its influence on other goals, like quality and productivity (Ansari & Modarress 1997).

Regarding construction, available data indicate a similar situation. The best safety performances have been found to be on projects that use sophisticated scheduling techniques, frequently update project schedules, hold coordination meetings and maintain the project on schedule (Veteto 1994). Furthermore, studies (Veteto 1994, Mattila et al. 1994) have demonstrated that projects with good safety performances are also likely to be well organized and have good housekeeping methods. Veteto rightly adds that both of these traits, scheduling and housekeeping, also lead to improved productivity.

Thus, safety depends heavily on the nature of material and work flows (and the design and planning processes that support them): general process improvement on its own can be anticipated to considerably reduce the accident rate. In other words the weaknesses of production control in general provide the root cause of considerable share of accidents.

However, where the working environment is constantly changing, as it is in construction, safety is ultimately dependent on the avoidance of unsafe acts by workers (Nishigaki et al. 1992). In this regard, the STOP-method (Safety Training Observation Program) developed by Dupont, aims at creating a procedure and atmosphere where all unsafe acts of workers, when observed by foremen, can be immediately noted and corrected. This rapid cycle of deviation detection and correction helps to realize a strict compliance to safety regulations in daily work. The STOP method is demonstratedly instrumental in a radical reduction of accident rate[vi].

Thus, it seems that major improvements of construction safety can be achieved through a three-pointed effort:

- Designing, controlling and improving engineering and construction processes to ensure predictable material and work flow on site
- Improving safety management and planning processes themselves to systematically consider hazards and their countermeasures
- Improving safety-related behavior: instituting procedures that aim at minimizing unsafe acts.

To summarize, the adoption of a production model based solely on the T concept appears to cause – indirectly – a considerable share of construction accidents. Thus, the implementation of the TFV concept into construction seems to be a major factor in the endeavor to eliminate accidents.

12.4.3.3 Information technology in construction

Advancement in the utilization of computers in construction has in recent years become a major, even dominating research and development target. It is reflected in the number of related scientific papers (Harris 1992) and in educational curricula (Paulson 1993). There are numerous conferences specifically addressing construction computing and integration issues[vii]. However, criticism[viii] has recently been voiced regarding the themes, methods and results of research in construction computing (Alshawi & Skitmore 1992, Fenves 1996, Harris 1992, Andersen & Gaarslev 1996).

On the other hand, investigations into the actual usage of IT in construction reveal a not very flattering picture. Especially regarding site construction, the use of information technology has not brought any major benefits – on the contrary, it is claimed that the impacts may have been negative (as discussed in Chapter 8).

Thus, the rhetoric and visions associated with construction IT have turned out to be alarmingly distant from the reality of construction IT usage. What may have been the reason for this development, and what should be done to correct the situation?

At the risk of oversimplification, it can be argued that the underlying conceptual framework (or mental model) of construction computing has been as shown in Figure 20. Information technology implementation leads directly to benefits and improvement in construction. This corresponds to the general approach to the use of information technology, largely prevalent still at the beginning of the 1990s (Davenport 1993). In fact, this view is compatible with – and actually has its origin in – the conventional view on production, based on the T concept of production. The underlying logic is that IT makes certain activities more cost effective, and thus the total costs are reduced.

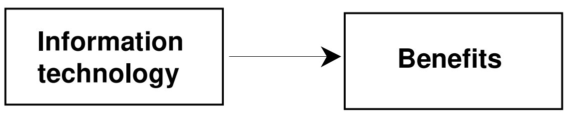

Figure 20. Underlying conceptual framework of construction information technology (inspired by Davenport (1993)).

However, it has been observed (Davenport 1994) that the underlying view on information technology, as presented above, has developed a bottleneck in itself due to its excessive focus on technology, rather than the context of its application. Indeed, at the generic level of information technology use in management, this model (Figure 20) is being rejected, thanks to re-engineering. In re-engineering[ix], it is acknowledged that information technology applications do not directly contribute to benefits, but through the intermediation of information processes (Figure 21). Information processes may restrain or amplify the effect of information technology. In re-engineering, the interest is especially focused on the cases where information technology enables a new, widely superior process design.

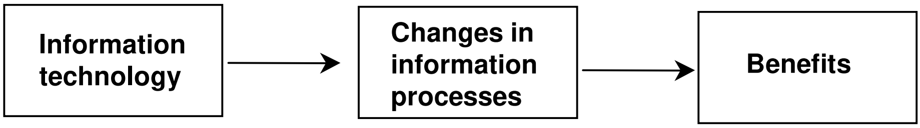

Figure 21. Underlying framework of re-engineering (Davenport 1993).

Interest in re-engineering has rapidly increased in construction research and practice (Betts & Wood-Harper 1994, Ibbs 1994). Indeed, re-engineering has to some extent shown the way towards a more effective approach to information technology. In spite of this, one cannot be fully satisfied with re-engineering as a foundation: it is rather a management recipe (Earl 1994), lacking an explicit theory.

However, interesting direction is given by Fenves (1996) as mentioned already earlier. He calls for a science base of application of information technologies in civil and structural engineering[x]. According to Fenves, one component of this science base would deal with the understanding of the processes of planning, design, management etc. that engineers use:

> ...we need to agree on an intellectual framework, in order to create a scientific understanding or abstraction of engineering processes in practice.

This can be interpreted as follows. The bottleneck in construction computing is not due to a deficiency in information technology in general or its specific applications, but to a deficient understanding of construction. Thus, what Fenves wants to add to computing research, is an understanding of operations in general and of construction specifically. It is proposed to structure this issue as illustrated in Figure 22. Here it is explicitly acknowledged, that:

- All three factors: generic operations management principles – such as the TFV principles; understanding of construction peculiarities; and information technology may bring about changes in information and material processes.
- These three approaches interact with each other.

In other words, *the introduction of computers to construction does not qualitatively provide anything new from the point of view of the theoretical analysis of production systems*: computing is worthwhile only as far as it can contribute – better than alternative means – to the realization of the principles of production.

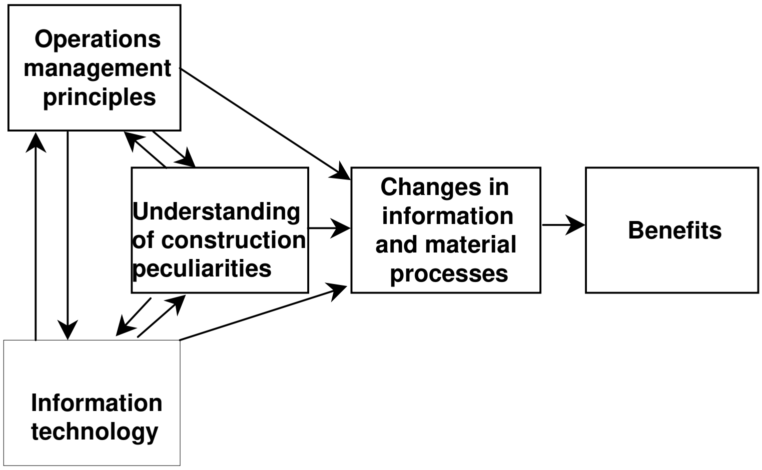

Figure 22. The interrelationships between operations management, understanding of construction and information technology.

The way changes and benefits emerge in construction is dependent on the fit between interventions emanating from these three fields depicted in Figure 22. Let us illustrate this through examples.

The *transparency* of the operational situation is one important principle of modern operations management (as discussed in Chapter 4). However, due to construction peculiarities, especially on-site production of a one-of-a-kind product, it is difficult to implement this principle in practice. But here computing would be very helpful, along with all the accompanying possibilities of simulation and visualization. Thus, computer aided transparency is suggested as one part of the implementation of operations management principles. On the other hand, simulation and visualization, when implemented in isolation, have apparently not up till now provided any solution because conventional construction management does not stress transparency, and can thus not benefit from it.

A central theme in modern operations management is that *variability* should be reduced in production. As analyses in this study have revealed, excessive variability is one chronic problem of construction. Thus, it is requisite to search for computer-based means for reduction of variability. One example is provided by Sekisui (Chapter 11), which uses artificial-intelligence based methods for ensuring correct bills-of-materials. Another example is provided by 3D CAD design, where possible geometric interference of components designed by different designers – a problem stemming from construction peculiarities – is automatically avoided. On the other hand, variability should not be increased by the introduction of information technology. Unfortunately, evidence[xi] shows that the various IT problems, like machine, software and communications breakdowns and deficient skills are a considerable source of variability. Thus the background variability of the IT infrastructure should be reduced, and variability-reducing applications should be developed in construction.

It follows that understanding and utilization of the interactions among these three fields (generic operations management theory and principles, understanding of construction peculiarities, and capabilities of computing) are most important in the successful advancement of IT in construction. On the other hand, it seems plausible that implementation of IT without due consideration of operations management principles and peculiarities of construction has been one root cause to modest benefits of IT, as experienced hitherto.

12.4.3.4 Sustainable construction

The quest towards sustainable development puts the spotlight on the built environment and the construction industry[xii]. Construction, buildings and infrastructure are the main consumers of resources: materials and energy. In the European Union, buildings require more than 40 % of total energy consumption and the construction sector is estimated to generate approximately 40 % of man-made waste (Sjöström 1998). The response of the building sector to the challenge of sustainable development is called sustainable construction[xiii].

While traditional design and construction focus on cost, performance and quality objectives, sustainable design and construction add to these criteria minimization of resource depletion, minimization of environmental degradation, and creating a healthy built environment (Kibert 1994). The shift to sustainability can be seen as a new paradigm where sustainable objectives within the building design and construction industry are considered in decision making at all stages of the life cycle of the facility (Vanegas et al. 1996, Cole 1998).

The various examples of good sustainable construction innovations, related international agreements, and national and local initiatives towards sustainability (Bourdeau et al. 1998) foster the belief that the change has started. However, it must be said that a solid methodology for implementing sustainable construction is still lacking[xiv].

From the point of view of the theme in this study, it is justified, again, to claim that the production model based solely on the T concept has not only neglected, but also directly contributed to the environmental burden. The following anecdote, related by Proverbs and Olomolaiye (1995), makes the point:

> Bricklayers were questioned with regard to the amount of wastage they had caused, and they responded by saying, "we do not get paid for saving materials, only for what is laid".

Thus, the adoption of the TFV model as such will further the goals of sustainable construction, especially minimization of resource usage[xv] due to the F concept. Beyond that, it is up to the players in construction to set specific targets for minimization of resource depletion and of pollution and to realize them as part of overall requirements; in this task, the V concept will be instrumental. The TFV concept of production seems to offer a conceptual basis and potential for novel methods and tools for sustainable construction.

The view presented is in sympathy with growing evidence on an underlying economic logic that links the environment, resource productivity, innovation, and competitiveness (Porter & van der Linde 1995). Thus, advanced production is good from the sustainability point of view, and sustainability is good from the production point of view.

12.4.4 Implications for practice

From the point of view of construction management practice, the crucial finding is that there exists a theoretical foundation, the application of which demonstratedly leads to better performance than by means of prevailing methods and principles. Thus, construction is now in an analogous situation to manufacturing in the 1980s, when JIT methods started to diffuse and led, together with ideas from the quality movement, to a re-evaluation of most aspects of production management. Similarly, in construction, a change to this new foundation will eventually be compelled by competition.

However, construction is in one respect in a better position than manufacturing: the new foundation is not implicit any more, but can be made explicit and accessible to the practitioners through the doctrine of construction management. Which benefits can be expected? From the functions of a theory of production, at least explaining, providing the basis for tools, communicating and directing have direct bearing also for the practice of construction management.

Especially regarding initial exploration and implementation of the new production model, it will greatly help if the anomalies of the prevailing production model can be explained and illustrated. On the other hand, the superior results to be achieved by the new principles and methods should be explained.

Evidently, the construction industry needs new tools and methods for realizing the switch to the TFV concept. A considerable number of the methods and tools developed in manufacturing can directly, or with minor modifications, be applied to construction. However, for the peculiar features of construction, new methods and tools have to be developed starting from first principles. Here the situation is similar to that faced by the developers of JIT in the 1940s; they, too, had only a theoretical perspective as a starting point. However, the theory of construction can now be understood much more clearly than the theory of manufacturing could be understood 40–50 years ago.

The role of a theory as a communicative device is crucial in such multi-organization endeavors as construction. This would imply that all parties of a construction project share common vocabulary, metrics and understanding of the success factors, as well as other issues. This target situation is analogous to the aims in the field of project management, where a project management body of knowledge (Project Management Institute 1996) has been compiled, or in quality management, where concepts, methods and practices have been internationally standardized (SFS-ISO 9000). However, presently neither project management or the quality movement cover all the views and principles needed. The realization of communication benefits of a foundation first requires that the body of knowledge has been sufficiently consolidated and validated. Secondly, it is necessary that the various professional bodies of construction subscribe to it and modify their codes of practice and other guidelines accordingly. However, project-wise, enhanced communication can be more rapidly achieved through focused training efforts.

The foundation provided by the TFV concept, even in its present state, already provides direction for the search for improved performance, as the industrial cases, described above, show. It can be anticipated that production templates, stressing all TFV views in a balanced way, will emerge in construction. The characteristic feature of such templates is that there is a good fit between the different parts and aspects of production, leading to synergic effects. Such templates are needed both for a permanent supply of intermediate products and services and for the temporary project activities.

As in manufacturing, the initial increase of competitive benefits can be anticipated to be so great, that the decision of implementing the TFV model overshadows all other competitive strategic decisions[xvi]. Further, the analogy from manufacturing would suggest that first implementers would have a lasting competitive benefit, assuming that they can create a capability to learn[xvii].

12.5 Conclusions

The main contribution of this study is the formulation of a theory of production, which, when applied to construction, provides a greater understanding of the subject and the potential for improvement. The validity of this new theory is grounded in three ways: historical justification; comparison to prior theories of production; and empirical evidence from case studies. It is intrinsic to the nature of the contribution that it leads to further research both in operations management in general and in construction management.

Thus, construction is on the threshold of a new paradigm that will bring about major changes in performance. In order to effectively improve construction by applying the new foundations, it is necessary that the discipline of construction engineering and management be reintegrated with the generic disciplines focusing on operations, design, production and projects. Major development efforts, like industrialized construction and use of information technology in construction, have to be redirected in concordance with the new foundation. In construction management practice, the new foundation should be adopted and new related tools should be created.

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[i] In their review of construction management literature, Betts and Lansley (1993) state:"…there is little evidence that this is achieved by approaches to research that are clearly driven by, or contribute to, theory…" and "patterns of citations suggest that studies are becoming increasingly inward-looking".

[ii] The analogy of a hermit may be illustrative: in isolation, without interaction with differing people, it is impossible for a hermit to learn what kind of a person he/she is.

[iii] There are already some examples of this. In Chalmers University of Technology, the department "Management of Construction and Facilities" has been organizationally positioned in the School of Technology Management and Economics.

[iv] However, Womack and Jones do not refer to statistical studies for verifying this trend.

[v] Josephson (1994) found that rework due to a defect often is carried out in unnatural and strenous working postures. Josephson takes the view that rework probably contributes greatly to strain injuries, common in construction work.

[vi] Indeed, Dupont, essentially a firm operating in the chemical business, has an excellent safety record in its plant construction projects. Recently, the company enforced the contractors of a polymer plant project in India to use systematic, safe practices, and the plant was constructed and its operation started without accidents or incidents, in spite of poor safety awareness and standards in local construction (Anon. n.a.). Analogously on a

Taiwanese TiO_2 plant site no lost mandays occurred during the four-year construction period (Dupont 1998).

[vii] This *Zeitgeist* may well be illustrated with the following quote from an editorial of the ASCE Journal on Construction Management and Engineering (Farid 1993):"The productivity and competitiveness of the construction industry can only be improved with the transfer and implementation of computing and other advanced technologies."

[viii] For example, Alshawi and Skitmore (1992) characterize the results of construction computing research in the following manner: "Research results are therefore either too far from reality to be disseminated easily or too complex to be accepted by construction professionals."

[ix] As presented in Chapter 2 (footnote xi), re-engineering or business process redesign are umbrella terms, and not all practitioners of re-engineering will subscribe to the analysis presented.

[x] Also Björk (1999) argues in support of such a theoretical framework. Likewise, Sriram (1998) suggests that researchers in information technology should actively participate in developing a rigorous theory of design.

[xi] Sverlinger (1996) found that design tools are the most frequent cause of internal disturbances in design firms. Most design tools were computer-based.

[xii] This section is based on (Huovila & Koskela 1998).

[xiii] Even if the main focus of sustainable construction is on ecological impacts, economic, social and cultural aspects are likewise stressed in some countries (Bourdeau et al. 1998).

[xiv] This is indicated by the need felt in various countries to adapt and develop tools to help designers and other actors to introduce sustainability concern (Bourdeau et al. 1998).

[xv] It is evident that much of waste, in the sense of operations management, also is or contributes to physical waste.

[xvi] As suggested by Womack and Jones (1996).

[xvii] The case of Toyota has been analyzed in this light in (Fujimoto & Takashi 1995).

13. Summary

Would construction be better understood and managed if we had an explicit theory of production? This briefly stated research problem may seem trivial at the first glance but, in the framework of operations/production management discipline, there has been little emphasis on theoretical development, and generally it is seen that there is no theory of production. To solve the problem posed this dissertation endeavors to answer to two more specific questions. Is it possible to formulate a theory of production? Does the theory lead to added understanding and improved performance, when applied to a specific production context, construction? Now, the answers to these questions on the basis of the preceding analyses and argumentation are presented.

13.1 Theory of production

Is it possible to formulate a theory of production? The answer to this question is sought by reviewing the history of production thinking both from the scientific and the industrial points of view.

A review of scientific literature reveals that there is no commonly accepted theory of production. There are at least three reasons for this state of affairs. Firstly, production models, like mass production or lean production, have diffused at a practical rather than a theoretical level. Secondly, the prevailing theory of production has not been explicit and so it has not been possible to make direct comparisons with rival theories or to validate it. Thirdly, the significance of a theoretical foundation of production has, by and large, not been acknowledged in the doctrine of production/operations management.

Thus, the first task is to clarify what theories have been put forward by scientists and what theories have actually been used in practice. Concluding evidence shows that during the 20th century, production has mostly been conceptualized as a transformation of inputs to outputs. There are a number of principles, by means of which production is managed. These principles suggest, for example, decomposing the total transformation hierarchically into smaller transformations, or tasks, and minimizing the cost of each task independently. However, this foundation of production is an idealization, and in complex production settings the associated idealization error becomes unacceptably large. There are two main deficiencies: it is not recognized that there are also other phenomena in production besides transformations, and it is not recognized that it is not the transformation itself that makes the output valuable, but that the output conforms with the customer's requirements. The transformation view is instrumental in discovering which tasks are needed in a production undertaking and in getting them realized. However, the transformation view is not especially helpful in figuring out how not to use resources unnecessarily or how to ensure that customer requirements are met in the best manner. Therefore, production, managed in the conventional way, tends to become inefficient and ineffective.

However, there has existed, since the first decades of the 20th century, another concept of production, namely the view of production as flow. This view was firstly translated into practice by Ford; however, the template provided by Ford was in this regard misunderstood, and the flow view of production was further developed only from the 1940s onwards in Japan, first as part of war production and then at Toyota. Currently, the flow view is embodied in lean production. In the flow view, the basic thrust is to eliminate waste from flow processes. Thus, such principles as lead time reduction, variability reduction and simplification are promoted.

Yet a third view on production has existed since the 1930s. In the value generation view, the basic thrust is to reach the best possible value from the point of view of the customer. Especially the quality movement has endeavored to translate this view into methods and practices useful in the industry. Principles related to rigorous requirement analysis and systematized flowdown of requirements, for example, are put forward.

Thus there are three major concepts of production, and each of them has produced practical methods, tools and production templates. Nevertheless, except for a few isolated endeavors, these concepts – as candidates for theories of production – have raised little interest in the discipline of operations management.

It is argued that these three concepts of production are not alternative, competing theories of production, but rather partial and complementary. What is needed is a production theory and related tools that fully integrate the transformation, flow, and value concepts. As a first step towards this, we can conceptualize production simultaneously from these three points of view: transformation, flow and value. Such an integrated view is presented in Table 15. Let us call the associated concepts and principles the TFV theory of production. However, the ultimate goal should be to create a unified conceptualization of production, instead of three partial conceptualizations.

Thus, the crucial contribution of the TFV theory of production is to draw attention to modeling, structuring, controlling and improving production from all these three points of view. A number of principles stemming from each view can be induced from practice or derived from theory (Table 16).

Table 15. Integrated TFV view on production.

	Transformation view	*Flow view*	*Value generation view*
Concept-ualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main principles	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices (examples)	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirements capture, Quality Function Deployment
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner

Table 16. Principles of production.

Main principles	*Associated principles*
Transformation view: Realize value-adding activities efficiently	Decompose the production task Minimize the costs of all decomposed tasks
Flow view: Reduce the share of non-value-adding activities	Compress lead time Reduce variability Simplify Increase transparency Increase flexibility
Value view: Improve customer value	Ensure that all requirements get captured Ensure the flowdown of customer requirements Take requirements for all deliverables into account Ensure the capability of the production system Measure value

It is noteworthy that this TFV conceptualization also applies to product design and development, where the traditional mode of management, stemming from systems engineering and project management, has been transformation oriented. Methods and tools based on the flow and value generation views have been recently introduced in the framework of concurrent engineering.

13.2 Application of the theory of production to construction

Does the theory of production lead to added understanding and improved performance, when applied to a specific production context, construction?

Historical analysis shows that in various countries construction has long since suffered from productivity and quality problems. A case study and the results of prior research on contemporary construction show that there are endemic management problems associated with both client, design, supply chain and on-site construction activities. Furthermore, the case study reveals that contemporary construction subscribes solely to the transformation view of production: for example, it is thought that by minimizing the costs of each construction activity, the total construction costs also will be minimized. However, the resultant managerial methods are counterproductive, neglecting or violating principles related to the flow and value generation views. Thus, a significant part of the problems mentioned are self-inflicted, caused by the principles in use. The TFV theory of production largely explains the origins of construction problems.

Industrial cases suggest that the application of the principles of the TFV theory of production lead to vastly improved performance. Major improvement can be created straightaway by the basic implementation of some principles, which reflects the poor starting point of construction – in other words, the high levels of waste and unnecessarily reduced customer value.

Analysis of practical cases of the implementation of the TFV theory to construction shows that it is important to have a comprehensive approach. Especially, this means that the TFV principles should be used in design, control and improvement of production systems in construction. Often practical implementation has failed due to the fact that it has been partial, concentrating only, say, on the design of the project delivery system. Thus, for example, the design-build procurement provides a design following some principles of the TFV concept, but, as empirical data suggest, on its own it is not sufficient to produce significantly better results than conventional procurement methods.

Construction is characterized by such peculiarities as one-of-a-kind production, site production and temporary project organization. Analysis of industrial cases shows that it is advantageous to eliminate or reduce these peculiarities, because they add to waste and/or value loss. However, even if their elimination is not possible, the TFV production principles can be effectively applied to control and improvement procedures so as to mitigate the effects of peculiarities. Site production is a good example: it is possible to decrease the interference between various activities through new innovative production control methods.

Thus the TFV theory has the potential of stimulating major changes in performance in the construction industry. In order to effectively improve construction through these new foundations, it is necessary that the discipline of construction engineering and management, having progressed in relative isolation, be reintegrated with the generic disciplines that focus on operations, design, production and projects. Major development efforts, like industrialized construction and use of information technology in construction, have to be redirected in accordance with the new foundation. In construction management practice, the new foundation should be adopted and new related tools should be created.

13.3 Conclusion

The answer to the overall research problem can thus be summarized shortly: the TFV theory of production provides a new, theoretical foundation for construction. This foundation, even in its emergent state, already provides new explanations for problems of construction, which have remained until now unsolved, as well as direction for experimentation and creation of new capabilities both in research and practice. It is not an exaggeration to say that the new foundation opens a practically new research frontier. The task is to further articulate and validate the new foundation, and to develop methods and tools based on it.

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Koskela, Lauri

Title

An exploration towards a production theory and its application to construction

Abstract

This thesis endeavors to answer to two specific questions. Is it possible to formulate a theory of production? Does such a theory add to our understanding and lead to improved performance when applied to construction?

The answer to the first question is sought by reviewing the history of production thinking both from the scientific and the industrial points of view. Historical analysis reveals that three different conceptualizations of production have been used in practice and conceptually advanced in the 20th century. In the first conceptualization, production is viewed as a transformation of inputs to outputs. Production management equates to decomposing the total transformation into elementary transformations, tasks, and carrying out the tasks as efficiently as possible. The second conceptualization views production as a flow, where, in addition to transformation, there are waiting, inspection and moving stages. Production management equates to minimizing the share of non-transformation stages of the production flow, especially by reducing variability. The third conceptualization views production as a means for the fulfillment of the customer needs. Production management equates to translating these needs accurately into a design solution and then producing products that conform to the specified design.

It is argued that all these conceptualizations are necessary, and they should be utilized simultaneously. The resulting transformation-flow-value generation model of production is called the TFV theory of production. It is noteworthy that this same new conceptualization also applies to product design and development, as revealed by a historical analysis of this field.

But does this explicit theory help us with regard to construction? In various countries, construction has long since suffered from productivity and quality problems. A case study and the results of prior research on contemporary construction show that there are endemic management problems associated with both client decision-making, design management and construction management. An interpretation based on the TFV theory reveals that a significant part of these problems are self-inflicted, caused by the prevailing, limited view on production. Thus, the TFV theory largely explains the origins of construction problems. When initial implementation by pioneering companies of the construction industry is studied it is also clear that methods based on the TFV theory bring manifest benefits. Thus, the TFV theory of production should be applied to construction. The theory explains the problems in contemporary construction, and suggests vastly improved efficiency.

The answer to the research questions can thus be summarized as follows. It is possible to formulate a theory of production, which also provides a new theoretical foundation for construction. The resultant TFV theory, even in its emergent state, already provides direction for experimentation and creation of new understanding and capabilities, both regarding construction research and practice.

Keywords
construction management, production, design, theory, utilization, thesis

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