Stellingen / Prepositions

Behorende bij het proefschrift:
The Economic Value of CAD systems in Structural Design and Construction;
A modelling approach
Reynold A. Chandansingh

1. De voordelen van automatisering worden vaak overschat omdat essentiële leereffecten van weg-geautomatiseerde activiteiten worden verwaarloosd.

   Benefits of automation are often overestimated, since the importance of "learning while doing" is neglected.

2. De wijze van toepassing, gebonden aan proces-kenmerken, zoals organisatie, personen, rationalisatie, cultuur en management, is minstens even bepalend voor de gebruikswaarde van CAD systemen als de mogelijkheden van de systemen zelf.

   The way in which CAD systems are deployed, as determined by process characteristics such as organization, employees, rationalization, culture and management, is equal in importance to functionality in determining their demand value.

3. De effectiviteit van CAD systemen zal toenemen door een hogere gebruikswaarde, ten gevolge van weloverwogen toepassing van meer geavanceerde systemen, bij een vrijwel constant blijvend investeringsniveau.

   The effectiveness of CAD systems will increase due to higher demand value, resulting from well-planned deployment of sophisticated systems, and a stable supply value.

4. Het gebruik van CAD systemen in het ontwerpproces kan een grotere waarde hebben voor het uitvoeringsproces dan voor het ontwerpproces van constructies.

   Deployment of CAD systems in structural design may result in a higher demand value in construction than in structural design.

5. De in het proefschrift beschreven benadering biedt het management een practisch hulpmiddel voor het analyseren van kosten-efffecten van CAD systemen.

   The approach described in the thesis provides management with practical guidelines for the analyis of cost-effects of CAD systems.

6. Persoonlijke gedrevenheid, blinde volharding en fixatie op een korte termijn doel (het promoveren) zijn vereisten voor het voltooien van een promotie.

   Personal ambition, blind perserverance, and fixation on a short-term goal are essential to complete a PhD.

7. Tele-werken gaat voorbij aan het essentieel belang van sociale contacten voor leven en overleven.

   The concept of tele-working neglects the vital importance of social intercourse.

8. Datgene, waarvan men zich moet afvragen of het belangrijk is, is onbelangrijk.

   If you wonder whether it is important, it is not!

9. Sociaal goed functioneren kan slechts door imperfectie te accepteren en de moed en flexibiliteit te kunnen opbrengen daarmee om te gaan.

   Adequate social functioning requires acceptance of imperfection and the courage and flexibility to handle it.

10. Dating-lijnen, babbel-boxen, en verwante 06-lijnen hebben een toenemende vereenzaming van individuen tot gevolg.

    Dating lines, chat-boxes and related telephone services increase the loneliness of individuals.

11. De tolerantie ten opzichte van een "vreemde" cultuur is helaas vaak omgekeerd evenredig met de manifestatie van die cultuur in de samenleving.

    Regretably, acceptance of "other" cultures is inversely proportonial to their visibility in society.

12. De wel of niet geforceerde aanpassingen bij de integratie van (jonge) allochtonen in de Nederlandse samenleving leiden tot een herwaardering van de eigen cultuur op latere leeftijd.

    The adaptations necessary for integration of young foreigners in Dutch society cause a re-valuation of their original culture at a later age.

13. Religie vormt voor velen een essentiële bron van waarden, hoop, en inspiratie; helaas, vormen de verschillen in religie, ondanks de veel grotere overeenkomsten, voor de enkeling een onuitputtelijke bron voor het zaaien van dood en verderf.

    For many, religion is an essential source of values, hope, and inspiration. Unfortunately, for a few individuals the differences between religions (despite the much larger similarities) are a source of violent reactions often leading to death and destruction.

THE ECONOMIC VALUE OF CAD SYSTEMS IN STRUCTURAL DESIGN AND CONSTRUCTION

A modelling approach

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Proefschrift

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de Technische Universiteit Delft,
op gezag van de Rector Magnificus, prof.ir. K.F. Wakker,
in het openbaar te verdedigen ten overstaan van
een commissie door het College van Dekanen aangewezen,
op vrijdag 07 april 1995 om 16.00 uur door

Reynold Anodj CHANDANSINGH

civiel ingenieur, Technische Universiteit Delft,
geboren te Paramaribo, Suriname

Dit proefschrift is goedgekeurd door de promotoren:

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To Sita, Romano
Natascha & Chantal

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Table of contents

Chapter 1
Introduction

This thesis reports research on the economic effects of CAD systems in structural design and construction. This chapter describes the relevance of this research by defining the problem, the aim and scope, and the research approach. The outline of the thesis is also described at the end of this chapter.

1.1 Background

1.1.1 Increased competition

At present the construction industry faces some serious challenges. Examples of these challenges - in particular to the European construction industry - are described in a report by KDConsultants (1991). This report calls attention to the fact that the construction industry will continue to face challenges in the future due to its dynamic nature, which is influenced strongly by social, economic, and technological developments within and between countries.

Partly these challenges originate from societal developments. International cooperation, global orientation, and further deregulation affect the construction industry seriously. Increased focus on environment and sustainable development may require dramatic changes in construction. Other societal influences stem from the importance of labour and employment issues. The influence of these developments is strengthened by the increasing role of clients (users) in construction, who value performance of structures and quality of the environment.

Another part of the challenges originates from changes in the construction industry, which are more dramatic than they have ever been. Tough international competition, and increased importance of suppliers and clients call for changes. The scarcity of resources, including human resources, stimulates redesign of construction processes. Reorganization of the construction industry, for example through vertical integration, is another example of change in the construction industry.

Within this challenging and dynamic construction market individual companies have to compete, internationally as well as nationally. Competitive advantage can be gained or maintained through differentiation or cost-leadership. This requires flexible response to client's requirements concerning products, processes, and services. Prerequisites are advanced knowledge and skills of staff, proper organization and management, and appropriate use of technologies.

1.1.2 Significance of Information Technology

Nowadays information technology (IT) is considered to be one of the key-technologies in construction, and information is considered to be a key resource within business activities. In the strategy of all major companies IT plays an important role. Betts (1992) describes how major international companies, such as the M.W. Kellog Co. and Taisei Co., compete through introduction and integration of information systems. Furthermore, Tatum (1990) indicates how Computer Aided Engineering (CAE) systems can be deployed to improve construction planning, operations, and quality.

However, up to now the use of IT has been dominated by technology push rather than by technology pull, based on strategic management. The recent past is dominated by information technological concerns, rather than on how IT can be managed and applied to support the company's strategy. As Betts (1992) concluded "up to now, there is little evidence of strategic use (of IT) despite the significant investments made", except for some examples only.

Fortunately, more and more companies are realizing that strategic management of IT is important. They are emphasizing exploitation of the potential IT offers, rather than simply applying the latest information technological advances. The problem in strategic management seems to be a lack of awareness of how to exploit IT rather than a lack of IT itself.

For strategic management information is required concerning the changes information systems induce on construction. The effects of not only current systems, but of future systems as well need to be analyzed to provide feedback for managerial decisionmaking. However, appropriate tools and techniques, which can easily be applied to construction, are not readily available. That is why current evaluation of information systems is rather poor.

1.1.3 Significance of CAD systems

To illustrate the significance of IT and the problems with the evaluation of effects, let us consider one of the major IT-concepts in construction: Computer Aided Design (CAD)[1]. CAD systems are computer-based information systems which aid the process of creation, analysis, modification, and representation of designs. Related IT-concepts are Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), and Product Data Interchange (PDI). Integration of these concepts in design and construction is referred to as Computer Integrated Construction (CIC).

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[1] By a CAD system is meant not only the software itself, but the infrastructure (consisting of hardware, network, etc.) as well. The infrastructure is considered to be an essential part, since the CAD system cannot be used without it.

table 1.1: implementation and use of CAD systems at engineering consultants in the Netherlands (1990)

IMPLEMENTATION & USE OF CAD SYSTEMS		***Small eng. cons.***	***Medium eng. cons.***	***Large eng. cons.***	***Average***
	Staff: structural engineers & draughtsmen	***< 6***	***06 - 30***	***>30***	
Implementation of CAD systems		30%	85%	100%	75%
Use of CAD systems for production of					
	concrete drawings	30%	85%	100%	75%
	reinforcement drawings	15%	55%	90%	55%
Drawings produced with CAD systems					
	concrete drawings	20%	50%	75%	45%
	reinforcement drawings	10%	35%	50%	30%

When considering structural design it can be concluded that CAD systems have been implemented by almost all engineering consultants, despite serious barriers (see Mahoney & Tatum, 1990). Table 1.1 shows the results of a survey among the members of the ONRI[2] (see also Chandansingh & Vos, 1991). The survey proved that the implementation of CAD systems is lower for smaller engineering consultants, but it is clear that almost all firms will have CAD systems in the near future. However, the intensity of use of CAD systems within the engineering consultants was still low: an average of 45% for the production of concrete drawings and 30% for the production of reinforcement-drawings. The intensity of use is expected to grow rapidly as well. Furthermore, the survey showed that several different CAD systems are used.

Chandansingh & Vos (1991) also performed a second survey among the larger engineering consultants in the Netherlands (a sub-set of the engineering consultants considered in the first survey) concerning the use of CAD systems for reinforced concrete detailing. It showed that several CAD systems are used, which differ with respect to their capabilities, limitations, structure, and functions. On top of that, the systems are implemented and used in quite different ways and intensities.

Secondly, it was found that implementation and use of CAD systems were mainly (information) technology-driven. Decisions concerning use were rarely based on anything other than the desire to gain experience with this rather new technology. In most cases costs[3] and benefits were not evaluated properly to support decisionmaking concerning use.

In the few cases that an evaluation was performed, the method of the payback period was used. However, it seemed hard to determine the benefits of a CAD system, in contrast with the costs. Most of the respondents in the survey were not able to estimate cost-savings, while others provided very rough estimates. In addition they were unable to relate the benefits to the specific features of the CAD system, although they stated clearly that the benefits depend on these features. Benefits were described in qualitative terms mainly, which were found to be inappropriate for proper decision-making. For example, it was often said that the quality of drawings is improved by use of CAD system.

---

[2] The Association of Consulting Engineers of the Netherlands

[3] Here is referred to the generic meaning of the term "costs", which includes both financial and non-financial aspects

Another method of evaluation is provided by Anadol & Akin (1993). They focused in particular on the effects of quality-improvements of drawings, produced with CAD systems. In their study the effects of CAD systems on the building delivery process were analyzed. Evidence was found for reduction of the number of change orders and improvement of control over project-costs, resulting from quality-improvements of drawings (in particular improvements in the accuracy).

It is clear that for strategic management of implementation and use of CAD systems (and information systems in general) current methods are not good enough. Management requires methods for analyses of the effects of CAD systems on business processes, which will support proper evaluation of CAD systems. An analytic framework is needed for both ex-post (descriptive) and ex-ante (predictive) analyses of the effects of the several CAD systems.

1.2 Aim and scope

CAD systems offer construction companies the possibility to meet challenges placed on them by developments in society and construction itself. However, adequate methods for selection of CAD systems and exploitation of their use are not readily available. Without these methods management will not be able to (re-) direct the use of CAD systems. The use will continue to be based on information technological push, rather than on strategic management.

> The aim of this research is to:
> *develop an analytical framework which will facilitate systematic analyses of the effects of CAD systems on design and construction.*

The research is restricted to the market value (or economic value) of CAD systems. The market value is determined by the supply value and the demand value. The supply value may be estimated by the minimal costs which are involved in purchase or development of the CAD system. The demand value may be estimated by the maximum amount of money the user is willing to pay for the CAD system. In this research the focus is on the demand value. The research tries to determine an upper-bound for the demand value of the CAD system, expressed in cost-reductions resulting from use of the system.

Realizing that it is not possible to consider the effects of CAD systems on design and construction as a whole within one PhD-research, it was decided to limit the research to the domain of structural design and construction of reinforced concrete (RC) structures. A major part of this process deals with the design and production of reinforcement. In the context of this research we refer to the production of reinforcement when speaking of construction processes.

CAD systems are considered to be information systems which support the structural design of RC structures and production of reinforcement. The majority of the systems are special-purpose systems for reinforced concrete detailing. Among those are systems which are often characterized as "draughting systems". In this research a "draughting system" is interpreted as a type of CAD system, which in turn is taken to be a kind of information systems.

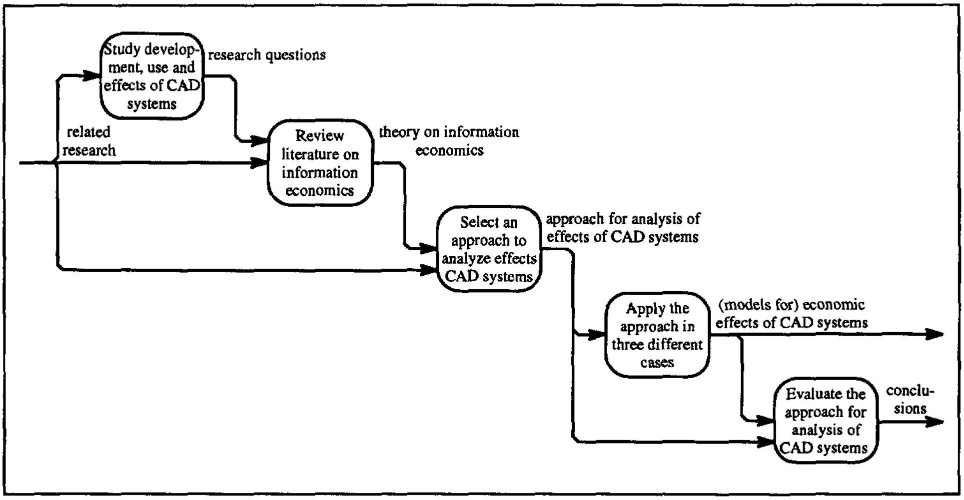

figure 1.1: phases of the research

The effects of CAD systems on design and construction seem to depend on two variables. The first is the type of CAD system under consideration, while the second represents the nature of the process. The first requires a framework for identification of value-adding attributes of CAD systems to be used for classification of such systems. The second requires a classification of design and construction processes, according to their activities and costs-structure.

1.3 Research approach

The research was performed in four successive phases, but iterations did occur during the research. The four phases were (see also figure 1.1):

1. global orientation on development, use and effects of CAD systems in structural design and construction,
2. review of the literature on information economics and related fields, resulting in the selection of an approach to model effects of CAD systems in design and construction,
3. application of the selected approach in three case-studies,
4. evaluation of the approach.

Phase 1 extensively studied the development and use of CAD systems in structural design and construction. This orientation-study was not focused on CAD systems alone but on related technologies as well, such as CAM systems and PDI. Furthermore, developments were studied not only in the Netherlands, but worldwide as well. Especially, the developments in Japan were included in this phase.

Initially the orientation aimed at determination of the several factors relevant to development, implementation and use of CAD systems. These factors were needed in order to develop scenario's for future development. In addition several forecasting-methodologies were reviewed on their usefulness for development of scenarios.

However, the research was re-directed to the economic value of CAD systems, because it appeared that:

1. developing and validating scenarios would require more time than available, while it would be hard to validate scenarios due to the dynamic nature of development of IT and construction itself,
2. economic value is one of the most important factors which determines development, implementation and use of CAD systems,
3. methods and techniques are needed to evaluate current and future use of CAD systems in order to support strategic management,

The orientation then focused on the effects of use of CAD systems on structural design and construction. Available literature was reviewed, and two surveys were performed among engineering consultants in the Netherlands. The first survey was an interview by telephone among the 64 engineering consultants, which are members of the ONRI. The second was a detailed written interview administered to 21 structural engineers at 11 engineering consultants. The results of these surveys are discussed in sections 1.1.3 and 7.3. of this thesis.

Phase 2 involved a study of the economics of information-related products, systems, and services. Several approaches to economic analysis were identified and the current methodologies were reviewed. The economic features of information-related products, systems, and services with regard to their use in production processes were determined. Furthermore, the relations between information and information products, systems, and services were studied. Based on this review it was concluded that a useful approach could be one which is based on the work of Mowshowitz (1992a-c).

In phase 3 the selected approach was used to model and analyze the effects of CAD systems on structural design and construction. The approach was tested in three case-studies. Two case-studies analyzed the effects of CAD systems on structural design. The last case-study analyzed the effects of CAD systems on the construction of reinforcement. This analysis is indirect: the effects on the construction of reinforcement were analyzed through examination of effects of the different information commodities, resulting from use of CAD systems in structural design.

For analysis, formal models of the structural design and construction processes were required. These models were partly based on description of the processes in available literature. However, the major input for modelling was obtained from empirical research in the form of interviews with experts, and the case-studies mentioned above. The case-studies include interviews, observations, analyses of cost-evaluations, and measurements during execution of activities. The emphasis was put on interviews with the employees of the several firms involved.

In phase 4 the results of the case-studies were evaluated. Evaluation of the case-studies focused on the usefulness of the approach to model the effects of CAD systems on design and construction. However, the effects of CAD systems were evaluated as well. In addition the applicability of the approach to model the effects of other information commodities on construction or on other production processes was considered.

1.4 Outline of the thesis

Following this introduction, both part 1 and chapter 1, the thesis is divided into three parts. Part 2 (chapters 2-4) describes the theory of the economic value of information-related products, systems, and services. Information, defined with regard to its use in production processes, is discussed. Economic features of information are discussed, leading to the definition of information commodities. Finally, production digraphs are introduced which will be used to analyze the effects of information commodities on production processes. Since costs are modelled, some cost-issues are discussed as well.

Part 3 (chapters 5-9) discusses the application of an approach to model the effects of CAD systems on structural design and construction. The processes are described and general production digraphs are provided. The several CAD systems used in structural design processes are discussed and classified as information commodities. The case-studies, which have been designed to analyze effects of CAD systems, are described in a chapter 8, while the results of the case-studies are provided in chapter 9.

Part 4 provides the conclusions of this research. Not only the usefulness of the approach taken to model the effects of CAD systems on design and construction is discussed, but the applicability of the approach to model effects of other information commodities on other production processes is discussed as well.

Chapter 2
Economic analysis of information technology

Information technology (IT) has serious economic effects. Literature reveals both macro- and micro-economic analysis of IT. This chapter focuses on micro-economic analysis. Current methods are evaluated and problems in analysis of IT are identified. The chapter concludes that micro-economic analysis of IT requires consideration of the use of IT-products in business processes.

2.1 Introduction

Modern information technology (IT) has economic effects, which are analogous to those of industrialization at the end of the last century. IT provides new information-related products, systems, and services in addition to the traditional ones. These products, systems, and services offer alternatives for the use of information in the different activities in organizations.

An indication of the economic significance of IT is provided by the greater interest in information-related activities in the economy (see Machlup, 1962, 1980, and Porat, 1977). Currently, information is considered to be a key resource in any business activity and IT is seen as a key technology in maintaining competitive advantage. Many IT-products, systems, and services have been applied in production, marketing, and administration.

Another indication of the economic significance is represented by the vast amount of investments in IT. Panko (1991) observed that 33% to 50% of capital expenditures in the USA are for IT of some type. In general it is assumed that up to 50% of capital expenditures of large organizations is invested in IT (See for example: Davenport & Short, 1990, and Keen, 1991).

Economic analysis of IT typically has three objects of study:
1. the economic effects of IT as a whole,
2. the economic effects of an IT-application, such as a product, system, or service,
3. the economic effects of information.

Two levels of economic analysis are discussed: macro-economic and micro-economic analysis (see figure 2.1). Macro-economic analysis considers the effects on the economy as a whole, a sector of the economy, or an industry (such as the construction industry). Micro-economic analysis focuses on the effects on an organization, a subdivision (business-unit) of an organization, or on a business process within an organization.

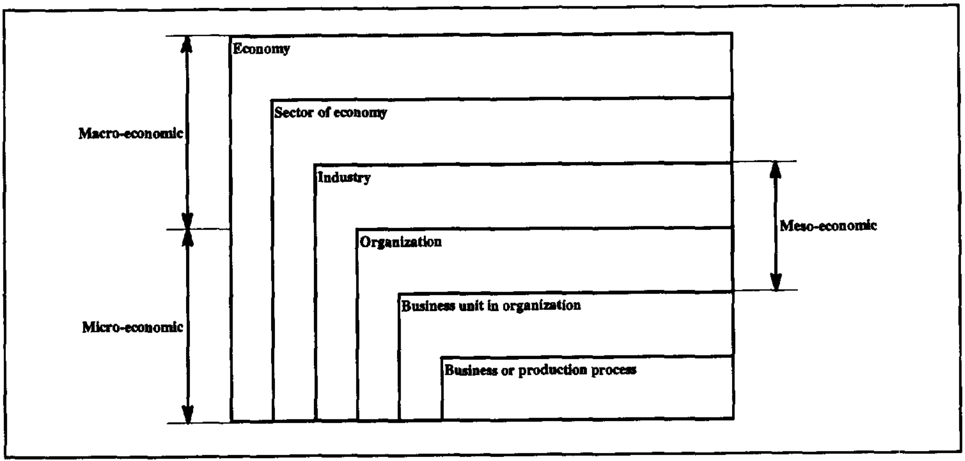

figure 2.1: levels of economic analysis of information technology

In the remainder of this chapter, the relevant research on economic analysis of IT is reviewed. Arguments are provided for focusing on the micro-economic level of analysis. The several aspects of micro-economic analyses and the different objects of study are discussed. It is argued that economic analysis starts with the analysis of the effects of information-related products, systems, and services on business processes. Information commodities, which are defined in the chapter 3 are the proper object of economic analysis.

2.2 Macro-economic analysis

Economists, like Machlup (1962, 1980) and Porat (1977) started to focus on the role of information in the economy, although information has always been important to economic activity. Looking at developments in IT, which provided new means for handling information, they argued that information-related activities should be regarded as a sector in its own right. In their macro-economic analyses they focused on information in the production and distribution of goods and services, and tried to identify its contribution to the Gross National Product (GNP).

Others focused in particular on the macro-economic analysis of information in the production of goods and services. Examples of such analyses of information are provided by Braunstein (1981, 1985, 1987), and Hayes & Erickson (1982). These studies are concerned with production functions, and make use of production function models.

Of particular interest here are the two macro-econometric analyses of IT by Roach (1986) and Loveman (1988). These analyses attempted to relate investments in IT to performance in the economy as a whole (see figure 2.2). However, their conclusions indicate that it is hard to analyze effects on macro-economic level. Roach concludes that it is still not clear whether investments in IT improved the productivity of the so-called information worker (in the service sector). Loveman (1988) states: "it is hard to document a large productivity boom from IT at the aggregate macro-economic level".

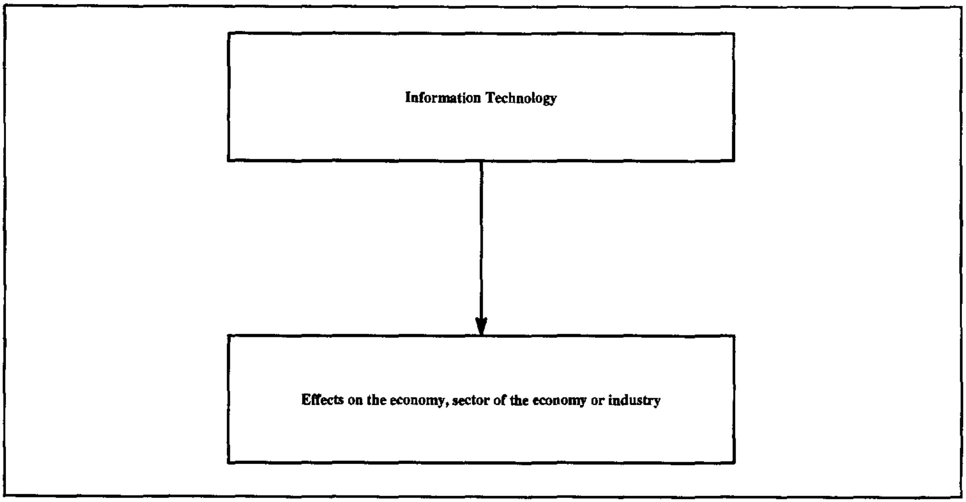

figure 2.2: macro-economic analysis of information technology

Macro-economic analyses are very difficult and the utility of the results are questioned, for example by van Nievelt (1992), who provides two critical observations. The first observation concerns the use of aggregates as performance-measure. Aggregation makes it hard to attribute effects to the use of IT, since other business-factors can impact performance as well. The second concerns implicit assumptions, which may bias analysis. For example, the assumption that investment in IT would by itself cause enhanced economic performance is questionable.

Micro-economic analyses are more appropriate than macro-economic analyses for our purposes since they support strategic management of IT within organizations. As van Nievelt (1992) argues: "the key question is not what IT contributes in the aggregate, i.e. the economy as a whole, but rather how and why some businesses use IT so much more profitably than others". This research will focus on micro-economic analysis, which is discussed in the next section.

2.3 Micro-economic analysis

Micro-economic analyses focus on the economic effects of IT in an organization. The analyses aim primarily at justification of the organization's investment in IT. A subdivision (business-unit) of an organization is the most appropriate unit of analysis. However, still only a few organizations make use of formal analyses of the effects of IT (Bacon, 1992).

The choice of the topic of analysis seems to be dictated by disciplinary affiliation. Micro-economic analyses of information-related products, systems, and services are preferred mainly by economists. Information scientists, such as King et al. (1982, 1984), Taylor (1982, 1984, 1986), Cronin (1986), and Repo (1989) have focused primarily on micro-economic analyses of information. In the next section, the different aspects of analysis and methods for analysis are described and evaluated.

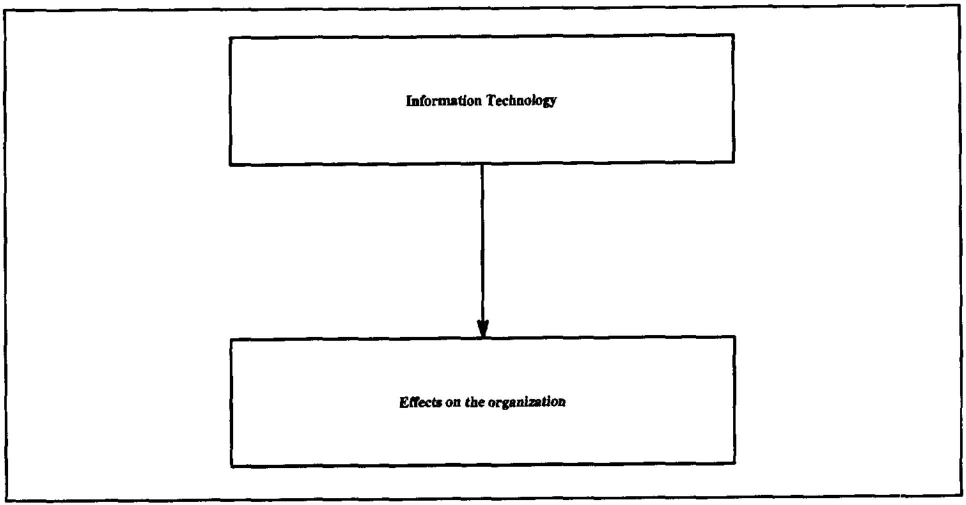

figure 2.3: micro-economic analysis of information technology

2.3.1 Aspects of micro-economic analyses

Micro-analysis of effects aims to support justification of the organization's investment in IT. Justification is needed during all activities in the strategic development and use of IT within the organization. For every activity the aims and conditions are different. Methods for micro-economic analysis and justification can be classified according to the activities they support.

Irsel & Swinkels (1992) have identified five activities required for strategic use of IT:
1. identification of possible application of IT for the organization,
2. legitimization of the investment for the application of IT, including assigning priority to investments for various applications of IT,
3. realization of IT-projects, including cost-management for realization,
4. exploitation of the operational IT-application, including management of operational costs and realizations of expected benefits,
5. evaluation, including verification of expected consequences of the investments.

In their review of the current methods, Irsel & Swinkels (1992) found that there is no method available which supports all activities. The majority of the methods focuses on the identification, legitimization and evaluation of IT. This means that perhaps the most important activity (exploitation) is not supported properly by current methods

2.3.2 Methods for justification of investments in IT

For justification of investments the consequences of application of IT are analyzed for the organization as a whole (figure 2.3). Several methods are available to analyze and determine the consequences. Farbey et al. (1993), Powell (1992), and Wilcocks (1992) for example reviewed such methods. They also concluded that the main activities supported by these methods are identification, legitimization and evaluation of IT.

The current methods seem to be based on one of four different approaches. This differentiation into four approaches is based on differences in the treatment of consequences. One can consider only those consequences which can be expressed in monetary terms, or all consequences (both in monetary and non-monetary terms). Furthermore, differences refer to the units used to express the consequences in order to compare alternatives (e.g. money, ratio's, and priority score).

The four approaches which can be determined are:
1. the financial approach,
2. the multi-criteria approach,
3. the ratio approach,
4. the portfolio approach.

The financial approach considers only the financial consequences of the investment, focusing on incoming and outgoing cash flows. Methods for the evaluation and selection of traditional investment proposals are applied to investment proposals in IT as well. Examples of these methods are the payback period, the internal rate of return, and the net present value.

The multi-criteria approach facilitates a single measure of consequences, which incorporates both financial and non-financial consequences of each investment. The approach consists of three major steps. First, determination of evaluation criteria and their relative importance, which is presented by assigned weights. Second, assignment of scores for each alternative proposal for the several evaluation criteria. Third, derivation of the final score of a proposal as the sum (for all criteria) of the weights times scores. The final score is used to rank the alternative proposals for investments in IT. Examples of these methods are the information economics method (Parker et al., 1988, 1989), and the Strategic Investment Evaluation and Selection Tool Amsterdam (SIESTA) method (van Irsel et al., 1992, van Irsel & Fluitsma, 1992).

The ratio approach uses ratio's of organizational effectiveness to evaluate proposals for investments in IT. The methods differ with respect to the particular ratio used. Examples of ratios used are:
1. IT expenditures divided by total turnover,
2. yield attributable to IT investments divided by total profits,
3. value added by management divided by costs of management, referred to as the Return on Management (see Strassmann, 1990, and van Nievelt, 1992),
4. financial and non-financial values divided by average values (benchmarks), referred to as IT assessment (see van der Zee & Koot, 1989).

The portfolio approach analyzes consequences by plotting the effects of the IT-investments proposals against the evaluation criteria. A main feature of this approach is that consequences are presented graphically. Portfolio methods, which are well-known in management literature, are applied to IT-investment. Examples of these methods are Bedell (1985), investment portfolio (Berghout & Meertens, 1992), and investment mapping (Peters, 1988, 1989).

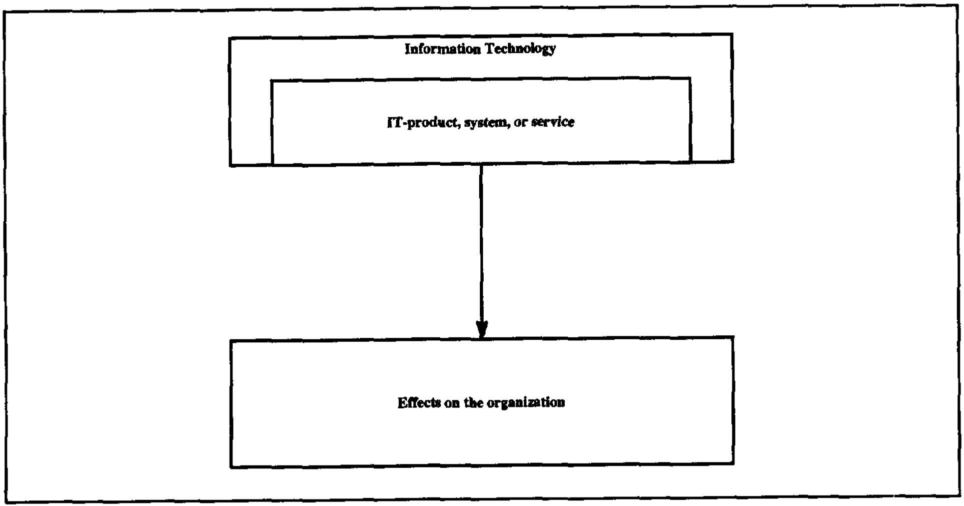

figure 2.4: micro-economic analysis of IT-products

2.3.3 Evaluation of current methods

An important example of micro-economic analysis is provided by Strassmann (1990). After an extensive study of 292 industrial companies, Strassmann indicates that no relation has been identified between investments in IT and the profitability of an organization. According to Lucas (1992) the failure to detect a relation between IT and organizational consequences might be attributable to an inappropriate set-up and incorrect assumptions made in the analysis.

Criticism of the current methods of analysis of the effects of IT focuses on three issues. The first refers to the object of study: IT as a whole or IT-products, systems, and services. The second refers to the organizational level of analysis of effects of IT. The third refers to some implicit assumptions in the analyses. This criticism is elaborated below.

2.3.3.1 IT or IT-product

The object of study in micro-economic analyses can be either IT in general or an IT-product, system, or service. The latter results from application of IT and is developed for a specific reason. IT as object of study focuses on the whole technology itself. This means that applications of IT, such as information systems, hardware, networks, and operating systems, are considered together.

It is more appropriate to choose the IT-product, system, or service as object of study rather than IT as a whole (see figure 2.4). Lucas (1992) claims that it is easier to find a direct linkage between an IT-product, system, or service and the effects of its use. First, he argues that often the goals for an IT-product, system, or service are clear. Secondly, the impact, in terms of IT-related performance measures, can be determined relatively easily, since the IT-product can be studied in depth. Finally, knowing goals and impact in advance provides good opportunities for appropriate measurements of effects. None of these desiderata - clear goals, determinable impacts, and appropriate measurements of effects - holds for IT as a whole.

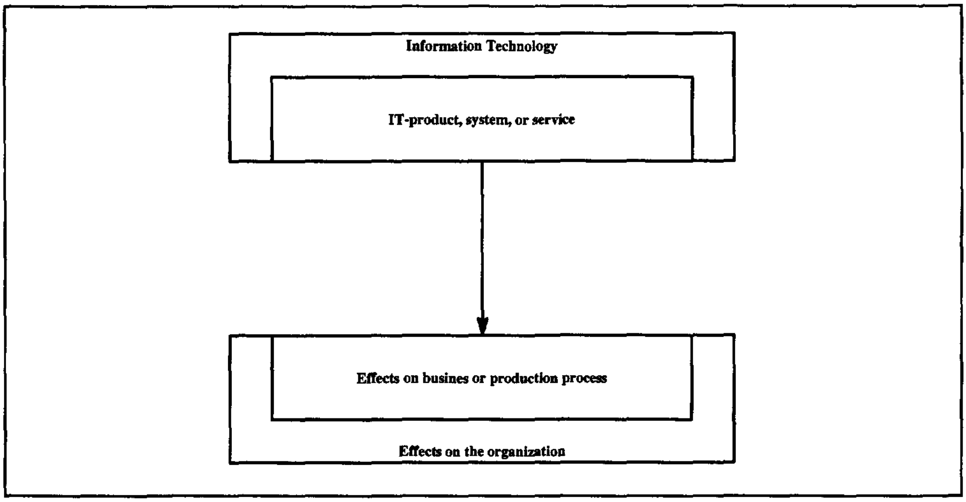

figure 2.5: analysis of effects of IT-productsin on business process

In-depth studies of IT-products, systems, and services reveal that effects depend on their features in relation to information processing in the organization. Ward (1988) indicates that effects relate to provision of appropriate information for activities in the organization. Furthermore, effects result from improvements in exchange of information between activities. Often restructuring of activities is required for effects to occur.

The effects of IT as a whole can be determined as an aggregate of the effects of the individual IT-products, systems, and services it consists of. When these components are identified clearly, their individual effects can be determined. Finally, the effects can be aggregated. However, it should be clear that analysis of the effects of IT starts with the analysis effects of an individual IT-product, system, or service.

2.3.3.2 Organization or business process

Often the effects of IT and IT-products are analyzed for the organization or business-unit as a whole. However, these effects are an aggregate of the effects on individual business processes. Often this aggregate is biased by other factors than the use of IT-products. Furthermore, it is difficult to relate an IT-product to general effects on the organization as a whole.

Study of business processes provides better potential for analysis of the demand value of IT-products (see figure 2.5). Irsel & Swinkels (1992) claim that the business process provides possibilities for more detailed analyses. It is most likely that the causal relations between an IT-product and its effects can be identified, when considering individual business processes.

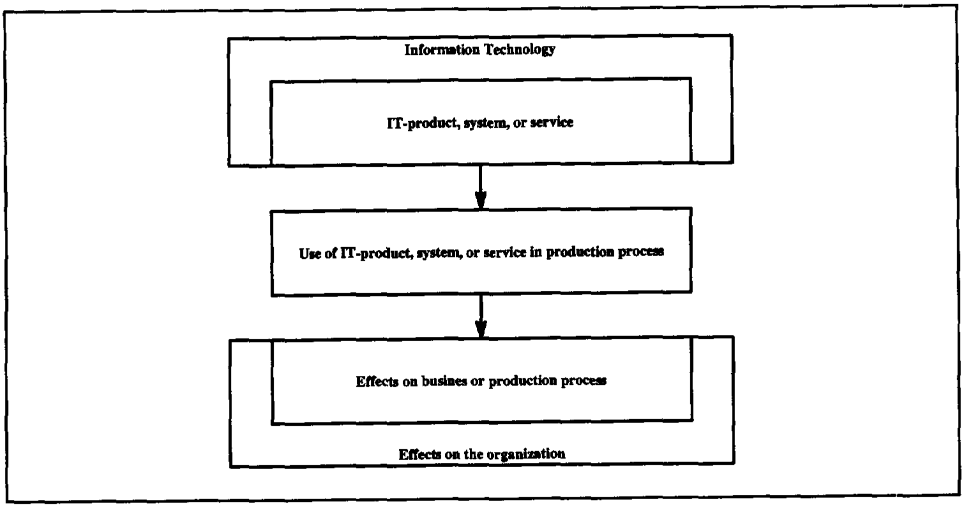

figure 2.6: analysis of effects of use of IT-products on business process

2.3.3.3 Use of IT-products in business processes

In analyses of effects of IT-products often some implicit assumptions are made, which are questioned by Lucas (1992). The first is the assumption that effects depend only on the features of IT-products. However, several other factors, which are not related to the IT-product can influence the effects. Examples of such factors are the organization of the business process and the willingness of staff-members to work with the IT-product.

The second is the assumption that the availability of an IT-product is sufficient to produce effects of some kind. It is assumed that the IT-product is appropriate for use and that it works. However, it does occur that development and implementation of an IT-product fails completely. In that case, the IT-product will be inappropriate for use and it is not expected to cause any effects on the business process studied.

Considering the use of IT-products in business processes deals with these potential problems (see figure 2.6). On the one hand, considering the use will force attention on other factors influencing effects of IT-products. These factors refer to the aim and the specific nature of the process. On the other hand, considering the use will automatically rule out IT-products which are inappropriate for the business process studied.

2.4 Conclusion

Analysis of the effects of IT requires consideration of the use of IT-products in business processes. Knowledge of effects of IT-products on a business process is a prerequisite for analyses of effects of IT on organizations. On the one hand, the effects of IT can be estimated as the aggregation of the effects of individual IT-products. On the other hand, the effects on the organization can be estimated as the aggregation of the effects on the individual business processes.

Analysis of the use of IT-products on a business process provides the highest potential for finding interesting results. It is most likely that causal relations between IT-products, systems, and services and effects on business processes can be identified. However, current methods do not focus on this level well enough and fail to provide useful techniques.

IT-products, systems, and services are related to the processing of information in business processes. The effects of these products, systems, and services can be analyzed through the use and value of information in business processes. To facilitate this, the notion of information and value of information with respect to (production) processes must be defined clearly. Furthermore, information-related products, systems, and services must be defined with respect to these definitions. These issues are discussed in chapter 3.

Chapter 3
Value of information

The effects of information-related products, systems, and services can be analyzed through the use and value of information in business processes. To facilitate this, this chapter discusses the notion of information and value of information. Information is defined with respect to (production) processes. Furthermore, information commodities - the appropriate elements for economic analysis - are defined, and its value-adding attributes are discussed. This chapter concludes that CAD systems are information commodities. This enables analysis of the value of CAD systems.

3.1 Introduction

Information seems to be present everywhere in production processes, appearing in different forms. Pure knowledge and skills acquired by staff-members, requisites for individual and organizational decision-making, specifications of products or production processes, and bits pumped through communication channels are just a few of the forms of information.

The importance of information as element of production in its own right has come to be recognized in recent decades. For example Porat (1977) observed: "production is the transformation of matter and energy from one to another ..., which is not possible without a sizeable input of planning, coordination, knowledge and control over information".

This research is concerned with the value of information in relation to production processes. For more general discussions of the value of information, see Griffiths (1982) and Repo (1986, 1989). The modelling approach taken in this thesis is based on the theory developed by Mowshowitz (1992a), which shows that the economic value of information is in fact the economic value of something called "information commodity". This chapter discusses the economic features, models, definitions, and measures of information, and the market value of information.

3.2 Ambiguity of "information"

The term "information" is ambiguous and used in different ways. Three principal usages of "information" are identified in the Oxford English Dictionary (1989). The first relates the term information to knowledge. Information is considered to be "knowledge communicated concerning some particular fact, subject, or event", "that of which one is apprised or told", or "intelligence, news". A key characteristic of this meaning of information is that it is intangible; it cannot be touched or measured in a direct way.

The second relates information to processes. Information is used to denote "the act of informing ...", "communication of the knowledge or 'news' of some fact or occurrence", or "the action of telling or fact of being told of something". I discard the use of the term "information" in this meaning. "Information processing" is a more suitable term for what is meant in this context.

The third relates information to objects or products. Information is seen as a set of objects which are regarded as being informative, "having the quality of imparting knowledge or communicating information", or "instructive". This meaning refers to the tangible form of information, since objects can be touched and measured.

In this discussion of information a distinction is made between intangibles and tangibles. Information is used to denote the intangible, related to knowledge, which has a function and structure. It must be emphasized that information is not identical to the tangibles (e.g. products, systems, and services) which seem to contain or furnish information in some sense. Information is more like an intangible. Section 3.3. discusses and defines information.

3.3 Definition of information

3.3.1 Current views of information

Mowshowitz (1994) identifies two different aspects of information in the current definitions of information. The first, which he termed selective information, considers the removal of uncertainty associated with the reception of information. The second, referred to as semantic or structural information, considers the content or meaning of information.

3.3.1.1 Selective information

The model of selective information considers the reduction of uncertainty about the state of the world, associated with the reception of information. This model of information originates from communication engineering. It is used to analyze the causes of errors and potential remedies in communication systems.

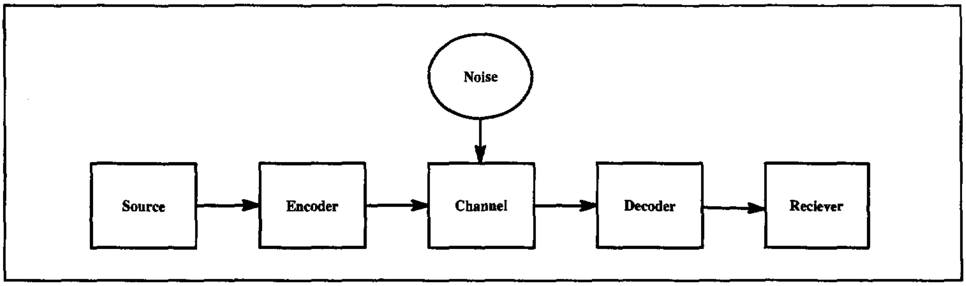

figure 3.1: basic model of a communication system

The basic model of a communication system is provided in figure 3.1. It consists of a sender or source which generates information to be transmitted over a channel to a receiver. At the source the information is encoded in a form suitable for transmission over the channel. At the end of the channel the information is decoded and delivered to the receiver. Errors can occur during the communication; the causes of errors are represented by noise acting on the channel.

Reception of information reduces uncertainty. The quantity of uncertainty removed depends on the mathematical form of the measure which is adopted. Shannon & Weaver (1948) introduced the famous entropy measure for communication engineering, which is defined for a set of outcomes with an associated probability distribution. It measures the amount of information (uncertainty) provided by a source transmitting **n** messages $\{m_1, m_2, ..., m_n\}$ with a-priori probabilities $\mathbf{p_i, ..., p_n}$. The amount of information is:

$$- \sum_{i=1}^{n} p_i \log (p_i)$$

Shannon chooses as base of the logarithm 2, but this choice is arbitrary. With 2 as base the measure is expressed in **bits** (which is short for *bi*nary dig*its*).

The entropy measure facilitated the development of what is known as the fundamental theorem of information theory. This theorem states that as long as the rate at which information is transmitted through a channel remains less than the channel's capacity, it is possible to transmit information at that rate with a desired low probability of error. This supports the motivation for Shannon's theory: to provide methods for the design of reliable and economic communication systems.

It must be emphasized that in this model the specific content of the information (informational meaning) transmitted is irrelevant. Researchers (e.g. Repo, 1987, and Mowshowitz, 1992a) argue that Shannon's theory is of limited use to define and determine the value of information, because the entropy function does not account for the meaning of the information. The entropy function is useful for measuring the quantity of information (data). However, it is not of any practical use to determine the value of information, since there is not necessarily any relation between the quantity of information (data) and its value.

Some researchers have tried to incorporate the meaning of information in entropy functions. See Hayes (1993) for a discussion of so-called weighted entropy. However, these attempts were not very successful, since the meaning may very greatly from one situation to another.

Despite these limitations the entropy measure of information has been adapted for use in many different domains. Researchers from various disciplines have been attracted to application of Shannon's theory simply because it provides a measure of information. Problems can be reformulated easily using the entropy measure. However, as Mowshowitz (1994) argues, the information theory is applied purely in a descriptive way to reformulate existing problems.

3.3.1.2 Structural information

The model of structural or semantic information considers the content or meaning of information. The informational meaning determines the extent to which the information can be used to reach specific goals or accomplish specific ends. The focus is on the significance of the information, which depends on the situation as well. Thus, this aspect of information is closely related to assessment of value of information.

To illustrate the difference between selective and structural information let us consider two messages with the same amount of uncertainty. However, the meanings of the message can be quite different. The meaning can be relevant in a specific situation, while it can be totally useless in another. This also implies that structural information depends on the user in a specific situation, or as Mowshowitz (1994) puts it: "information is in the eye of the beholder".

Several measures of structural information have been proposed. One approach to measure informational meaning is the empirical technique, called semantic differential, which is developed by Osgood et al. (1957). A second approach is related to the measure of the structural complexity of graphs (Mowshowitz, 1968a-b). Furthermore, the hierarchical series of information measures as proposed by Hayes (1993) also includes measures of structural aspects of information at three levels: the syntactic, semantic, and data-reduction levels.

3.3.2 Information as ability

3.3.2.1 Definition

Mowshowitz (1992a) noted that a measure is not the same as a definition of information. A measure presupposes a definition which specifies the domain of the measure's applicability. The definitions proposed thus far fail to specify the domain. The domain can be incorporated by viewing information as a property of the domain, system or environment.

Because information is used to make decisions and control processes, Mowshowitz (1992a) defined information as: "the ability of a goal-seeking system to decide and control". Decide means: choosing one alternative among several that may be executed in pursuit of a well-defined objective. Control means: the ordering of actions that may be executed in pursuit of a well-defined objective. A goal-seeking system is a system whose actions are designed to achieve a well-defined objective.

The definition of information as ability allows integration of the selective and semantic aspects of information. The ability to decide depends on the reduction of uncertainty about alternatives and determination of the significance of alternatives. The first calls attention to the selective aspects of information, while the latter deals with the semantic aspects.

3.3.2.2 Characteristics of information

The definition of information as the ability to decide and control facilitates a sharp distinction between what information is, what forms it may assume, and what properties it possesses. Selective and structural aspects of the ability to decide are characteristics of the functions of information. With regard to the non-material character it can be concluded that information is clearly not identical to objects which seems to "contain" or "furnish" information. Information is definitely not the same as its embodiment or representation, but becomes "available" during use of products, systems, and services.

Furthermore, the definition incorporates the declarative ("what") and the procedural ("how") aspects of information. Both aspects determine the structure of information (see Mowshowitz, 1992a for a detailed discussion). Information as ability has two complementary aspects: the ability to observe or experiment, and the ability to express beliefs. Information results from the combination of belief (or declaration) and command (or procedure). Declarative statements express believes about the state of the world. Procedural statements describe how to transform the world, and are embedded in procedures, algorithms, etc. Information is thus of the same class as knowledge and skills.

3.3.2.3 Representing information

The structure of information is independent of any particular representation of information. However, information must be represented to make it interpretable and communicable. A system of symbols and conventions must be available with regard to the different representations of information, such as natural language text, instructions in a programming language, graphs, charts, etc.

3.4 Definiton of information commodities

Mowshowitz (1992a) defines an information commodity as "a type of commodity which furnishes information (or the ability to decide and control)". To be a commodity an entity must meet two factors: appropriability and valuability. Appropriability is the capacity of being owned. Valuability is the capacity of being assigned a market value in some standard unit. To be an information commodity, the commodity must furnish information in some sense.

This implies that information commodities differ from traditional commodities only with respect to their contents. Information commodities "contain" or furnish information in some sense. However, they remain commodities, just as like other commodities, such as television sets, cars, bread, etc. So, information commodities can be treated in the marketplace similar to these commodities, meaning that it should be possible to assess their market value.

Examples of information commodities are information-related products, systems, and services. A distinction can be made between passive and active information commodities. This distinction is based on processing power. Books, magazines, and catalogues are examples of passive information commodities. Computer systems and on-line databases are examples of active information commodities, because they are capable of inferring new facts from items currently in the file.

3.5 Market value of information and information commodities

Information is an intangible with unique characteristics (see for example Cleveland, 1982). Special features of information in relation to economic analyses are also described by Boulding (1966), Hall (1981), Braunstein (1981), and Repo (1987). These features are related to problems and approaches with respect to assessing the value of information by Ahituv (1989).

The unique characteristics clearly show that information can not be appropriated or exchanged in the marketplace. This implies that it is impossible to determine the market value of information. In particular Cherry (1985) argued that information gives rise to sharing rather than exchange relations, since information is not lost or destroyed through ordinary use.

The appropriate element of analysis of economic value is the information commodity rather than information. Since information commodities can be appropriated or exchanged in the marketplace, it is possible to analyze its economic value. Insight concerning information (see Mowshowitz, 1992a, 1994) shows that the economic value of information is in fact the economic value of information commodities

The market value of information commodities behaves much like that of conventional commodities. According to Mowshowitz (1994) some information commodities are valued according to their age (e.g. a financial report), others according to their innovative design (e.g. software). All information commodities are subjected to the laws of supply and demand. Section 3.6 discusses the value-adding attributes of information commodities.

3.6 Value-added model of information commodities

The value of an information commodity derives from its capacity to furnish information. Its market value depends not only on the information content of the commodity, but on other factors as well. These other factors are related to carrying and accessing characteristics of information commodities. Based on this observation, Mowshowitz (1992b) developed the value-added model of information commodities. This model consists of the factors that determine the capacity of information commodities to furnish information. The value adding dimensions may be interpreted as the means for providing access to information.

The value-added model of information commodities consists of five major value adding dimensions, which can be used to classify information commodities:

1. kernel, consisting of:
    a. procedural information,
    b. declarative information,
2. storage,
3. processing,
4. distribution,
5. presentation.

An information commodity can be seen as a point in a five-dimensional space. The contribution to the market-value of a dimension varies with the information commodity. The value of a commodity could depend on its information kernel, but could depend on innovations in storage or presentation as well. The kernel of an information commodity is only one of the determinants of market value, not always the most important.

For a detailed description of the value-added model of information commodities, see Mowshowitz (1992b). This section will be limited to a brief description of the dimensions in the model. In the description the value adding dimensions of both paper-based information commodities (e.g. tender-documents, books, catalogues) and computer-based information systems (e.g. CAD systems) are illustrated. Here an information system is assumed to include hardware (incl. network-facilities), operating system, and application software.

Information kernel

The information kernel of an information commodity refers to the information furnished by it. The information kernel consists of an organized set of procedural and declarative statements. Traditional information commodities, such as tender-documents, books and catalogues, furnish mainly declarative information, while procedural information is the dominant feature in modern information commodities, such as CAD systems. Important features of the information kernel are indexing, arrangement, the structure of primitive elements (data structure), and the accuracy of data items in the kernel.

Storage

The storage dimension of an information commodity consist of both the medium used to store the information and the method used to gain access to the medium. Storage has been the most important aspect of traditional artifacts (such tender-documents, books and catalogues). The medium used is paper on which the information is printed. The information in CAD systems is stored mostly on media that can be handled by a computing device, such as the Random Access Memory (RAM), magnetic disks, optical disks, magnetic tapes, floppy disks, CD-ROM, etc. The main attributes of storage are: capacity, speed of access, re-usability, reliability, portability, and longevity.

Processing

The processing dimension of an information commodity refers to the ability to reorganize and represent the information carried by it. As mentioned earlier, tender-documents, books and catalogues are passive; the reader (human user) has to do whatever processing is needed. A CAD system, having a CPU[4], an operating system, and application programs can process and reconfigure information. Features of processing power are software-related (operating systems, compilers, etc.) and hardware-related (processors).

Distribution

The distribution dimension of an information commodity refers to the ability to provide access to the information, furnished by an information commodity. Traditional information commodities, such as tender-documents, books and catalogues do not have distribution-feature or their own; they are distributed by means of mechanical transport systems. These are slower than the electronic or optical transmission of information trough modern data communication systems, e.g. the network-facilities of CAD systems. The main feature of distribution is timeliness of delivery of information.

Presentation

The presentation dimension of an information commodity refers to the ability to display and represent the information to the user in a comprehensible form. Representation requirements vary with the type of user. If the user is human, the information can be presented in the form of natural language, text, or specially formatted numbers and symbols. Menu's, icons, and other "navigational" aids may also be used. If the user is a machine (or process) the information must be presented in a format which is accepted by the machine (or process). In that case, there is a need for a protocol and/or conventions for formatting information, which must be shared by both the sender and the receiver.

The information of tender-documents, books and catalogues are displayed on (printed) paper, while information of CAD systems is often displayed on monitors. So-called internal features of presentation on printed paper are page size, paper quality, type face, style and size of the font, page lay-out, etc. External features could be magnifying glass, special lighting, etc. Internal features for presentation by a CAD system are related to the display (size, resolution, chromaticity, etc.) or to the key-board (available functions, size and lay-out of keys, actions of keys, etc.). External features may include lighting and (ergonomic) placing of display and keyboard.

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[4] Central Processing Unit

3.7 Are CAD systems information commodities?

In the previous section (3.6) CAD systems were described as information commodities. See section 7.1 for a discussion and definition of CAD systems. If CAD systems represent a class of information commodities, it should be possible to asses their economic value. To be considered an information commodity, a CAD system must meet the two requirements of an information commodity. The first is appropriability and the second valuability (see Mowshowitz, 1992a-b).

CAD systems are information commodities (of a certain type), since they meet the two specified requirements. Each token (license) of a CAD system has an unique owner, who has purchased it. The same token can not be owned by any other owner, so a token of a system meets the requirement of appropriability. As (individual components of) CAD systems are traded, it is possible to determine both supply and demand value. So, the second requirement of valuability is met as well.

3.8 Conclusion

The fact that CAD systems are information commodities (of a certain type), facilitates analysis of their economic value. The various CAD systems differ with respect to their value adding dimensions. The value of CAD systems can be analyzed through analysis of the effects of their value adding dimensions on production processes. These effects can be measured in terms of cost-savings and quality-improvements. This research will consider the modelling of cost-effects of the use of CAD systems.

How to analyze the demand value of CAD systems (as information commodities) on a production process is another issue. The next chapter discusses an apparatus to model and analyze cost-effects of the deployment of CAD systems. This apparatus is termed the "production digraph model", and is based on graph theory.

Chapter 4
Modelling cost-effects

Chapter 3 shows that the value of CAD systems can be analyzed, using the value-added model of information commodities. This chapter describes how effects of CAD systems occur in production processes. Secondly, the production digraph model is introduced to determine the cost-effects of CAD systems on production processes. Finally, some costing issues are discussed, since the model is used for analysis of cost-effects.

4.1 Introduction

Chapter 3 shows that the market value of information commodities can be analyzed in terms of supply and demand. The market value of information commodities depends on the value from the perspective of the supplier (supply value), and on the value from the perspective of the user (demand value). This research restricts the analysis of value of information commodities to demand value (perspective of the user).

An information commodity can be desired for two reasons. It can be desired to be used in a production process, as a resource or production factor. This case is referred to as derived demand, since the information commodity is used to produce another commodity. On the other hand, an information commodity can be desired for consumption, which is referred to as final demand. This research is interested in the derived demand value of information commodities only.

Two approaches are possible in determining the derived demand value of an information commodity. The first, termed decision theory model, analyzes the role of an information commodity in decisionmaking. Applications of this approach are found in Marschak & Radner (1972) and Gotlieb (1985). The second, termed productivity model, analyzes the contribution of the information commodity to the productivity of the user.

This research applies the productivity model to determine the demand value of an information commodity, which is estimated as the maximum price (amount of money) the user is willing to pay for it. This draws attention to two important issues. The first issue relates to the measure of productivity. The production-costs are applied as measure of productivity, and the derived demand value is estimated by determining cost-reductions. Cost-reductions are considered to be the major component of the benefits. Another component of benefits is represented by new (or higher) revenues.

The second issue relates to the effects of information commodities on productivity. Ward et al. (1990) identified five main effects of computer-based information commodities on (business) processes. These are:

1. benefits within an activity, resulting from improvements in efficiency in the execution or processing of an activity of a business process,
2. benefits resulting from improvements in the exchange of information between the activities of a business process, termed value linking,
3. benefits resulting from speeding up the exchange of information between the activities of a business process, termed value acceleration,
4. benefits resulting from the redesign of business processes (re-structuring and re-arranging activities), termed value restructuring,
5. benefits resulting from better and more flexible servicing of customers, termed innovation value.

What is needed is a formal method to analyze the cost-effects of information commodities on production processes. Mowshowitz (1992c) introduced the production digraph to model costs of a process. A production digraph is as a collection of interrelated activities, which facilitate the modelling of costs by assigning weights to nodes and arcs. The resulting weighted production digraph allows analyses of cost-effects. The following description of the production digraph model is based on Mowshowitz (1992c). At the end of this chapter, cost accounting issues in relation with the production digraph model are discussed.

4.2 Production digraph model

For a detailed discussion of the production digraph model, see Mowshowitz (1992c). The graph theoretic terminology is based on Harary (1969). Figure 4.1 summarizes the terminology and the basic components of the production digraph.

Definition (Mowshowitz, 1992c):
P is a *production digraph*,
if: $P = P(V, E, a, z, c, w)$, where:
V is a set of vertices or nodes;
E is a set of directed edges or arcs joining distinct pairs of nodes
a is an unique node (the *source*) of indegree zero;
z is an unique node (the *sink*) of outdegree zero;
c is a function mapping V to the non-negative reals;
w is a function mapping E to the non-negative reals;
and: $O(x) = c(x) + I(x)$ for all nodes x in P, where:
$O(x)$ is the output of x, $O(x) = \sum w(xi)$ for all nodes i,
(i.e. the sum of weights of the arcs directed from node x);
$c(x)$ is the weight assigned to node x;
$I(x)$ is the input of x, $I(x) = \sum w(ix)$ for all nodes i,
(i.e. the sum of weights of the edges directed to node x);
and: ***P*** is *acyclic*.

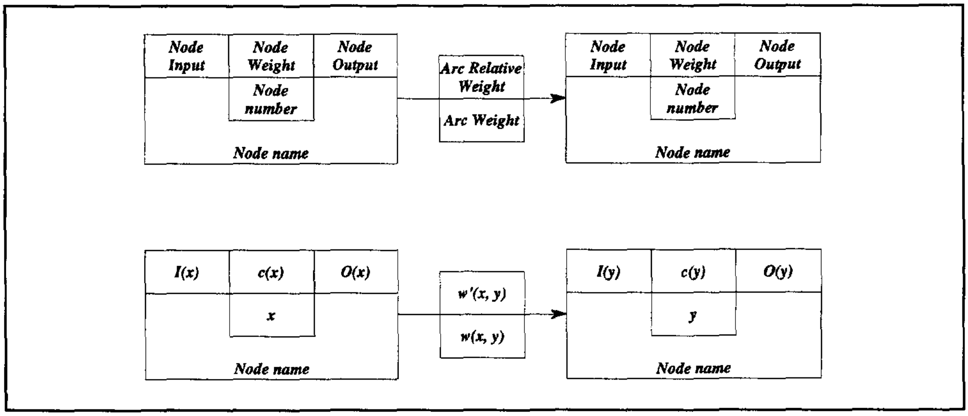

figure 4.1: terminology and basic components of the production digraph

The nodes of a production digraph represent the activities of a production process. An arc from node x to node y signifies a dependence-relation: the activity corresponding to node y requires input from the activity corresponding to node x in order to perform its function. The boundaries of the production process being modelled are set by an initiating and a terminating node: the source and the sink respectively.

The function c assigns a weight to each node, representing the property being modelled. In this case such a node-weight represents the costs of the processing performed within the activities on its input. The function w assigns a weight to each arc (directed edge) in the production digraph, which reflects the cost-relations. For example arc-weight $w(x, y)$ is the portion of the costs of the output of x that is allocated to y.

Production digraphs are formal structural models of the production-costs, based on graph theory. Although other properties can be modelled as well, production graphs are used to model production-costs mainly. An important feature of the production digraph is its graphical representation, which facilitates identification of differences. This makes it very suitable for systematic analysis of the effects of information commodities on production processes.

Figure 4.2 illustrates the use of the production digraph model. Suppose it represents a simplified example of the interacting activities and the costs of a building process. Such a representation is useful to analyze the cost-effects. For example, to analyze the cost-effects resulting from the use of specific software for design and detailing of prefab elements of concrete structures. Figure 4.3 shows the cost-effects due to the use of this software.

To avoid misunderstandings, it must be emphasized that the arcs represent cost-relations and do not deal with time-relations. An arc (x, y) represents only that node y requires input from node x. This does not imply that activity x must be completed before activities y. For example, figure 4.2 shows that the activity "construction" requires input from both the activity "design" and the activity "prefabrication". The conclusion is that the output of the activity "construction" includes the inputs from the activities "design" and "prefabrication", as well as the (processing) costs of "construction" itself.

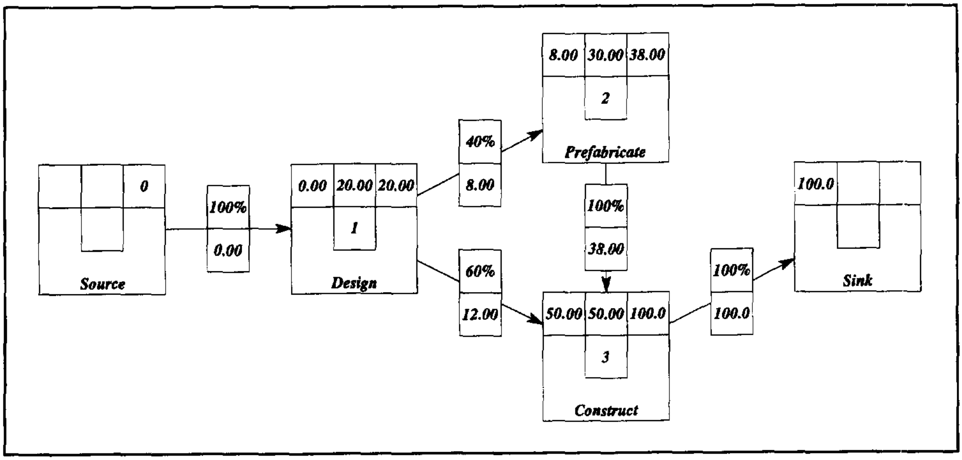

figure 4.2: production digraph of simplified building process

4.3 Constructing production digraphs

The detailed procedure for constructing a production digraph depends on the specific process which is being modelled. The differences refer to methods of data-collection mainly. However, there is a general procedure for constructing production digraphs, which consists of four steps (see Mowshowitz, 1992c):

1. analyze the production process and identify its constituent activities,
2. determine the interdependences among the activities identified,
3. determine the unit processing costs incurred by the activities,
4. allocate each activity's output costs to the activities depending on it.

The four steps aim to derive the two major parts of a production digraph: the structure and the weights. Steps 1 and 2 aim at determining the structure of the production digraph of the production process; steps 3 and 4 aim at determining the weights of nodes and arcs of the production digraph.

Constructing a production digraph involves considerable empirical effort. The effort required, depends on the knowledge of the process and its activities already available. Furthermore, the availability of cost-information, and the structure of the cost-information determine the empirical effort needed. An example of the empirical effort needed to model effects of information commodities on a production process is provided in Bellin (1991).

In particular, the determination of the relevant weights to model production-costs may require considerable empirical effort. This requires precise determination of the relevant costs, and obtaining the required cost-information. Considerable effort may be required also for reconfiguration of cost-information, because of inappropriate administration with respect to this type of use of the information.

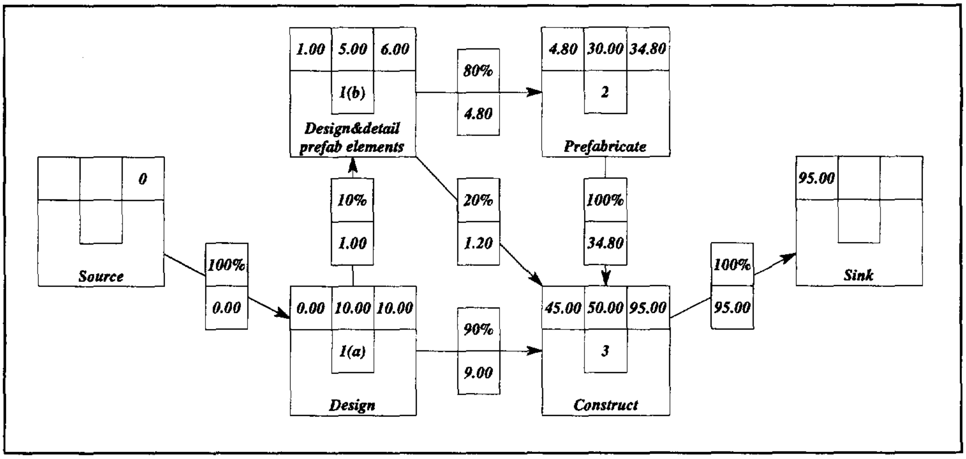

figure 4.3: changes in production digraph of simplified building process

The four-step procedure provides a good start for the construction of production digraphs. The detailed procedure followed in this research to construct production digraphs is described in chapter 8. It is tailored to the aim of this research: determining the cost-effects of CAD systems on structural design and construction. Perhaps the experience gained can be used to define the procedure for constructing production digraphs in greater detail.

4.4 Effects on the production digraph

Five types of effects can be modelled in a production digraph, either separately or in combination, to represent changes in the costs of a production process. The first effect refers to change in the processing within an activity of the process, resulting in change of the activity's costs, while cost-relations between activities remain the same. This change is modelled as an effect on the node-weight (corresponding to the activity), while the arcs are not altered. However, often the arc-weights following on the altered node-weights have to be re-adjusted to the new node-weight.

The second effect refers to modifications in the cost-relations between activities, e.g removal or addition of cost-relations. This is modelled as elimination or addition of arcs in the production digraph. Neither the set of nodes nor the node-weights are affected by this kind of effects. However, both the set of arcs and the arc-weights must be re-adjusted to the new situation.

The third effect refers to the separation of activities of the process into two or more separate activities. This involves complicated effects on the production digraph. Updates of both the set V of the nodes and the set E of arcs may be required. Often this means that the weighting functions c and w (the node-weights and the arc-weights) have to be modified as well.

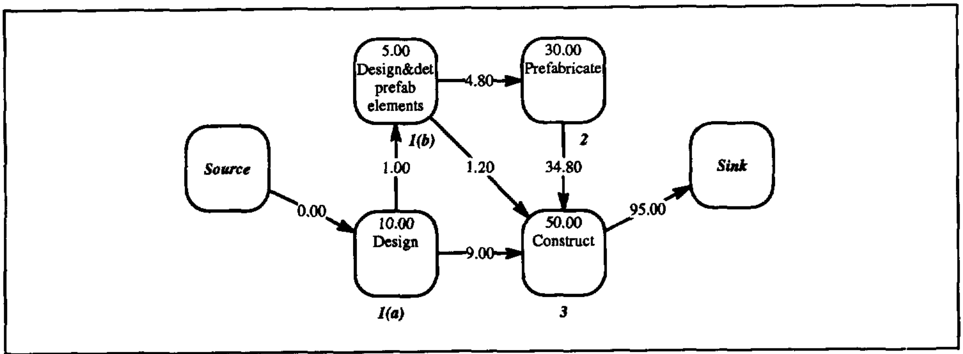

figure 4.4: production digraph of fig. 4.3 according to the conventions used in this thesis

The fourth effect refers to changes due to the combination of several activities to one activity. This is modelled as effects on the production digraph, which are similar to those needed for splitting activities into two or more separate activities. The set V of nodes, the set E of arcs, and the weighing functions c and w have to be modified.

The fifth effect refers to changes in activities in the process, resulting from the deletion of an existing activity or the addition of a new activity. This also involves complicated effects on the production digraph. The change requires modification of the set V of nodes, the set E of arcs, and the weighing functions c and w as well. An example of such effect can be determined by comparing figures 4.2 and 4.3. Figures 4.4 and 4.5 show the representation of production digraphs, as will be used in the remainder of this thesis.

4.5 Discussion of features of production digraph

One might get the idea that the production digraph is the same as a PERT chart (Program Evaluation and Review Technique) or a CPM chart (Critical Path Method) because of superficial similarities. A PERT-chart deals with time. Time needed for the processing of an activity, and time-relations between activities are modelled. The relations are precedence relations, meaning that an arc *(x, y)* implies that activities *x* must be completed before activity *y*.

A production digraph is not the same as a PERT-chart. A production digraph models the costs of processing within an activity and cost-relations between activities. The relations are not precedence relations but dependence relations. An arc *(x, y)* in a production digraph implies that node *y* requires input from *x*, without implying that activity *x* must be finished before activity *y*. For a detailed discussion of similarities and differences between PERT charts and production digraphs, see Bellin (1991).

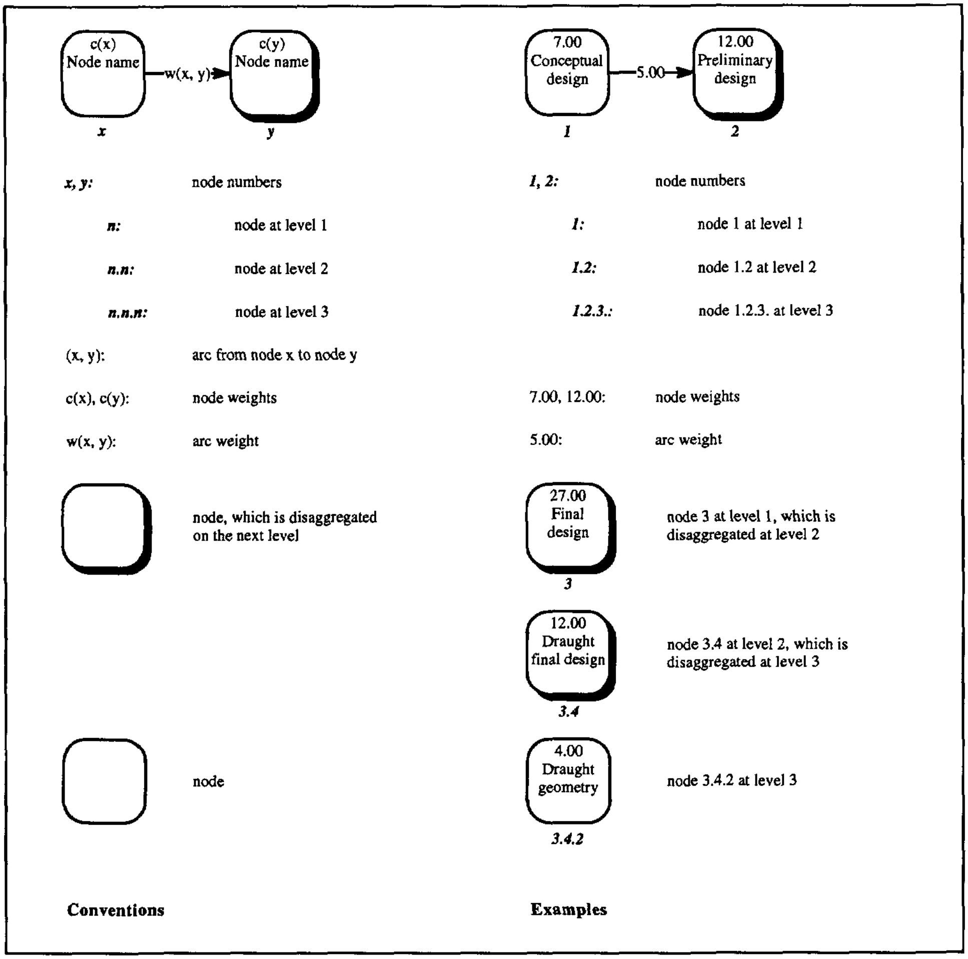

figure 4.5: conventions for representations of production digraphs, used in this thesis

4.6 Cost accounting and the production graph

4.6.1 Cost and management accounting

Several definitions of cost accounting are known, but the definition by Rayburn (1983) is perhaps the most complete: "That part of accounting which identifies, defines, measures, reports, and analyzes the various elements of direct and indirect costs associated with manufacturing and providing a good and/or service". In the process of accumulating costs for inventory valuation and income determination, the needs of external users and management are fulfilled. Cost accounting also provides management with accurate, timely information for planning, controlling, and evaluating company operations."

Cost accounting supports both financial accounting and management accounting, with emphasis on the latter. In fact it is hard to make a sharp distinction between cost accounting and management accounting. A proper definition of management accounting is provided by Kaplan (1982): "A system that collects, classifies, summarizes, analyzes, and reports information that will assist managers in their decision-making and controlling activities." This implies that cost accounting is that part of management accounting dealing with cost-information only.

Cost accounting aims at providing relevant cost-information for strategic and operational decision-making. By relevant is meant actual, useful, and accurate. The importance of cost-analyses is increasing in today's planning and controlling (management accounting). One of the central issues deals with the relation between costs, activities, and causes of costs.

Relevant cost-information draws attention to one of the fundamentals of cost-issues, which has been termed by Clark (1936): "Different costs for different purposes". Which costs are relevant is determined mainly by the aim of cost accounting. Furthermore, the object of calculation, the activities, and the resources used, are considered in determining which costs are relevant to the decision.

This research focuses on cost accounting that aims to support planning and controlling, with special emphasis on questions concerning efficient use of resources. In particular, effects of the use of information commodities on efficiency in business processes are examined. Which costs are relevant for these analyses will be discussed next.

4.6.2 Relevant costs

Costs are considered with respect to business economics; cost-issues related to the economy as a whole are excluded. From the business economics perspective costs are defined as: "sacrifices of production-resources, expressed in monetary measures". Often, processes or products (of these processes) are chosen as cost-objects in cost accounting.

The various perspectives on costs provide several cost categories (see for example Schroeff & Groeneveld, 1987). Fixed and variable costs on the one hand, and direct and indirect costs on the other hand are the two cost dimensions most often discussed in the literature. Since they are relevant to this discussion of cost accounting, they are discussed briefly below.

Whether costs are fixed or variable depends on the behaviour in relation to the level of activity or the volume of the object of calculation. Fixed costs are defined as costs which do not depend on changes in level of activity or volume (within a relevant time period and range). Variable costs do depend on changes in level of activity or volume (volume related).

Whether costs are direct or indirect depends on the existence of causal relations between the costs and the object of calculation. For direct costs a causal relation exist, while such a relation can not be identified for the indirect cost. However, it must be emphasized that a strict distinction between direct and indirect costs is not possible in practice; it is better to speak of a "level of directness" of costs (in relation to a calculation object).

With respect to the aim of this analysis (a type of managerial decision-making) the focus is on incremental costs rather than on absorbed costs. Incremental costs focus attention on the relation between causes, activities and costs. Of particular interest are the incremental costs caused by the use of a (new) information commodity. Incremental costs are costs, which depend on the different alternatives considered (e.g. with and without the use of an information commodity).

Incremental costs are either avoidable costs or opportunity costs. Avoidable costs are costs which do not appear if the alternative is chosen (e.g. the use of an information commodity). Opportunity costs can be defined as missed revenues, resulting from the choice for the next best alternative.

Sunk costs are not incremental. Sunk costs result from decisions made earlier. They are not relevant since they are not affected by current managerial decision-making. For example, depreciation of computer hardware is not affected by decision-making concerning the use of some specific software.

Fixed costs can be seen as an example of sunk costs. Fixed costs do not depend on changes in level of activity or volume (within a relevant time period and range). They are not very likely to be affected by the use of an information commodity within a short period of time. Often fixed costs are considered to be period costs.

Two types of costs are distinguished in processes: material costs and conversion costs. This research considers mainly conversion costs, since there are hardly any costs for material costs in structural design processes. Secondly, only minor effects are expected on the material costs of the production processes considered in this research.

The incremental conversion costs in production consist of direct and indirect costs in relation to the object of calculation. One of the central issues in the analyses deals with the relation between costs, activities, and causes of costs. What is needed is a cost accounting method which will account for these relations as accurately as possible.

4.6.3 Cost accounting methods

Two classes of cost accounting methods are of particular interest to modelling costs using production digraphs. Boons et al. (1991) refer to them as Product Based Costing (PBC) and Activity Based Costing (ABC). They differ with respect to the assignment of costs to cost-objects, in particular the indirect (conversion) costs.

The first class, Product Based Costing (PBC), allocates costs directly to products, using volume-based drivers. Cost-allocations are arbitrary rather than based on strictly causal relationships. Although based on fair and reasonable assumption of relationships, allocations do not lead to accurate costs. This holds in particular with regard to the indirect costs.

Several product based cost accounting methods are used, each having a specific solution for the allocation of indirect costs to cost-objects. Most of these methods couple the allocation of indirect costs to direct costs. The direct costs are raised to account for the indirect costs. The raise can be determined using several raise-procedures.

Although not really a PBC-method, the cost-centre-method is often applied as such in practice. This method uses a four-step allocation procedure, with several cost-drivers, and intermediate cost-objects to allocate costs to products. This enables a more accurate allocation of indirect costs to products than the PBC-methods mentioned above.

The second class, Activity Based Costing (ABC), traces costs or allocates costs to products, using several cost-drivers and intermediate cost-objects. To trace costs means that cost-allocations are based on strictly causal relationships between cause of the costs and the cost-objects. In practice this is not always possible, but ABC aims to allocate costs to products as good as possible in accordance with causal relations. ABC stresses the importance of activities in relation to costs. Activities are considered to induce costs rather than cost-objects. ABC uses several (intermediate) cost-objects rather than one cost-object.

Cooper and Kaplan introduced ABC, as a result of their criticism on traditional product based cost accounting (see Cooper, 1988a-c, 1989). Some argue that ABC is not new, but has been rediscovered after the introduction of the work of Porter (1985). After its introduction much has been written about ABC. Good reviews are provided by Boons et al. (1991), Innes & Mitchell (1990), and Werre (1992).

4.7 Conclusion

ABC is appropriate for proper analyses of effects of information commodities on production costs. ABC provides accurate costs since it traces costs or allocates costs as good as possible (based on causal relations) to products or cost-objects. Hence it draws attention to incremental costs, focusing in particular on the causes of costs.

Furthermore, ABC is complementary to the production digraph model, since both use activities as basic element. The starting point is the definition of the major activities in a production process. Based on these activities, ABC lays out the cost-structure of a production process, which can be modelled effectively with the production digraph. Value-added and non-value-added activities (see Porter, 1985) can be identified, which may lead to improvement in the efficiency of the production process. Together they provide a sound basis for analyses and managerial decision-making concerning the use of information commodities in production processes.

Chapter 5
Structural design and construction

This chapter discusses the specific characteristics of the building process. The several phases and activities of structural design and construction of concrete structures are determined. These are required for construction of production digraphs.

5.1 Building process

Structural design and construction are important parts of every building process. Much has been written about the specific features of the building process when compared with other (industrial) production processes. Wagter & Vos (1989) for example characterize building processes as unique, situation-dependent, segmented, and multi-disciplinary. These characteristics relate to the nature of the structure (as the final product), the project-organization, and the design and construction technologies applied.

Building processes deliver structures, which are unique products, fixed to a specific location. There is a wide variety in the nature of structures, which can be distinguished on several aspects. In the first place, on the function they perform, such as houses, offices, industrial buildings, bridges, tunnels, and fly-overs. Secondly, on the material they are constructed of, such as steel structures, concrete structures (reinforced, prestressed, high-strength, lightweight, etc.), and timber (wooden) structures. Thirdly, on the size and complexity of the structure, for example houses in contrast with offshore oil-production platforms.

The structure is realized by a project-organization, which is formed for each building process. Such a project-team is determined by (a representative of) the client and is influenced by the nature of the structure, and the design and construction technologies involved. The building process is segmented, while several disciplines are involved and all important stake-holders are represented. Furthermore, the project-organization differs for each building project.

The current segmentation and the multidisciplinary features of the building process are the result of historic development. In medieval times a structure was realized by a master builder and craftsmen. Due to the increased specialization of the participants, the decreased skills of labourers and other social changes the building process has developed to what it is now. The historical development from the organization of master-builder and craftsmen to the current organization is briefly described in Zutphen et. al (1991).

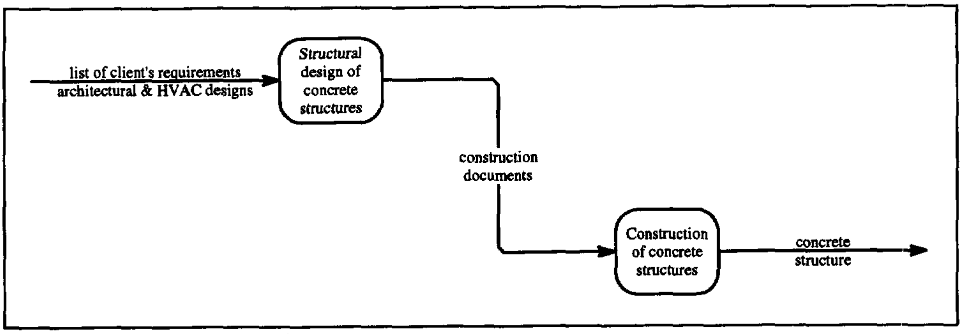

figure 5.1: structural design and construction

Finally, the building process involves various design and construction technologies. The use of a specific technology can alter the building process seriously, such as the changes resulting from the use of the prefabrication technology. It is expected that the use of new technologies will have at least a similar impact on the building process. Examples of new construction technologies are Computer Aided Manufacturing (CAM), robotics, machine learning, and other related technologies. New structural design technologies include artificial intelligence (knowledge technology), object oriented programming, neural networks, database management, parallel processing, and visualisation of design. The developments and anticipated impacts are discussed by Adeli (1992).

It would be impossible to consider the whole building process in this research. Since concrete is an important material in construction, the research focuses on structural design and construction of concrete structures. A general representation of this process is provided in figure 5.1. This research studies both structural design and construction, since it is expected that use of CAD systems affects structural design as well as construction. In particular the construction of reinforcement, which involves the production and fixing of reinforcing bars (rebars) is considered in this research (see figure 5.2).

5.2 Current design and construction of concrete structures

A vast body of literature is available on structural design and construction of concrete structures in the Netherlands. The use of CAD systems in these processes is discussed in a CIAD[5]-report (Spanje & Toepoel, 1989) and a set of publications, initiated by Vos (1989). Recently another report was delivered by CUR[6]/CIAD/SITRUB[7] (Buvelot, 1994) on the use of IT in structural design and construction of reinforcement. Furthermore, another set of publications, introduced by Kooiman et al. (1992), discussed problems related to the construction of reinforcement.

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[5] Association for Computer Applications in Applied Engineering (in the Netherlands)

[6] Centre for Civil Engineering Research and Codes (in the Netherlands)

[7] Sectoroverleg Informatie Technologie RUwbouw Beton (in the Netherlands)

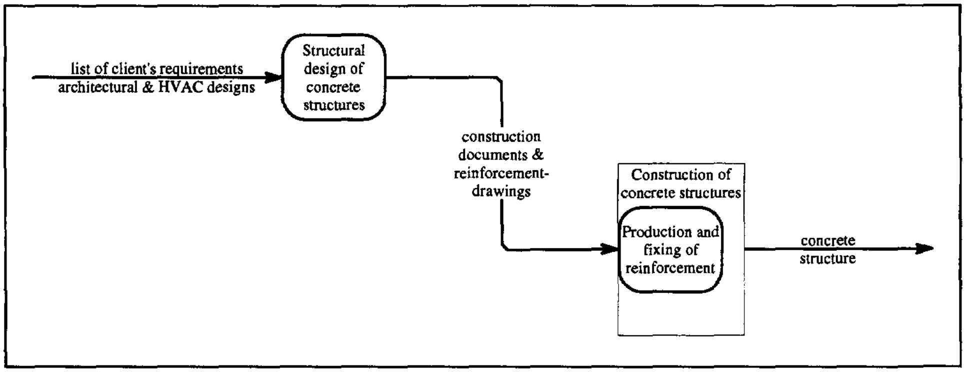

figure 5.2: structural design and construction of reinforcement

The discussion in the remainder of this chapter is based on this literature. These descriptions of the design and construction process of concrete structures were checked in interviews with experienced structural designers. Furthermore, they were checked in interviews with the staff-members at the engineering consultants and reinforcement-subcontractor during the case-studies.

The current processes in the Netherlands (as represented in figures 5.1 and 5.2) are described according to three main characteristics. The first is the type of project-organization. The second refers to the several (intermediate and final) products of the processes. The last focuses on the design and construction technologies used. These characteristics are elaborated in this section.

Project-organization

In a traditional project-organization at least three participants are involved (see figure 5.3): the engineering consultant, the contractor, and the reinforcement-subcontractor. The engineering consultant is responsible for the structural design of the structure. In this process, the client is often represented by the engineering consultant. The contractor is responsible for construction of the structure. With regard to reinforcement the contractor has a coordinating role and interfaces with both the engineering consultant and the reinforcement-subcontractor. Finally, the reinforcement-subcontractor is responsible for a part of the construction: the construction of reinforcement.

The different participants aim at efficiency in their individual activities in the process, which are focused on the production of prescribed interface products. Examples are drawings, tender-documents, etc., which are still document-based. Occasionally informal interfacing occurs through phone or fax. With regard to reinforcement, the contractor coordinates the construction, but does not use the reinforcement-drawings. These are conveyed to the reinforcement-subcontractor to be used for production and fixing of rebars.

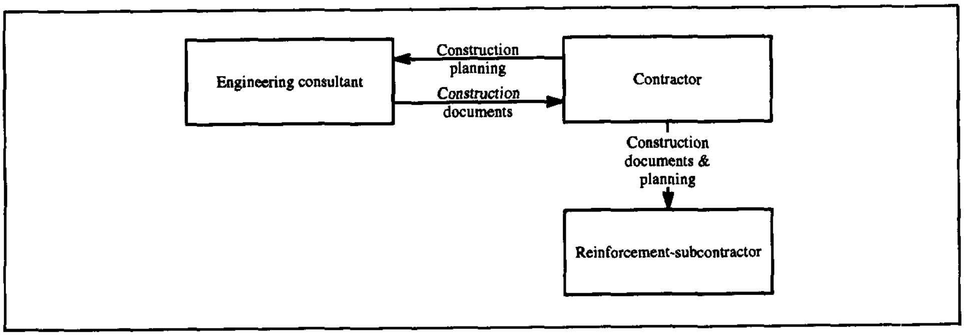

figure 5.3: participants in structural design and construction

Products

Several intermediate and final products can be distinguished in structural design and construction. In structural design the output of a design phase consist of intermediate products (documents), since they are used in the next phase for further detailing of the design. The output of structural design consist of documents, which are used in construction. These documents, such as reinforcement-drawings specifying information for the production and fixing of rebars, are the final products of structural design.

Intermediate products in construction of reinforcement are documents, such as modified reinforcement-drawings and bar-bending-schedules. Other intermediate products are rebars or reinforcing nets, which are prefabricated in a factory. The final product is the fixed reinforcement on site, consisting of the rebars and reinforcing nets. The documents are used for fixing the reinforcement. There is a wide variety in reinforcement, rebars, and nets with respect to the shapes and diameters used.

Technology

One of the main technologies used in current structural design is represented by CAD systems. CAD systems are applications of modern information technology, which are used to aid designers and draughtsmen in the design and detailing of concrete structures and reinforcement. Several different CAD systems are available, which are discussed in chapter 7 of this thesis. CAD systems do not only alter structural design. Construction is altered as well, if complementary construction technologies are used, such as CAM systems.

Advanced construction technology is represented by CAM systems and related Numerical Controlled (NC) machines. These technologies are used in the current construction process of reinforcement, especially in the production of rebars in factories. Rebars are produced, using advanced NC-machines for cutting and bending. The machines are connected to a CAM system via a computer-network, through which instructions are provided. Another example of construction technology is represented by robots. In Japan for example, robots have been developed for the positioning and fixing of rebars on site.

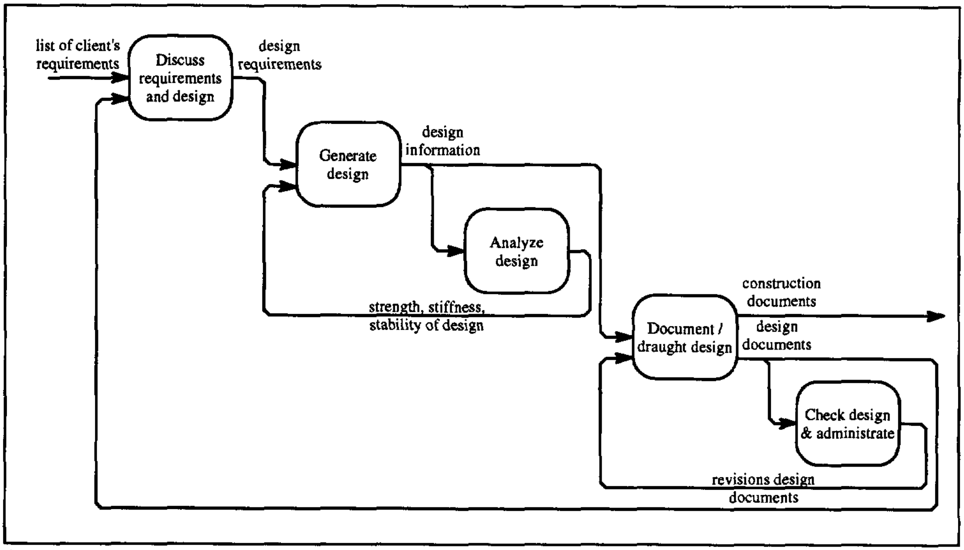

figure 5.4: generic representation of structural design

5.3 Structural design

5.3.1 Characteristics

This discussion is based on the description of the structural design process for civil structures by Chandansingh (1994). A generic representation of structural design is provided in figure 5.4. Input to the process consists of the list of client's requirements and information from others, e.g. architects and designers of HVAC[8]. The output of the structural design process consists of documents, such as drawings, to be used for construction. There are some specific characteristics of structural design which need to be stressed here.

Design methodology, techniques, and aids

Structural design is an heuristic process, which is difficult to formalize. It is a creative process, with "brainstorms" and many iterations. It is based on knowledge, experience, intuition and feeling. Especially in the initial phases of the structural design process, when solutions are generated rather quickly. Only for rather complex structures, such as oil-production platforms, this pragmatic approach is combined with a structured design methodology.

In the initial phases of design "rules of thumb" are often used, together with other traditional design-aids, such as tables, etc. Nowadays, structural design is supported by modern computer-based tools, such as CAE systems. The traditional draughting-tools are gradually being replaced by CAD systems, which provide support for draughting and other additional functions.

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[8] Heating Ventilation and Air-Conditioning

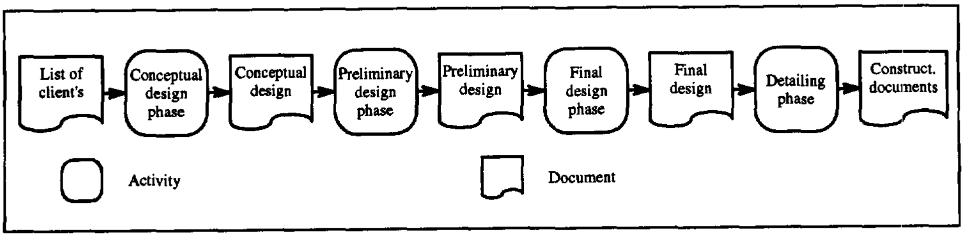

figure 5.5: phases and products in structural design

Interfacing

Structures are often designed under extreme time-pressure, while a lot of interfacing is required with other designers. In parallel to the structural design, the architectural design and HVAC-design are developed. Furthermore, the planning of construction by the contractor is done in parallel to structural design, while the construction methodology of the contractor has to be considered during structural design. The multi-disciplinary nature of design requires an extensive interfacing with other designers and the contractor. During the interfacing the designs are discussed and geared to one another. Furthermore information is often obtained for further detailing of the design.

Activities

Discussion, design, analysis, and documentation are the main activities in structural design. By analogy with the separation between design and construction, a separation has occurred within the structural design as a result of increased specialization. Nowadays, the structural engineer is responsible for design and analysis, while the draughtsman represents the design in drawings. Fortunately, there is a close relationship between structural engineers and draughtsmen, and some overlap in activities. Sometimes the activities are combined and performed by a structural engineer / draughtsman, especially when CAD systems are involved.

5.3.2 Phases in structural design

Structures are designed in several phases. The design develops from a preliminary sketch to detailed drawings through a series of phases. The activities mentioned above are performed in each stage. However, the intensity of the activities differs as a result of differences in the required level of detail of the design for each phase. The end of a phase marks a point for formal decision-making based on prescribed outputs. The design is evaluated, and choices are made concerning technical, financial, and aesthetic aspects. Finally it is decided whether to proceed or stop with the design of the structure.

Although sharp distinctions between phases are hard to make, four major phases in the structural design can be determined: the conceptual design phase, the preliminary design phase, the final design phase, and the detailing phase. The phases and related intermediate products of this generic distinction are provided in figure 5.5. However, often design phases are combined, for example the conceptual and preliminary design phase. Furthermore, the phases are executed successively, but iterations do occur based on feedback from "later" phases.

Next the different phases are discussed briefly, focusing on the objective, input and output of each phase. The activities of each design phase are described in table 5.1, while table 5.2 provide descriptions of the (sub-) activities of the different draughting activities in the structural design process. These activities are based on literature (mentioned in section 5.2), interviews, and observations. The descriptions of the activities consist of specification of the objective and the procedure of the activity. The procedure includes descriptions of input, output, and use of resources.

The conceptual design phase

Input for conceptual design is the list of client's requirements. Sometimes drawings of the architectural design are provided as well. This is often the case when the design of office-buildings is coordinated by an architect. The objective is the generation of alternatives, consisting of a structural system (or concept), specification of construction-material, and shape and main sizes of structural elements and key details. The output consists of several alternative conceptual designs, presented in sketches or indicated on the architectural drawings.

The preliminary design phase

Input for preliminary design is the conceptual design chosen at the end of the previous design phase, often complemented with additional information. The objective of the preliminary design is determination of the main sizes of structural elements and key details. This includes analysis of the preliminary design to check whether it meets the requirements concerning strength, stiffness, stability, and durability. Output is the preliminary design, often represented in preliminary design drawings.

The final design phase

The preliminary design is input for the final design, while additional information is provided as well. The objective is to provide an accurate description of the structure in the tender, which is used as a contract-document between the client and the contractor. The final design includes determination of all relevant sizes of elements and key details and analysis to check whether the requirements are met. Output is a detailed documentation of the structure in tender-specifications and final design drawings.

The detailing phase

The input for the detailing phase is the final design and additional information. The objective is to detail and specify all elements and key details in order to get it constructed. The detailing phase includes (detailed) analysis, and design and detailing of reinforcement. The output consists of documents, such as drawings and schedules, which are used for construction of the structure. These documents are very detailed.

table 5.1: activities in structural design

STRUCTURAL DESIGN		
PHASE / Activity	**Objective of activity**	**Procedure of activity**
CONCEPTUAL DESIGN		
Discuss requirements	Obtain additional information and determine requirements and constraints for the conceptual design phase.	Structural engineer discusses the client's requirements with the architect or client.
Generate conceptual design	Determine structural system, construction-material, shapes and sizes of structural elements.	Structural engineer generates alternatives and presents the designs roughly in sketches.
Analyze design	Check and select one conceptual design (or a few conceptual designs).	Structural engineer analyses alternatives, estimates costs of the structure, and evaluates the designs.
PRELIMINARY DESIGN PHASE		
Discuss conceptual design	Obtain additional information and select a conceptual design.	Structural engineer discusses the conceptual design with the architect
Generate preliminary design	Determine main sizes of structural elements and key details.	Structural engineer determines the sizes, based on experience and rules of thumb.
Analyze preliminary design	Check whether requirements concerning strength, stiffness, stability, and durability are met.	Structural engineer analyses the preliminary design, using design-aids and/or computers.
Draught preliminary design	Represent main sizes of the design of the structure.	Draughtsman produces drawings of preliminary design and checks them. Often these drawings are not made for small structures. In that case the main sizes of the structure are represented on preliminary design drawings of the architect.
FINAL DESIGN PHASE		
Discuss preliminary design	Obtain additional information for the final design.	Structural engineer discusses the preliminary design with the architect and the HVAC-designers.
Generate final design	Determine all relevant sizes of structural elements and key details.	Structural engineer determines the relevant shapes and sizes.
Analyze final design	Check whether requirements are met (code-checking) and provide information for detailing.	Structural engineer analyses the complete structure, using FEM-analysis, etc.
Draught final design	Represent all relevant sizes of structural elements and key details.	Draughtsman produces the final design drawings and checks them. These drawings are a part of the tender.
Write & check tender	Describe the structure as accurate as possible in the tender (contract document for construction).	Structural engineer estimates the quantities of material, estimates construction costs, documents the structure in tender, and checks the tender. The tender includes the final design drawings.

DETAILING PHASE		
Discuss final design	Obtain additional information and gear structural design to other design-activities.	Structural engineer discusses the final design with the architect, HVAC-designers, and contractor.
Generate detailed design	Determine size of key details.	Structural engineer generates alternatives for structural details.
Analyze detailed design	Check detailed design and determine the amount of reinforcement.	Structural engineer analyses detailed design and determines the reinforcement.
Draught detailed design	Specify all elements and details for construction.	Draughtsman produces the detailed design drawings and checks them. The drawings are based on the final design drawings and the detailed design drawings of architects. The detailed design drawings have a higher level of detail (geometry and sizes) than the final design drawings. They are used by the (main) contractor to design formwork.
Draught reinforcement	Specify the reinforcement for construction.	Draughtsman designs reinforcement according to specifications of the structural designer, produces the drawings and checks them. These drawings are based on the detailed design drawings.
Check design & construction	Assure quality of drawings and construction according to the drawings.	Structural engineer checks and approves the drawings and structural design activities of others, and checks on site whether the structure is realized according to the drawings.

table 5.2: activities in draughting

DRAUGHTING		
Activity	**Objective of activity**	**Procedure of activity**
Study drawings & schedule draughting	Determine number and type of drawings, and schedule draughting.	Draughtsman studies previous drawings and additional information, determines the number and type of drawings, and schedules draughting.
Draught geometry	Represent the structure's geometry.	Draughtsman chooses a drawing-size and scale and draught the geometry.
Mark sizes	Indicate the sizes of the structure.	Draughtsman determines the relevant size and indicates them on the drawings. The sizes are related to the representation of the structure's geometry.
Finalize drawings	Complete the drawings.	Draughtsman adds descriptions and features to the drawings to improve proper interpretation. Information concerning the responsible structural engineer and the status of the drawings is added as well.
Check & administrate	Assure the quality of the drawings, and file and administrate them.	Draughtsman checks, files, and distributes the drawings, and takes care of the necessary administration.

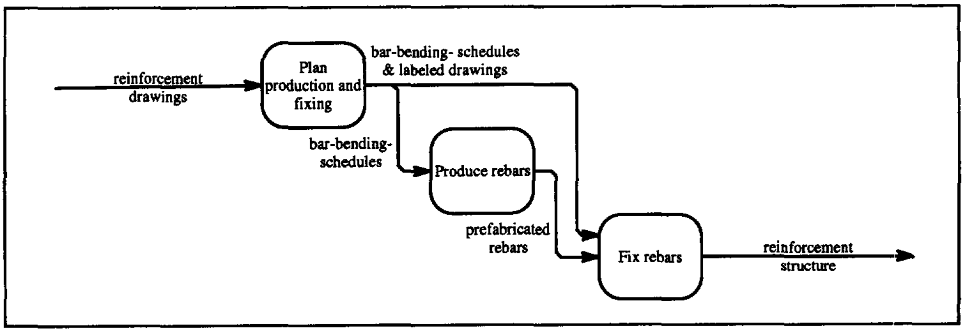

figure 5.6: construction of reinforcement

5.4 Construction of reinforcement

5.4.1 Characteristics

The construction process of reinforcement is presented in figures 5.6. Input to this process consists of the reinforcement-drawings made by the engineering consultant and provided through the contractor. Output of the process is the complete reinforcement for the concrete structure, ready in the formwork, just before approval for pouring the concrete. Some characteristics and specific problems are discussed here.

Production methodology, techniques, and aids

Construction of reinforcement is a quite straightforward process. The scheduling of this process requires experience (knowledge) of the fixing of reinforcement in particular. The fixing of reinforcement is labour-intensive, and is still done in the traditional way. However, the production of rebars has changed. Reinforcing bars (rebars) are not produced in the traditional way - on the construction site - any more, but prefabricated in a factory. Advanced computer controlled machines for cutting and bending of reinforcement are used there. These machines are connected to the CAM system via a computer-network.

Interfacing

Construction of reinforcement is influenced strongly by the planning and progress of construction activities of the contractor. Especially the fixing of reinforcement is critical in every project and is subjected to extreme time-pressure. On top of that, often relevant information is too late available for the reinforcement-subcontractor. This holds not only for the reinforcement-drawings, but for planning-information as well.

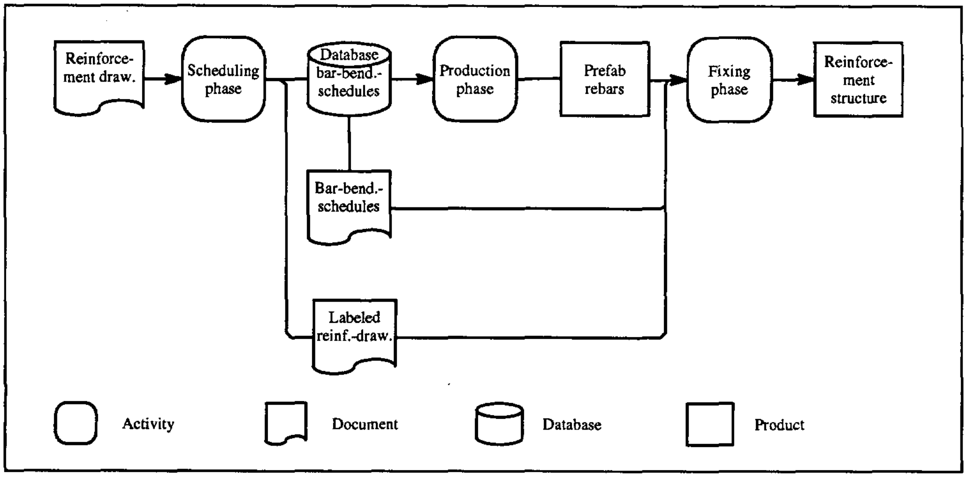

figure 5.7: phases and products in construction of reinforcement

Problems related to inappropriate design of reinforcement often occur. Formally, the reinforcement-subcontractor is not allowed to discuss these problems with the engineering consultant. The problems must be discussed via the contractor, which takes a lot of time and effort. Fortunately, the contractor may allow the reinforcement-subcontractor to discuss these problems with the engineering consultant directly. In some cases the reinforcement-subcontractor is consulted by the engineering consultant, concerning the design of reinforcement.

Activities

The various activities are discussed per phase in the next section. One of the main activities is the production of the bar-bending-schedules in the scheduling phase. All other activities in the construction process of reinforcement have the bar-bending-schedules (and drawings) as input. These schedules provide information for both production and fixing of reinforcement. Knowledge about the fixing of reinforcement is essential for the production of bar-bending-schedules. That is why this activity is performed by staff-members with (previous) experience in the area of fixing of reinforcement.

5.4.2 Phases

The construction process of reinforcement consists of three operational phases: the scheduling phase, the production phase, and the fixing phase. The phases, together with the intermediate and final products are represented in figure 5.7. The activities are based on literature (mentioned in section 5.2), interviews, and observations. Descriptions of the different activities for each phase are described in table 5.3. The (sub-)activities in the production of bar-bending-schedules are provided in table 5.4, since they will be studied in-depth.

table 5.3: activities in construction of reinforcement

CONSTRUCTION OF REINFORCEMENT		
PHASE / Activity	**Objective of activity**	**Procedure of activity**
SCHEDULING PHASE		
Produce bar-bending-schedules	Check the reinforcement and determine the properties of the rebars to facilitate production and fixing.	Bar-bending-scheduler checks the reinforcement-drawings, determines the properties of rebars, annotate the rebar-labels on the drawings, inputs the information in a database, and checks the information.
Schedule production	Optimize the production of rebars and improve efficiency of production.	Production-scheduler checks the bar-bending-schedules in the database, optimizes production, prepares rebar-labels, and transfers information to the production units.
Schedule fixing	Determine the period of fixing and the required resources.	Manager determines the fixing-time available, the number of fixers needed, the use of equipment, etc.
Schedule transport to site	Optimize transport of produced rebars from the factory to the several sites.	Production-scheduler determines transport-schedules, optimizes transport, and prepares the documents.
PRODUCTION PHASE		
Transport rebars (intern)	Get the different intermediate products from one production unit to another.	Labourers transport the raw material and intermediate products to the several production units in the factory: cutting units, bending units, and storage /loading units.
Cut rebars	Deliver rebars with the appropriate length.	Labourers cut rebars of appropriate length from the raw-material, using advanced (automatic or semi-automatic) equipment. The raw-material is delivered as bars or as rolls.
Bend rebars	Produce rebars with the appropriate shape.	Labourers bend the rebars into their appropriate shapes, using advanced (automatic or semi-automatic) equipment.
Check and administrate	Assure the quality of rebars and take care of administration.	Production manager checks the produced rebars to verify if the required quality is achieved, and takes care off the necessary administration.
Transport rebars (to site)	Get the rebars to the site for fixing.	Labourers load the rebars on trailers. The rebars are transported to the several sites.
FIXING PHASE		
Prepare fixing	Check the rebars and organize fixing.	Chief-fixer checks delivered rebars and studies the documents. Tasks are assigned to the fixers.
Transport rebars on site	Get the rebars to the appropriate places on site.	Fixers transport the rebars to appropriate places on site, sometimes using a crane.
Fix rebars	Produce the reinforcement-structure.	Fixers lay out the rebar and connect (fix) them to form the reinforcement-structure.
Check and administrate	Assure the quality of reinforcement-structure and take care of administration.	Chief-fixer checks the quality of the reinforcement-structure, and administrates.

table 5.4: activities in production of bar-bending-schedules

PRODUCTION OF BAR-BENDING-SCHEDULES		
Activity	**Objective of activity**	**Procedure of activity**
Study drawings	Check comprehensiveness, correctness, and accuracy of drawings, and gain insight in the structure of the reinforcement.	Bar-bending-scheduler studies the reinforcement-drawings.
Study rebars	Gain insight concerning individual rebars.	Bar-bending-scheduler studies the individual rebarson the drawings.
Annotate drawings	Label the rebars on the drawings for identification during fixing.	Bar-bending-scheduler labels the rebars on the drawings in a certain order. The labels are used for identification bars during fixing. Furthermore they denote some form of fixing sequence.
Determine rebar sizes	Determine the properties of rebars to be used for the production.	Bar-bending-scheduler determines the number, shape, diameter, and sizes of the rebars from the drawings.
Note rebar	Write down the properties of the rebars during determination.	Bar-bending-scheduler notes the properties of the rebars, which will be used for input in the database.
Input rebars in database	Store the properties in a database.	Bar-bending-scheduler inputs the properties into the database, based on the notes.
Check and administrate	Assure the quality of the bar-bending-schedules and administrate.	Bar-bending-scheduler prints and checks the bar-bending-schedules, and administrates the drawings and related bar-bending-schedules.

The scheduling phase

Input to the scheduling phase are the reinforcement-drawings. In addition planning-information, which is essential for scheduling of production and fixing of rebars, is provided by the contractor. Often this information is provided rather late. The objective of this phase is the production of bar-bending-schedules and scheduling of production, transport, and fixing of rebars. The output consists of the bar-bending-schedules with the related drawings, annotated with rebar-labels for fixing. Nowadays, the bar-bending-schedules are stored in a database, which is accessible for the production of rebars. A hardcopy of these schedules and the drawings are used for fixing of rebars.

The production phase

Input to the production phase are the bar-bending-schedules, which are stored in a database. The objective is the preparation and the production of rebars. This phase includes preparation of cutting-lists, bending-lists, and rebar-labels. Production includes cutting, bending, internal transport, quality control, administration, storage, and (external) transport to the site. The output consist of prefabricated rebars, ready to be fixed on the construction site.

The fixing phase

The input to this phase consists of the bar-bending-schedules, the related drawings, and the prefabricated rebars. This phase's objective is to fix the rebars on site. It includes checking the delivered rebars, preparation, transport on site, fixing, quality-control, and administration. The output is the reinforcement, ready in the formwork.

5.5 Conclusion

This description of structural design and construction processes provides a start for modelling cost-effects. For example cost-effects resulting from the use of CAD systems. The description is based on current literature, interviews with experienced structural designers, and discussions with the staff-members at the engineering consultants and reinforcement-subcontractors, which participated in this research. The important phases and activities of structural design and construction are included.

This description will be used to construct initial production digraphs of the structural design and construction processes. Chapter 6 discusses these production digraphs, together with the modelling objectives and a discussion of the relevant costs. When needed the phases and activities provided, will be studied in detail.

Chapter 6
Production digraphs of structural design and construction

This chapter discusses the objectives of production digraphs of structural design and construction. The production digraph model is applied to structural design and construction to model production-costs. Generic production digraphs of both structural design and production of bar-bending-schedules are provided. They will be used to model the cost-effects of CAD systems.

6.1 Modelling objectives

Costs associated with structural design and construction must be modelled to analyze cost-effects of CAD systems. This model must clarify all costs and cost-relations between the activities in the process. In particular, the model must show the costs for each individual activity of the process.

Costs for each individual activity consists of both costs of input required to carry out the activity and costs of performing the activity. The first is related to cost-relations or interactions with other (previous) activities. The latter is related to the costs of the individual activities. Often the costs of input are overlooked in cost-analyses, but are significant in the analysis of cost-effects of CAD systems.

The model should improve understanding of costs and cost-relations in the process. It should be able to show the costs of resources from three perspectives. Firstly, as costs associated with input required to perform an activity. Secondly, as costs associated with the costs of performing the activity. Finally, as costs associated to the output of the activity to other activities.

The costs of structural design and construction can be modelled by the production digraph model, discussed in chapter 4 of this thesis. Examples of application of the production digraph model to structural design and construction are provided by Chandansingh & Vos (1993a-b). The major activities of a process are represented by nodes, while node-weights are used to represent the costs associated with performing the activity. The cost-relations are represented by directed edges or arcs between activities. An arc between two activities exists only if there is a cost-relation between the activities. The arc-weights represent the costs allocated from one activity to another.

Apart from appropriate modelling of costs, production digraphs have some other important features. These features are the graphical representation of the production digraphs and the directed acyclic characteristic of the production digraphs. These features enable the representation of process-costs in a way that makes perfect sense for managers.

The directed acyclic feature simplifies the analysis of the graphs, since it removes complex interaction effects. However, this requires the elimination of every possible cycle in the production digraphs. This can be done quite systematically as shown by Bellin (1991).

A production digraph has two basic components: the structure and weighting-functions (see also chapter 4). The structure illustrates the relevant activities in the process and their cost-relations. The weighting-functions allocate costs to the nodes and arcs. A general structure of the graph can be constructed for a class of processes. However, the weighting-functions refer to the costs of an individual process.

6.2 Relevant costs

In chapter 4 the concept of "different costs for different purpose" (Clark, 1936) was already discussed. The analyses of cost-effects of CAD systems are used mainly to support short-term planning. In this type of analysis, the incremental costs with respect to the use of CAD systems are relevant. In particular, the avoidable costs and the opportunity costs, related to the execution of activities. This excludes costs related to the input of material, such as steel for reinforcement, etc.

6.2.1 Structural design

The relevant costs of structural design with respect to the use of CAD systems consist of labour costs mainly. Current structural design is a labour-intensive process. The labour-costs are much larger than costs associated with the use of equipment. Furthermore, the latter are sunk costs, e.g. the costs of so-called drafting-boards, etc. The labour costs are affected by the use of CAD systems, and seem to be the only relevant costs.

The labour-costs of structural design are modelled in production digraphs. However, to be able to compare cost-effects, relative rather than absolute values are used. That is to say, the total costs of the initial (reference) process is indexed at 100, and the node-weights are expressed as percentages of the total costs. The costs of an alternative process are determined relative to the initial process. This is needed to avoid problems, due to difference in projects with respect to size and other features.

6.2.2 Construction of reinforcement

The construction, especially the fixing of reinforcement, is also very labour-intensive. Almost all costs for fixing are associated with labour-costs. In the production of rebars, labour has been replaced by advanced machines. Although a lot of labourers are still active in the production of rebars, the costs are associated with the use of these machines mainly.

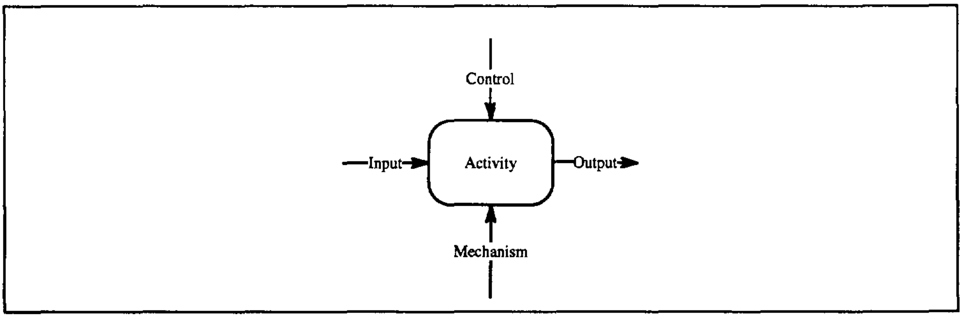

figure 6.1: syntax of the IDEF-0 *method*

This research focuses on the production of bar-bending-schedules, being one of the most important activities in the scheduling phase of construction of reinforcement. The relevant costs are associated with labour and the use of the information system. However, since the costs related to the use of the information are low and consist of sunk costs mainly, only the costs associated to labour are considered.

Similar to the costs of structural design, the total costs of the initial production digraph of the production of bar-bending-schedules is indexed at 100. The node-weights are expressed with respect to this index. The costs of an alternative process are determined relative to this initial process.

6.3 Generic production digraphs

Generic (initial) structures of production digraphs for both structural design and the production of bar-bending-schedules are provided (see figures 6.2 and 6.3), based on the analysis in chapter 5. These structures were verified and modified during interviews with experienced designers and bar-bending-schedulers. Also node- and arc-weights were estimated during these interviews.

However, it must be emphasized that these structures must be checked in individual situations. Furthermore, the node- and arc-weights must be determined for that specific production process. The generic production digraphs can be used as input to the process of constructing specific production digraphs. The production digraphs presented in this chapter were used as input to the case-studies, which are described in chapter 8 and 9.

In chapter 5 the main activities in structural design and the production of bar-bending-schedules are provided, based on literature. However, the process-analyses reported in the literature were not restricted to identification of the activities. These analyses provide information which can be useful in determining the cost-relations between activities as well. Often these process-analyses are presented according to the IDEF-0 method (Icam DEFinition method), which was developed for a major U.S. Air Force project (for a description, see SofTech, 1981).

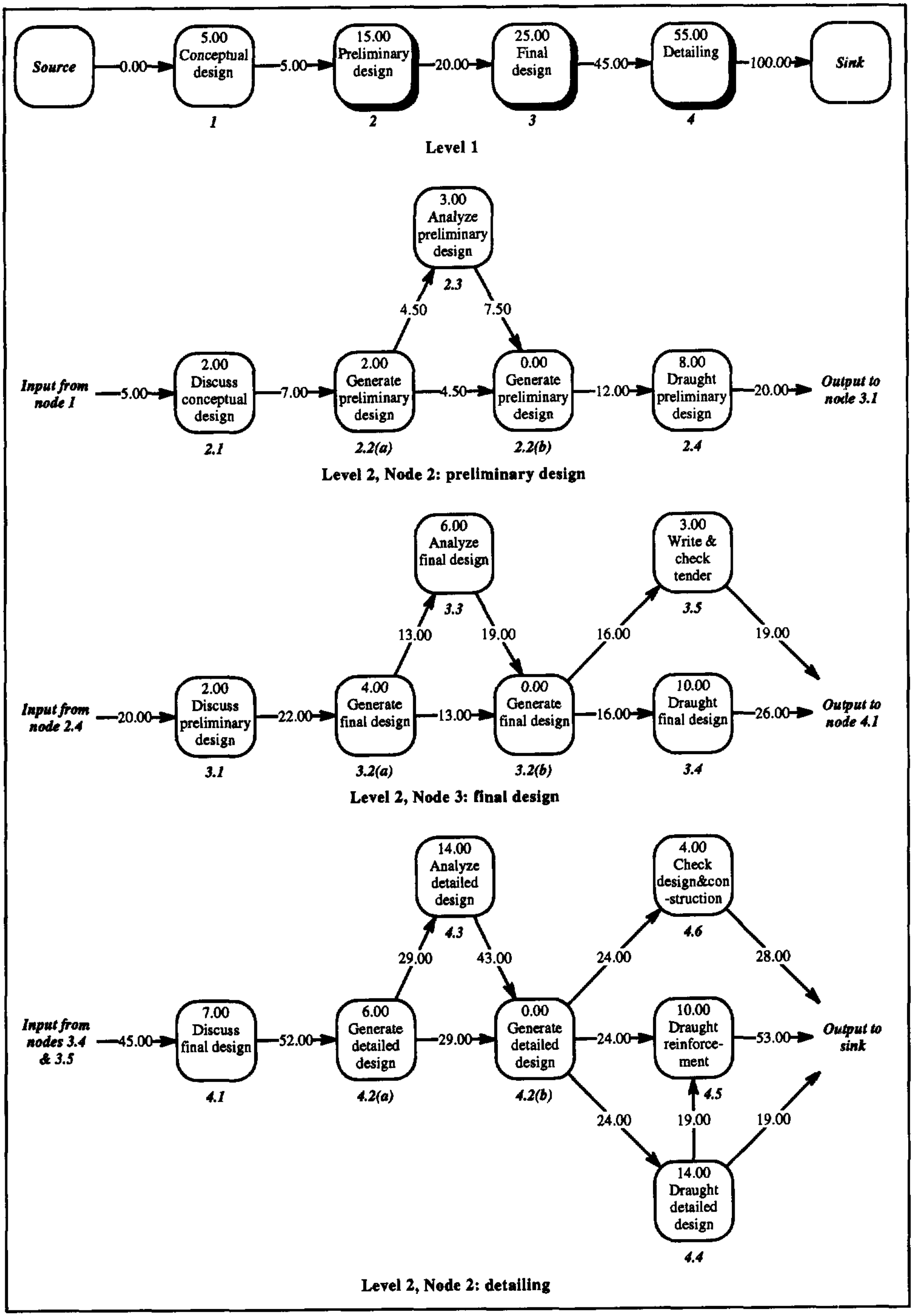

figure 6.2: initial production digraph of structural design

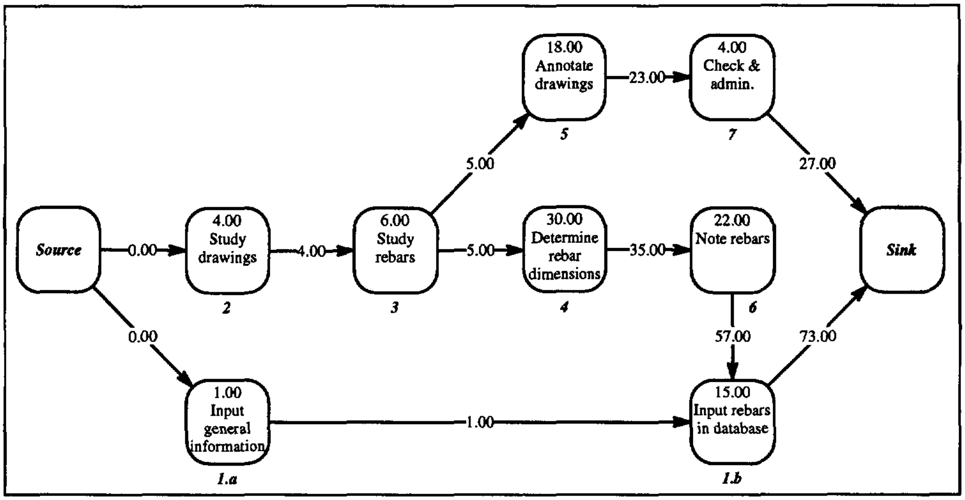

figure 6.3: initial production digraph of production bar-bending-schedules

The IDEF-0 method has a well defined syntax for identification of major process-activities and their relations (see figure 6.1). It facilitates identification of activities on several hierarchical levels. Furthermore, it facilitates identification of input and output relations. Four categories of relations are identified for an activity: "input", "control", "mechanism", and "output". "Control" designates information which specifies conditions and requirements for an activity. "Input" denotes information concerning the object of design or construction. "Mechanism" refers to staff-members and tools (resources) employed to perform the activity. "Output" of one activity can be either input or control to another activity.

Using these IDEF-0 representations, initial structures of production digraphs can be determined, assuming that the relations indicates the existence of cost-relations as well. All relations between two activities in these IDEF-0 representations are aggregated to one (cost-)relation between the two activities. The resources are irrelevant for the identification of cost-relations, but are useful for determining node- and arc-weights.

Often, in IDEF-0 representations cycles occur to indicate process-iterations, based on feedback. These are not allowed in production digraphs and must be eliminated to maintain the directed acyclic nature of the production digraph model. How to avoid cycles is discussed in detail by Bellin (1991).

6.4 Conclusion

A generic production digraph for the structural design process is provided in figure 6.2, while figure 6.3 provides that of the production of bar-bending-schedules. These digraphs are based on a review of the literature (see chapter 5). They are verified through interviews with experienced designers and bar-bending-schedulers in the concrete construction industry in the Netherlands.

During the interviews, node- and arc-weights were estimated by designers and bar-bending-schedulers. The interviews showed that, in contrast to the node-weights, the arc-weights were hard to determine. Often an arbitrary, equal distribution was applied for assigning arc-weights (see figures 6.2 and 6.3). This means that, if the output of an activity is distributed over two arcs, the arc-weights assigned are equal to half of the output. However, the interviewed designers and bar-bending-schedulers expected that better arc-weights could be determined in a detailed analysis of the production-costs.

These generic production digraphs were used as input to the modelling of the cost-effects of CAD systems in case-studies (see chapters 8 and 9). However, during the case-studies, detailed analysis was required to:

1. check these initial structures of production digraphs, and tailor them to the specific situation of the structural design process and production process of bar-bending-schedules in the companies considered;
2. determine the node- and arc-weights to model the costs and cost-relations in the processes;
3. determine the effects on the production digraphs, resulting from the use of the various CAD systems.

Chapter 7
CAD systems in concrete construction

Different CAD systems are used in structural design. This chapter pinpoints the types of CAD systems considered in this research. Not only the general (draughting) systems are considered, but the more specific applications (for e.g. detailing of reinforcement, quantity take-out, engineering and analysis) as well. A sharp distinction between CAD systems and other computer-based engineering tools (e.g. expertsystems, knowledge-based systems) is hard to make.

7.1 Defining CAD systems

Developments in computer and information technology provides various possibilities to support the design and construction process. For example, Adeli (1992) expressed his belief that computer and information technology will continue to have a significant impact on design. He reviewed the emerging areas which may be relevant, such as artificial intelligence, knowledge-based expert systems, machine learning, object oriented programming, neural networks, database management, parallel processing, computer aided visualization, and genetic algorithms.

Computer Aided Design (CAD) systems represent just one group of possibilities. CAD systems are defined as computer based systems to aid the process of creation (generation), analysis, modification, and representation of designs. This is a rather large group of systems which are based on different information technologies, such as computer graphics, finite element analyses, simulation techniques, artificial intelligence techniques, database management techniques, etc.

Related to CAD systems are Computer Aided Engineering (CAE) systems. CAE systems are computer based systems to aid the structural analysis of structures in order to verify and optimize designs. CAE systems are considered to be a part of CAD systems. Nowadays, most CAE systems are based on the Finite Element Method (FEM).

Also related to CAD systems are the Computer Aided Manufacturing (CAM) systems. CAM systems are computer based systems to generate information for production. Often CAM systems use the information which is produced by CAD systems in the design process, using CAD systems. Sometimes CAD systems and CAM systems are connected or integrated. That they go together is illustrated by the fact that it is common to use the term CAD/CAM systems.

There are similarities between the CAD systems used in the different sectors of industries. However, often these systems are tailored to the needs and culture within a sector. The modifications are important to a sector and must be considered in in-depth analysis to determine the value of these systems. Not much is left of the similarities when CAD systems are considered on that level. That makes it necessary to define the sector of interest.

In this research the sector of interest is structural design and construction, and structural design of concrete structures and the production and fixing of reinforcement in particular. Vos (1990) provided several reasons for focusing on CAD systems in this sector:

1. concrete construction is a difficult process within construction, with a specific way of handling and transferring information,
2. concrete structures are unique, one-of-a-kind products, with huge variations in shape,
3. specific features of reinforcement and the exchange of reinforcement-information complicate the concrete construction process further.

A review of developments in the Netherlands concerning CAD systems in structural design and construction of concrete structures is provided by Vos (1990). In this article not only CAD systems are considered, but CAM systems as well. In the United Kingdom this subject was discussed earlier in a conference organized by the Storer et al. (1987). A recent review of CAD systems in structural design in provided by Chandansingh (1994). El-Rahman & Shaw (1989) reviewed the use of computers in concrete technology, focusing on engineering. A review of CAD/CAM systems for building and civil construction industry is provided in Wagter and Vos (1989).

7.2 CAD systems for structural concrete design

CAD systems are intended to support the structural design process. As discussed earlier, the structural design process consists of several activities, such as generation (creation), analysis, and presentation (documentation). These activities provide a means to classify the various CAD systems currently available or under development.

Currently there are just a few CAD systems available which support the generation (creation) of the design of a concrete structure. This is due to the heuristic nature of this design-activity. Development of such CAD systems are based on artificial intelligence, neural networks, knowledge based systems, etc. An example is the expert system which is developed for the design of concrete bridges (Stuurstraat & Veen, 1994). It is expected that in the future, new developments will facilitate appropriate support of the generation (creation) of designs.

The design-activity analysis (or engineering) is better supported by CAD systems. This is due to the fact that the construction can be modelled in such a way that it can be analyzed mathematically. Most CAD systems in this category, currently applied in design, are based on the finite element method. However, there are various other analysis systems currently available. For example, systems performing analysis, code-checking, and detailing of reinforcement within limits defined by shape, sizes, and specifications in the final design.

The design-activity presentation (documentation) is well-supported by CAD systems based on developments in computer graphics. These CAD systems are mainly used in the final phase of design: the detailing phase. At first these systems were used to support the production of drawings primarily. That is why they are still referred to as Computer Aided Draughting systems. An example of such a system is AUTOCAD from Autodesk Inc., which is well-known world-wide.

The CAD systems based on computer graphics have evolved into systems with broader applicability as a result of several developments. First, modifications have been made to support the design and modelling of reinforcement. Secondly, possibilities for analysis of concrete structures have been incorporated. Thirdly, the exchange with CAE systems and CAM systems have been improved. Finally, enhanced possibilities for modelling, such as 3D-modelling, object-oriented modelling, productmodelling, etc. have been added.

These developments have made CAD systems more applicable to structural design and construction. The information stored by the systems is used by other activities in the design process, such as cost-estimating, etc. Furthermore the information can be used by other activities of structural design and construction. For example information in CAD systems can be used as input for CAM systems in construction.

This research will consider CAD systems based on computer graphics, which support structural design of concrete structures. They will be referred to as CAD-CRETE systems, an acronym for CAD systems in structural conCRETE design and detailing of reinforcement. The research will not consider CAE systems and other CAD systems, based on artificial intelligence, etc. The framework of value adding dimensions of information commodities will be applied to classify these systems and determine their effects on structural design and construction in case-studies. The next section will discuss this type of CAD systems.

7.3 CAD-CRETE systems

7.3.1 Classes of CAD-CRETE systems

Several classes of CAD-CRETE systems can be distinguished, based on the nature of support to the structural design process. The nature of support has two aspects. The first relates to the activities it executes or supports. The more activities are supported or executed the more advanced the CAD system is. For example, a CAD system which supports design and draughting of reinforcement is more advanced than one that supports only draughting. The first requires more information (knowledge) in order to design the reinforcement.

The second aspect relates to the nature of the information stored (and retrieved) form the CAD system. The previous CAD systems focused on the handling of 2D-graphical information only. This information was used to produce drawings, representing the geometry of reinforcement and concrete structure. Some current CAD systems combine 2D-graphical information with alphanumerical information concerning quality and quantity of the reinforcement and concrete structure. Furthermore, other CAD systems facilitate the storage of 3D information.

table 7.1: several classes of CAD-CRETE systems

CAD-CRETE SYSTEMS		
Class	**Information handled**	**Supported activities**
1	2D-graphical information	Modelling (draughting) in general
2	2D-graphical information	Modelling (draughting) concrete structures and reinforcement
3	Graphical and alphanumerical information	Modelling concrete structures and reinforcement
4	Graphical and alphanumerical information	Analysis, design, and modelling of structural concrete elements and reinforcement

The different classes of CAD systems which are used in the Netherlands nowadays, are discussed here (see table 7.1). Class 1 represents the 2D computer graphics systems that are used for modelling 2D-graphical information for the production of drawings. These systems are used for producing concrete drawings, while they are used occasionally for the production of reinforcement-drawings. Examples of these systems are AutoCAD, Microstation, CADAM, CADvance, Medusa, etc.

Class 2 represents CAD systems which are improved by adding routines and standard components. They are used to improve the productivity in the production of drawings. Standard components are pre-defined graphical elements which can be used during modelling. They have either fixed dimensions or dimensions based on assignments of values for parameters. Routines are a collection of activities which are performed together and speed up the modelling.

The improvements within class 2 can be split up into three categories:
1. for the production of concrete-drawings,
2. for the modelling of reinforcement and the production of reinforcement drawings,
3. for both the modelling of concrete and reinforcement.

The latter is often possible for standard structural elements. Based on the input of some parameters (e.g. the dimensions of the element) both the concrete-drawings and the reinforcement-drawings are produced.

Class 3 represents CAD systems which model not only graphical information but alphanumerical information as well. For example, during modelling of reinforcement with CAD-CRETE systems exact information concerning dimensions, quality and quantity of the reinforcement is determined and stored. Modelling is done using pre-defined components of reinforcement which uses the input value for their parameters. The information stored in CAD systems can be used to support other activities, e.g. material-take-off and cost-estimation to support the production of rebars. For a discussion of class 2 and 3 type of CAD systems for reinforced concrete detailing see Chandansingh & van Tongeren (1993).

table 7.2: implementation of CAD systems in the Netherlands

IMPLEMENTATION OF CAD SYSTEMS	***Small eng. cons.***	***Med. eng. cons.***	***Large eng. cons.***	***Average***
Staff: structural engineers & draughtsmen	***< 6***	***06 - 30***	***>30***	
CAD system class 1	20%	40%	20%	35%
CAD system class 2	10%	30%	60%	30%
CAD system class 3	0%	15%	20%	10%
CAD system class 4	15%	30%	40%	25%

Class 4 represents CAD systems which integrate the design and modelling of reinforcement based on the analysis of concrete elements. Often these systems are stand-alone systems in contrast with the previous classes, which can be seen of an extension of class 1. Analysis, design, and modelling are performed by the CAD systems without human interference. However, structural engineers can influence the process either by changing the input or modifying the output directly.

These CAD systems (class 4) are currently available for a limited set of structural elements, such as concrete beams (with rectangular cross-section) and for slabs (reinforced with reinforcement-nets). Furthermore, these CAD systems are also available for specific products, often prefabricated structural concrete elements. These products are rationalized and standardized, which enables a parametric description of the products suitable for implementation in CAD systems.

7.3.2 Use of CAD-CRETE systems

Table 7.2 provides the results of a survey, performed by Chandansingh & Vos (1991), on the implementation of the several classes of CAD systems in the Netherlands. It shows that in general the implementation of class 1, class 2, and class 4 CAD systems are similar. The implementation of class 3 CAD systems is lower, in particular for the smaller engineering consultant.

Two trends can be determined from table 7.2. The first trend is that the bigger the engineering consultant, the higher the implementation of class 2 and class 3 CAD systems. The second is that implementation of class 1 CAD systems is relatively lower for the bigger engineering consultants. These systems are replaced by class 2 and class 3 CAD systems. It is expected that this replacement will continue, for the larger as well as for the smaller engineering consultants.

7.4 Nature of CAD-CRETE systems

CAD systems assist the designer, but in what way is not often considered and described. Rouse (1986) shed some light on this topic by considering CAD systems in relation to the nature of the design task. Design is viewed as a form of problem-solving. The most important part of problem-solving is getting the right information (the ability to decide and control). CAD systems support information modelling and thus provide the ability to decide and control.

Hence, in relation to the design-activities, it is better to view CAD systems as computer-based information systems in general, and as computer-based decision support systems in particular. The effectiveness/value of CAD systems depends on the provision of useful information to the designer. Information provides a link between CAD systems and its value to the user.

Artificial intelligence systems, expertsystems and knowledge based systems are information or decision-support systems. Often, CAD systems based on computer graphics are not considered to be information systems; they are still considered to be electronic draughting-boards. This is due to the fact that the product of these system is the same as traditional draughting: the drawing. Furthermore, the activities resembles traditional draughting, only the draughting-board is replaced by a computer-screen and the pencil by mouse or electronic pen.

However, CAD systems based on computer graphics are information systems. Compared to the draughting-board, a CAD system is active in the sense that the system provides information to the user. Examples of such information include presentation of options to choose from, descriptions of calculations, feedback, etc. Furthermore, a CAD system provides information in the form of standard components and routines.

Another justification for viewing CAD systems as information systems lies with the ability to re-use information provided by CAD systems. Kaas (1993) described the different forms and intensities of re-use of information from CAD systems in mechanical engineering. The information can be re-used for engineering, production, scheduling, planning, logistics, etc. Vos (1992) described the possibilities for re-use of information in CAD systems for the production of reinforcement. It is expected that the exploitation of this ability will increase in the future.

Viewing CAD systems as information systems provides possibilities to analyze CAD systems and relate their features to their value for the user. Since CAD systems meet requirements of appropriability and valuability they can be considered information commodities (Mowshowitz, 1992a). The value-added model of information commodities facilitates analyses of the value of CAD systems to the user.

7.5 Value adding dimensions of CAD systems

Chapter 3 provides the value-added model of information commodities. This model consists of the following value adding dimensions: kernel (consisting of procedural information and declarative information), storage, processing, distribution, and presentation. This framework is useful for classification of CAD systems; it highlights the differences between the systems.

A CAD system consists of three components: the computer hardware, the operating system and the CAD system software. Each individual component may be viewed as an information commodity. Differences between CAD systems can occur in each individual component. However, the most important differences refer to the value adding dimensions of the CAD system software. These are the main determinants of the value of the CAD system.

7.5.1 Computer hardware

The most important value adding dimensions of the computer hardware are storage (e.g. capacity, speed of access, reliability), processing (e.g. speed of processing), distribution (e.g. speed of the channel), and presentation (e.g. size and resolution of display, and lay-out of keys). Computer hardware includes a kernel as well, which is not included in this discussion, since it is roughly the same for all the competing hardware.

Table 7.3 provides the value adding dimensions of two computer hardware configurations: a stand-alone personal computer and a personal computer in a network. The computer hardware is important, since it determines the speed of response to the user. However, cost-effects are not very sensitive to (differences in) the value adding dimensions of the computer hardware.

table 7.3: value adding dimensions of computer hardware

Value Adding Dimensions	***Personal Computer (network)***	***Personal computer (stand-alone)***
Kernel **- procedural information (routines for:)** **- declarative information (libraries with:)**		
Storage	Cache 256 Kb. Random Access Memory (RAM): 16Mb. Hard-disk local: 40 Mb. Disk drive: 3.5". Hard-disk server: 1.7 Gb. Magnetic tape server (DAT): 2 Gb	Cache 256 Kb. Random Access Memory (RAM): 4Mb. Hard-disk local: 260 Mb. Disk drive: 3.5".
Processing	Intel processor: 80486 DX2, 66 MHz	Intel processor: 80386 DX2, 20 MHz
Distribution	Vesa Local Bus (32 bits) Local Area Network: Novell 3.1	Vesa Local Bus (32 bits)
Presentation	SVGA, video-memory: 1 Mb. Black/white monitor (command) 12/14". Colour high resolution monitor 21". Keyboard and mouse. Digitizer and tablet. Printers and plotters.	SVGA, video-memory: 1 Mb. Colour monitor 14". Keyboard and mouse. Digitizer and tablet. Printers and plotters.

7.5.2 Operating system

The operating system has one significant value adding dimension, namely the kernel, with procedural information as the most important component. The procedural information consists of routines for controlling the processor, hard-disk, RAM, and software (e.g. CAD system software). Several operating systems are used today (e.g. MS-Dos, MS-Windows, Unix, etc.). The most widely used operating system is MS-Dos. but the use of MS-Windows is increasing. It is very difficult to relate cost-effects to the operating systems used.

7.5.3 CAD system software

Cost-effects of a CAD system depend on the value adding dimensions of the CAD system software mainly. The main value adding dimension is the kernel. CAD system software furnishes procedural information in the form of routines for the processing of declarative information. In addition, the CAD system software provides databases with declarative information, and possibilities to create and maintain databases.

Table 7.4 provides the value adding dimensions of two types of CAD system software: a standard CAD system and a specific CAD system. From the table it can be seen that the specific system consists of the standard system, extended with routines and databases. This is often the case as standard systems are tailored for a specific domain by extending it with routines and databases. These specific CAD systems are often referred to as CAD-applications.

table 7.4: value adding dimensions of CAD system software

Value Adding Dimensions	***CAD-system 1***	***CAD system 2***
Kernel - **procedural information (routines for:)**	Managing project-database and files. Modelling of graphical elements: input, edit (copy, move, group, etc.), and presentation. Determining measures of the model. Numbering of symbols and generating lists. Generating structural grid.	Managing project database and files. Modelling of graphical elements: input, edit (copy, move, group, etc.), and presentation. Determining measures of the model. Numbering of symbols and generating lists. Generating structural grid. Generating predefined structural elements (parametric design). Checking consistency. Generating material lists. Determining and annotating measures. Determining additional information.
- **declarative information (libraries with:)**	Settings (defaults) for model-layers. Symbols, shading, text, etc. Structural elements and details (graphical). Reinforcement-elements and symbols. Project information stored in project-files.	Settings (defaults) for model-layers. Symbols, shading, text, etc. Structural elements and details (graphical). Reinforcement-elements and symbols. Project information stored in project-files. Prefab structural elements.
Storage		
Processing		
Distribution		
Presentation		

7.6 Conclusion

The CAD systems described in this chapter aim primarily at supporting draughting activities. In particular, they are focused on supporting the draughting in the final phases of design (final design and detailing). In these phases and activities changes are expected due to deployment of CAD systems. The case-study (chapter 9) will prove whether this is correct. Before that the case-study process is described in the next chapter.

Chapter 8
Case-study process

To verify the approach to model the cost-effects of CAD systems, case-studies were undertaken. Three case-studies were selected: 2 at engineering consultants and 1 at a reinforcement-subcontractor. This chapter describes the case-study process, which is different for the two first cases when compared with the third case-study.

8.1 Introduction

Case-studies have been selected to test the approach for modelling the cost-effects of CAD systems on structural design and construction. Furthermore, the case-studies where chosen to identify possible patterns in the cost-effects of the value adding dimensions of CAD systems on production digraphs of structural design and construction. This chapter describes the case-study process.

A generic representation of the case-study process is provided by figure 8.1. The process consisted of four phases: initiation, determination of initial digraphs, determination of alternative digraphs, and evaluation. The activities within the process-phases involved interviews, analyses, experiments, and modelling.

In total, 3 case-studies were performed: 2 at structural engineering consultants and 1 at a reinforcement-subcontractor. It was decided to model the cost-effects of CAD systems on the production of reinforcement, since it is expected that CAD systems affects production as well. Use of CAD systems alters information for the production of reinforcement. The case-study process for the two first cases differs from the last case. The first case-study process is described in section 8.2, the latter in section 8.3.

8.2 Case-study process at engineering consultants

Several staff-members at the engineering consultants were involved in the cases studies. Table 8.1 provides the kinds and numbers of the staff-members involved. In this way, information was gathered for both the entire structural design process, as well as for the several design-activities. Furthermore, it provided possibilities to check estimates of managers with staff-members performing the activities and vice versa.

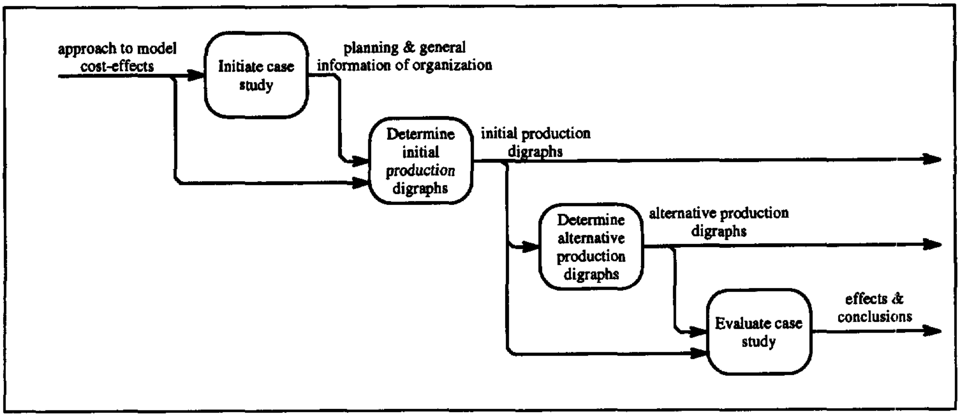

figure 8.1: phases in the case study process

table 8.1: staff involved in case-study at engineering consultants

NUMBER OF STAFF-MEMBERS		
Staff-member	**Engineering consultant 1**	**Engineering consultant 2**
Managing structural engineer	2	1
Structural engineer	2	2
Draughtsman	5	4

Table 8.2 provides the activities of the case-study process at the engineering consultants. The major part of the case-study consisted of interviews with the staff-members, based on a checklist (see appendix 1). Sometimes unstructured interviews were performed as well, for example during the initiation and the evaluation phase. Besides interviews, cost-evaluations of previous projects were analyzed and discussed. Furthermore, the activities in which CAD systems were used were frequently observed, and costs of the current and alternative structural design process were modelled. The activities are discussed briefly.

Initiation

Initiation consisted of interviews with managing structural engineers at the engineering consultants. The interviews were used to:

1. discuss the aim and planning of the case-study, and make further arrangements concerning reporting, use of confidential information, etc.,
2. gather general information concerning strategy, policy, organization, number of staff-members, annual turn-over, number of projects, average size of projects, and the office's specializations.

table 8.2: case-study process at engineering consultants

CASE-STUDY PROCESS	
PHASE / Activity	**Description of activity**
INITIATION	
Interviews	Discuss aim and plan of the case-study. Gather general information about the engineering consultant.
DETERMINATION OF INITIAL DIGRAPHS	
Interviews	Discuss and modify the initial structure of the production digraph of structural design. Identify cost-relations between design-activities.
Analyses	Determine costs of the design-activities using of cost-evaluations Verify and modify the costs with managing structural engineers.
Modelling	Construct initial production digraphs of the structural design process.
DETERMINATION OF ALTERNATIVE DIGRAPHS	
Observations	Study the use of CAD systems in structural design. Identify valuable features of CAD systems and changes in design-activities.
Interviews	Discuss valuable features of current and alternative CAD systems and changes in design-activities. Estimate the effects on activity-costs and cost-relations.
Modelling	Construct alternative production digraphs of the structural design process.
EVALUATION	
Interviews	Evaluate the initial and alternative production digraphs. Evaluate the approach for modelling the cost-effects of CAD systems.

Determination of initial digraphs

The first step of this phase consisted of interviews with managing structural engineers. In the first place, the interviews were used to discuss and taylor the initial model of the production digraph. Relevant design-activities, and relations between the design activities in the current process were determined. During the interviews the managing structural engineers had every opportunity to modify the model. The specific nature of production digraphs were determined and summarized.

In the second place, the interviews were used to identify cost-relations (arc-weights) between activities. Although the relations could be determined easily, determination of the arc-weights proved to be very difficult, since the staff-members had not considered cost-relations before. Often the output of an activity is equally distributed over the outgoing arcs.

The second step consisted of analysis of cost-evaluations of previous projects, to determine the activity-costs (node-weights). Eight projects were selected by the managing structural engineers, which were believed to be representative for the projects of the engineering consultant. The costs of the design-activities were calculated as a percentage of the total project-costs, and verified with the managing structural engineers.

The third step was modelling: construction of the production digraphs of the initial structural design processes. The graphs are valid for the structural design process in which CAD systems are not applied and serve as reference to analyze the cost-effects of CAD systems. These initial production digraphs were verified by structural engineers and draughtsmen.

Determination of alternative digraphs

In the first step of this third phase the use of CAD systems in the structural design process was observed. The observations were compared with observations of the process without application of CAD systems to identify differences in design-activities. Furthermore, the main features of CAD systems were determined during the use of the systems.

In the second step the draughtsmen were interviewed. In the first place, the observations concerning changes in design-activities and the main value adding dimensions of CAD systems were discussed. The discussions were not restricted to the current CAD system, used at the engineering consultant. The value adding dimensions of alternative CAD systems were discussed as well.

Secondly, the draughtsmen estimated the effects of the CAD systems on the node-weights and arc-weights of the production digraph. The effects were estimated by 4 draughtsmen separately, and related to the value adding dimensions of the CAD systems. The estimates were provided with regard to the initial production digraphs. An average of these estimates was used to construct alternative production digraphs.

In the third step the information gathered was used to model the cost-effects of CAD systems. Alternative production digraphs of the structural design processes were constructed. The alternative graphs were compared to one another and to the initial graphs to determine the cost-effects. In interviews, the results were verified by structural engineers and draughtsmen.

Evaluation

In this last phase the case-study was evaluated. In the first place the cost-effects of use of CAD systems were discussed and checked with the experience of the managing structural engineers. Secondly, the production digraphs and the value of the approach to model cost-effects of CAD systems were discussed.

8.3 Case-study process at reinforcement-subcontractor

Two managers and three bar-bending-schedulers were involved in the case-study process at the reinforcement-subcontractor (see table 8.3). They provided information about the production and fixing of reinforcement, in particular about production of bar-bending-schedules. The major input was provided by the three bar-bending-schedulers. They were observed and interviewed extensively, since the research focused on the production of bar-bending-schedules. The interviews were also based on the checklist provided in appendix 1.

table 8.3: staff involved in case-study at reinforcement-subcontractor

NUMBER OF STAFF-MEMBERS	
Staff-member	**Reinforcement-subcontractor**
Manager	2
Bar-bending-scheduler	3

In contrast to the process at the engineering consultants the main parts of the case-study process at the reinforcement-subcontractor, were observations and experiments (see table 8.4). The activities of the bar-bending-schedulers were studied extensively, while time-measurements were performed during the experiments. Interviews were performed to check findings and to gather additional information. The process-activities - including modelling of the costs in production digraphs - are discussed briefly.

In the experiments the production of bar-bending-schedules for the reinforcement of a specific floor-slab was studied. Two bar-bending-schedulers with similar qualifications were involved. Two cases of the production of bar-bending-schedules were considered:
1. with reinforcement-drawings as input (traditional),
2. with WUF-diskettes (and related drawings) as input: information from CAD systems, stored on a diskette according to WUF, the Dutch acronym for "Wapenings-Uitwisseling-Formaat" (Reinforcement Exchange Format). See also section 9.4.2.

table 8.4: case-study process at reinforcement-subcontractor

CASE-STUDY PROCESS	
PHASE / Activity	**Description of activity**
INITIATION	
Interviews	Discuss aim and plan of the case-study. Gather general information about the engineering consultant.
DETERMINATION OF INITIAL DIGRAPHS	
Observations	Determine the activities and relations in the production process of bar-bending-schedules. Measure the time involved for each activity.
Interviews	Discuss and modify the activities, relations, and the time involved for each activity.
Experiments	Determine activity-costs and cost-relations in a experimental situation.
Modelling	Construct initial production digraphs of the production process of bar-bending-schedules.
DETERMINATION OF ALTERNATIVE DIGRAPHS	
Interviews	Discuss valuable features of WUF and the changes in process-activities and costs.
Experiments	Determine activity-costs and cost-relations in a experimental situation, using WUF
Modelling	Construct alternative production digraphs of the production process of bar-bending-schedules.
EVALUATION	
Interviews	Evaluate the initial and alternative production digraphs. Evaluate the approach for modelling the cost-effects of WUF on the production of bar-bending-schedules.

Initiation

The initiation phase is similar to the previous case-study process. Managers at the reinforcement-subcontractor were interviewed to:

1. discuss the aim and planning of the case-study, and make further arrangements concerning reporting, use of confidential information, etc.,
2. gather general information concerning strategy, policy, organization, number of staff-members, annual turn-over, number of projects, and average size of projects.

Determination of initial digraphs

In the first step of this phase the production process of bar-bending-schedules was observed. Relevant activities, and relations between the activities in the current process were determined. The current process refers to the process with the reinforcement-drawings as input. The time needed for each activity was determined as well. The information was used to verify the initial structure of the production digraph (see chapter 6).

In the second step the results of the observations were discussed with the managers and the bar-bending-scheduler in interviews. The staff-members verified and modified the activities and the time measured. Furthermore, they provided insight in the cost-relations between the activities and appropriate arc-weights. In this specific case it was not difficult to determine arc-weights.

In the third step the activities, costs and cost-relations of the production process of bar-bending-schedules were determined in an experiment. The experiments allowed detailed measurements of the time required for each activity. Furthermore, they allowed better comparison with the alternative situations, in which WUF-diskettes are used as input.

In the last step the costs of the initial process were modelled. This initial production digraph is used as reference to determine the effects of use of WUF-diskettes as input to the process. The time, measured in the experiments, was used to determine the costs of the activities and the cost-relations. The initial production digraph was verified by the managers and the bar-bending-scheduler.

Determination of alternative digraphs

To determine the alternative digraphs the bar-bending-schedulers were interviewed first. The experience with recent experimental use of WUF-diskettes was discussed. The features of WUF-diskettes and the process were discussed. The process was compared to the initial process and differences were determined. Estimates of changes in node- and arc-weights were provided by the bar-bending-scheduler.

The findings in the interviews were verified through an experiment on the production of bar-bending-schedules, using WUF-diskettes. Furthermore, the experiments provided possibilities to measure the several node- and arc-weights. Since bar-bending-schedules were produced for the same reinforcement in a concrete slab it was possible to determine effects properly.

Finally, the information gathered was used to model the effects of the use of WUF-diskettes. Alternative production digraphs of the production process of bar-bending-schedules were constructed. The alternative graphs were compared to one another. Furthermore, they were compared with the initial production digraphs to determine the effects. The results were verified by the managers and the bar-bending-scheduler.

Evaluation

The case-study at the reinforcement-subcontractor was evaluated. With both the managers and the bar-bending-scheduler the effects, determined in the case-study, were discussed and checked against previous experiences. Secondly, the suitability of the approach to model the effects of use of WUF-diskettes, resulting from the use of CAD systems in structural design, was discussed.

8.4 Conclusion

This chapter described the case-study process for three case-studies, which have been selected to test the approach for modelling the cost-effects of CAD systems on structural design and construction. Secondly, the case-studies were chosen to identify general patterns in the cost-effects of the value adding dimensions of CAD systems on production digraphs of structural design and construction. Chapter 9 describes the results of the case-studies and analyzes the effects of the deployment of CAD systems in structural design and construction.

Chapter 9
Results of case-studies

In the previous chapters the theory, the approach and the case-study process were discussed. The approach is applied in three different case-study. The first two analyzed the cost-effects of CAD systems on structural design. The third analyzed the cost-effects of the so-called WUF-diskette on construction of reinforcement. The results of these case-studies are described in this chapter.

9.1 Introduction

In chapter 8 the case-study process was described. The first objective of the case-studies was to test the approach for modelling cost-effects of CAD systems on structural design and construction. The second, to provide insight in the effects of CAD systems in order to support decision-making concerning the use of CAD systems. This chapter presents the results of the case-studies.

Three case-studies were undertaken. The first two case-studies considered the cost-effects of CAD systems on the structural design processes at two different engineering consultants. The results of these case-studies are presented in section 9.2 and 9.3.

The third case-study considered the cost-effects of the WUF-diskette on the construction process of reinforcement. The WUF-diskette enables the transfer of information concerning reinforcement from CAD systems at the engineering consultants to CAM systems at the reinforcement-subcontractor. The WUF-diskette represents one form of PDI. The results of this case-study is presented in section 9.4.

Initially, the case-studies were to be used to identify general patterns in the relations between value adding dimensions of CAD systems and their cost-effects. Some general patterns are determined, based on these case-studies. However, since the number of cases is limited to three, these patterns must be treated carefully.

In this chapter production digraphs are presented, resulting from the case-studies. They are presented on three levels of aggregation, according to a fixed set of conventions. For quick reference, these conventions (with some examples) are copied from figure 4.5, and presented in figure 9.1.

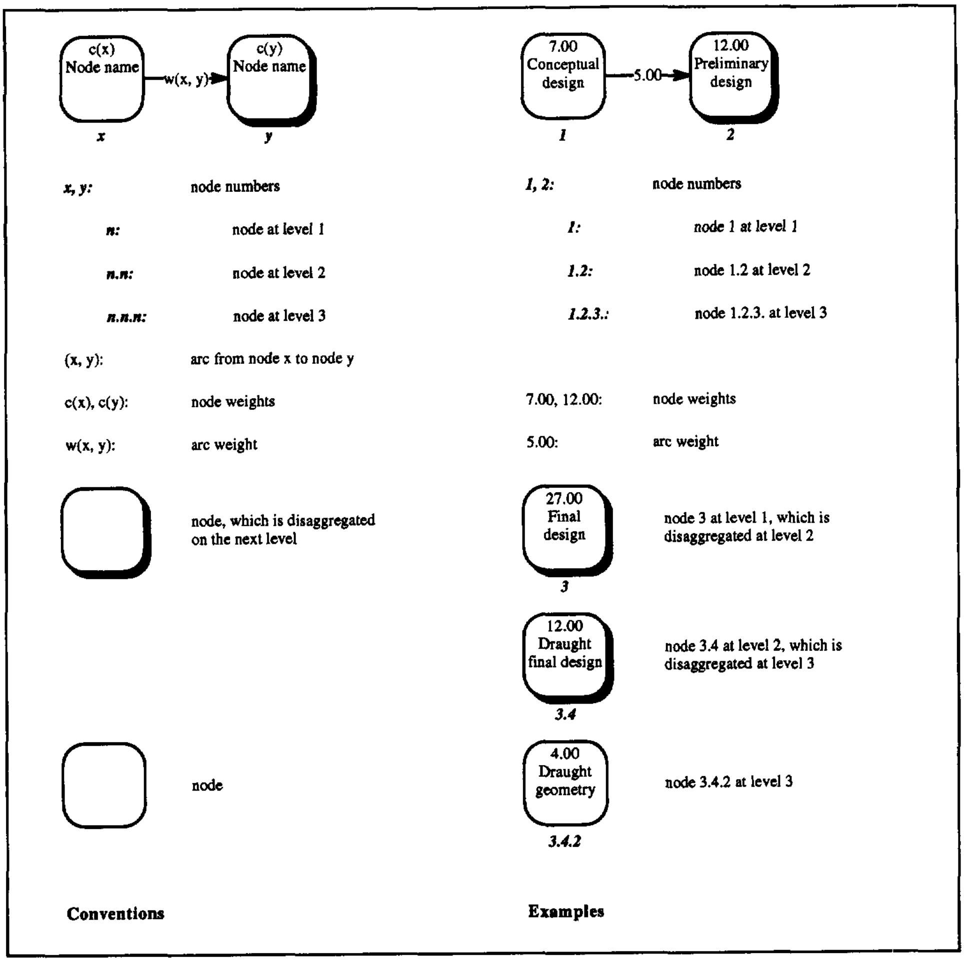

figure 9.1: conventions for representations of production digraphs

9.2 Case 1

9.2.1 Engineering consultant's profile

Case 1 involved a structural engineering consultant, with a single branch-office in the Netherlands (which will be referred to as engineering consultant 1). This engineering consultant has more than 25 years experience in designing structures world-wide, but in particular in Europe and the Netherlands. The consultant's strategy is focused primarily on providing high quality services and designs rather than on offering cheap design services. The consultant is a member of ONRI[2] and MERGE[9] (a network of leading European engineering consultants). A profile of this engineering consultant is provided in table 9.1.

Engineering consultant 1 is involved in the structural design of a wide array of structures, varying according to type and size of projects (see table 9.1 and 9.4 for details). The analyses of cost-effects of CAD systems focused mainly on the structural design of office-buildings. The time required for structural design of office buildings exceeds one year. It varies between 12 and 24 months, taking an average 18 months.

table 9.1: profile of engineering consultant 1

<table>
<tr><td colspan="5">ENGINEERING CONSULTANT 1</td></tr>
<tr><td colspan="4"><i>Number of staff-members</i></td><td><i>28</i></td></tr>
<tr><td colspan="4">Managing structural engineers</td><td>4</td></tr>
<tr><td colspan="4">Structural engineers</td><td>9</td></tr>
<tr><td colspan="4">Draughtsmen</td><td>11</td></tr>
<tr><td colspan="4">Administrative personnel</td><td>4</td></tr>
<tr><td colspan="4"><i>Annual turnover (Dfl.)</i>
<i>Average number of projects per annum</i></td><td><i>4.000.000,-</i>
<i>250</i></td></tr>
<tr><td>Type of project</td><td>Share in turnover</td><td>Average project size</td><td>Bandwidth project size</td><td>Number of projects (finished per annum)</td></tr>
<tr><td>Structural design of office-buildings</td><td>75%</td><td>100.000</td><td>25.000
1.500.000</td><td>30</td></tr>
<tr><td>Structural design of houses</td><td>5%</td><td>5.000</td><td>4.000
10.000</td><td>40</td></tr>
<tr><td>Detailing of structural elements</td><td>15%</td><td>6.000</td><td>4.000
8.000</td><td>100</td></tr>
<tr><td>Research and development</td><td>5%</td><td></td><td></td><td></td></tr>
</table>

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[2] The Association of Consulting Engineers of the Netherlands

[9] Multi-disciplinary Engineering Resources Group Europe

9.2.2 Experience with CAD systems

Engineering consultant 1 has about 5 years of experience with the use of CAD systems. This firm's main reason for introducing CAD systems was to maintain and/or improve its competitiveness in the market. As clients somehow identify the use of CAD systems with a higher design-competence of an engineering consultant, and increasingly demand design-information in electronic form, the use of CAD systems is crucial for competitiveness. The consultant was influenced by the adoption of CAD systems by other consultants.

CAD systems are used by the engineering consultant to support draughting-activities. The particular CAD system chosen was AutoCAD. The system was chosen to replace the previous CAD system (CADVance), and also to increase the number of workstations. Standard AutoCAD (release 11 and 12) is used on stand-alone personal computers. Only some minor modifications have been made to increase the efficiency in the production of drawings. Examples are the definition of standard settings in layers, a (limited) set of graphical symbols, and a set of routines (so-called macro's) for re-scaling of graphical symbols.

The implementation of CAD systems in this consultant's office was not complete at the time of the case-study, but was expected to be completed by the mid 1995. The company deliberately opted for gradual implementation in order to overcome resistance from draughtsmen who are reluctant to use CAD systems. Some drawings, such as reinforcement-drawings, are still being produced without the use of CAD systems. This is based partly on the management's belief that the use of CAD systems is not cost-effective for the production of such drawings.

According to the firm's management, the use of CAD systems led to improvements in quality of service. These improvements were deemed sufficient to justify the introduction of CAD systems. However, management still doubts the cost-effectiveness of the use of CAD systems. Reliable information on cost-effects of CAD systems is needed for evaluation of the current CAD system and for decision-making concerning future investments in CAD systems.

9.2.3 Classification of CAD systems

Typically, a CAD system consists of three complementary components: the computer hardware, the operating system and the CAD software. Each individual component represents an information commodity, but the components are only useful when used together. At engineering consultant 1, differences in CAD systems refer to the CAD software mainly. The computer hardware and operating systems remain the same (see table 9.2 for a description of the value adding dimensions of these components).

In the interviews with 4 draughtsmen the specific elements of the value adding dimensions of CAD software were identified (see table 9.3). The current CAD software, together with the other components referred to as CAD system A1, were evaluated. Furthermore alternative CAD software (as part of CAD system A2) was considered.

table 9.2: value adding dimensions of components of CAD systems

Value Adding Dimensions	***Personal Computer (stand-alone)***	***Operating system (MS Dos)***
Kernel **- procedural information (routines for:)** **- declarative information (libraries with:)**		Managing processing, storage, distribution, and presentation. Running software, such as CAD software.
Storage	Random Access Memory (RAM): 4MB Hard-disk: about 100 MB Diskette: 3,5" Magnetic tape	
Processing	Intel processor: 80386	
Distribution	Vesa Local Bus (32 bits)	
Presentation	SVGA, video-memory: 1 Mb. Colour monitor 14". Keyboard and mouse. Digitizer and tablet. Printers and plotters.	

table 9.3: value adding dimensions of CAD software

Value Adding Dimensions	***CAD software A1***	***CAD software A2***
Kernel **- procedural information (routines for:)**	1. Modelling of graphical entities; input, edit (copy, move, group, etc.), and presentation. 2. Determining measures from the model. 3. Re-scaling of graphical entities and symbols. 4. Managing project-database and files.	1. Modelling of graphical entities; input, edit (copy, move, group, etc.), and presentation. 2. Determining measures from the model. 3. Re-scaling of graphical entities and symbols. 4. Managing project-database and files.
- declarative information (libraries with:)	5. Settings (defaults) for model-layers. 6. Symbols, shading, text, etc. 7. Graphical symbols (very limited). 8. Project information stored in project-files.	5. Settings (defaults) for model-layers. 6. Symbols, shading, text, etc. 7. Graphical symbols (very limited). 8. Project information stored in project-files. 9. Graphical symbols of (standard) construction details, including simple reinforcement bars.
Storage		
Processing		
Distribution		
Presentation		

From table 9.3 one can notice that both CAD systems aim at improving the efficiency of draughting-activities. It is generally accepted that the main reason for using a CAD system, like CAD system A1, is to improve efficiency of draughting. The additional value adding dimensions of CAD system A2 aim at improving the efficiency of draughting as well. Note that the difference between the two CAD systems is formed by a database of graphical symbols of (standard) construction details only.

9.2.4 Production digraphs of structural design

The case-study at engineering consultants 1 revealed differences in the nature of the several structural design projects. Three categories can be distinguished, with respect to the design-activities performed and the type of structure:

1. structural design and detailing of complete structures;
2. structural design of prefabricated structures, except for the detailing of the prefabricated structural elements;
3. detailing of prefabricated structural elements.

Category 1 assumes that all structural design activities are performed by the engineering consultant. However, category 2 excludes the detailing of prefabricated structural elements from the structural design activities. Finally, category 3 represents structural design which consists of the detailing of prefabricated structural elements only; often in close cooperation with the producer of the elements (the client in this case).

table 9.4: project-categories of engineering consultants 1

CASE 1: ENGINEERING CONSULTANT 1		
Project-category		***Share in turnover***
1	Structural design and detailing of complete structures	70%
2	Structural design of prefabricated structures, without detailing	10%
3	Detailing of prefabricated structural elements	15%
	Research and development	5%

table 9.5: production digraphs for engineering consultants 1

Production digraph number	***Project-category***	***Use of CAD system***	***Figure number***
A0	1. Structural design and detailing of complete structures	No use	9.2 (2 pages)
A1		CAD system A1	9.3 (2 pages)
A2		CAD system A2	9.4 (2 pages)
A3		CAD system $A2^{alt}$: alternative deployment of CAD system A2	9.5 (2 pages)
A4		CAD system ^{hypo}: deployment of a hypothetical CAD system	9.9 (2 pages)

Table 9.4 shows the importance of the various categories for the engineering consultant. The analyses of cost-effects of CAD systems will focus on category 1, since it proved to be the most important for the consultant: a major part of the annual turnover is realized in such projects. The other categories can be seen as instances of category 1 and can be determined by omitting the excluded design-activities.

table 9.6: activity-costs, based on cost-evaluation and corrected by managers

Costs for selected projects		Proj. 1	Proj. 2	Proj. 3	Proj. 4	Aver.	Sum	Corr.	Sum	Corrections by managers
Conceptual&preliminary design							20%		18%	Conceptual&preliminary design
	Discuss design	2%	3%	2%	0%	**2%**		**4%**		Discuss design
	Generate design /							**4%**		Generate design
	analyze design	2%	3%	18%	9%	**8%**		**4%**		Analyze design
	Draught design	2%	0%	11%	7%	**5%**		**4%**		Draught design
	Check	0%	1%	1%	0%	**1%**		**2%**		Check /
	Administrate	2%	8%	2%	6%	**5%**				administrate
Final design							30%		27%	Final design
	Discuss design	5%	4%	5%	12%	**7%**		**2%**		Discuss design
	Generate design /							**4%**		Generate design
	analyze design	9%	9%	8%	5%	**8%**		**6%**		Analyze design
	Draught design	7%	4%	11%	18%	**10%**		**10%**		Draught design
	Check	2%	0%	2%	1%	**1%**		**4%**		Check /
	Administrate	6%	4%	1%	2%	**3%**				administrate
	Check construction site	0%	3%	0%	0%	**1%**		**0%**		Check construction site
								1%		Write tender
Detailing							50%		55%	Detailing
	Discuss design	8%	16%	4%	12%	**10%**		**7%**		Discuss design
	Generate design /							**6%**		Generate design
	analyze design	17%	13%	9%	1%	**10%**		**14%**		Analyze design
	Draught design	6%	13%	13%	5%	**9%**		**12%**		Draught design
	Draught reinforcement	5%	3%	6%	9%	**6%**		**8%**		Draught reinforcement
	Check	3%	4%	1%	0%	**2%**		**4%**		Check /
	Administrate	23%	4%	1%	1%	**7%**				administrate
	Check design others	0%	8%	2%	0%	**3%**		**4%**		Check design others /
	Check construction site	1%	0%	3%	12%	**4%**				check construction site
Total		100%	100%	100%	100%	**100%**	**100%**	**100%**	**100%**	
Project size		556210	288875	238620	121850	**301389**				

Table 9.5 provides an overview of the production digraphs constructed in this case-study. Production digraph A0 represents the initial production digraph for project-category 1, in which CAD systems are not deployed. The structure of the production digraph is based on the generic production digraph, presented in chapter 6. It was verified, checked and extended, through interviews with the managers, structural engineers, and draughtsmen (see chapter 8 for details). The main design activities, relations, and arc-weights (cost-relations) of the design phases were reviewed, and modified when necessary. The draughting activities were analyzed in further detail with the draughtsmen. As expected, it was found that the design activities in each phase are quite similar, but the level of detail increases with the phases.

The node-weights (activity costs) of the initial graph were determined through analyses of cost-evaluations. From the eight projects analyses, 4 were selected which fit the conditions of project-category 1. The average of the total project-costs is determined as well as averages for the various activity-costs. The total project-costs of the initial graph are indexed at 100 to function as reference for cost-analyses. The activity-costs are expressed with regard to the total project-costs, for convenience purpose expressed as percentages.

table 9.7 costs of the several draughting activities for production digraph A0

DRAUGHTING COSTS		**Dr.man 1**	**Dr.man 2**	**Dr.man 3**	**Dr.man 4**	**Average**	**Working average**
Draught preliminary design							**6,0%**
	Study	0,50%	0,75%	1,00%	1,00%	**0,81%**	**0,8%**
	Draught geometry	2,00%	2,00%	1,75%	2,25%	**2,00%**	**2,0%**
	Mark sizes	1,25%	1,00%	1,00%	0,75%	**1,00%**	**1,0%**
	Finalize drawings	0,25%	0,25%	0,25%	0,00%	**0,19%**	**0,2%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Draught final design							**12,0%**
	Study	0,50%	1,50%	2,50%	1,50%	**1,50%**	**1,5%**
	Draught geometry	5,00%	4,00%	3,00%	4,00%	**4,00%**	**4,0%**
	Mark sizes	4,50%	3,50%	4,00%	4,00%	**4,00%**	**4,0%**
	Finalize drawings	0,00%	1,00%	0,50%	0,50%	**0,50%**	**0,5%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Draught detailed design							**14,0%**
	Study	0,50%	1,75%	3,00%	2,00%	**1,81%**	**1,8%**
	Draught geometry	6,00%	4,50%	4,00%	4,75%	**4,81%**	**4,8%**
	Mark sizes	5,00%	5,00%	4,50%	4,75%	**4,81%**	**4,8%**
	Finalize drawings	0,50%	0,75%	0,50%	0,50%	**0,56%**	**0,6%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**

The calculated node-weights (see table 9.6 left) were checked and modified by managing structural engineers in the interviews. This resulted in the node-weights as presented in table 9.6 right. Corrections were needed because:

1. activities in the cost-evaluations were too aggregated and did not match with those determined in the interviews (and used in the production digraphs);
2. activities of conceptual design were not included in the cost-evaluations,
3. unexpected features of some selected projects disturbed the activity-costs, e.g. extra costs for administration, discussion, etc.
4. project-cost-evaluations are performed for different purposes.

The interviews revealed that the draughting activities were affected by the use of CAD systems. These activities were analyzed in detail, during the interviews with draughtsmen. Estimates of the costs of the different draughting activities were provided by 4 draughtsmen. These estimates, presented in table 9.7, were used to determine the node-weights of the draughting-activities. The node-weights are rounded values of the average of the estimates.

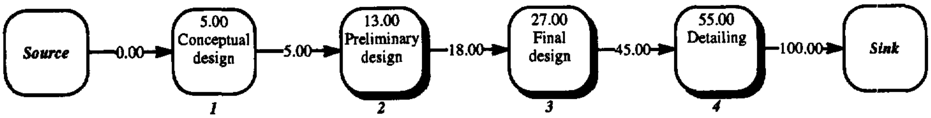
The effects of CAD systems are represented in the alternative production digraphs A1-A3. These alternative production digraphs are based on changes in activities and relations, as identified by the individual draughtsmen. Furthermore, node-weights (activity-costs) are determined as the average of the estimates provided by 4 draughtsmen (see tables 9.8 and 9.9).

table 9.8: costs for modelling, to be used for production digraph A1

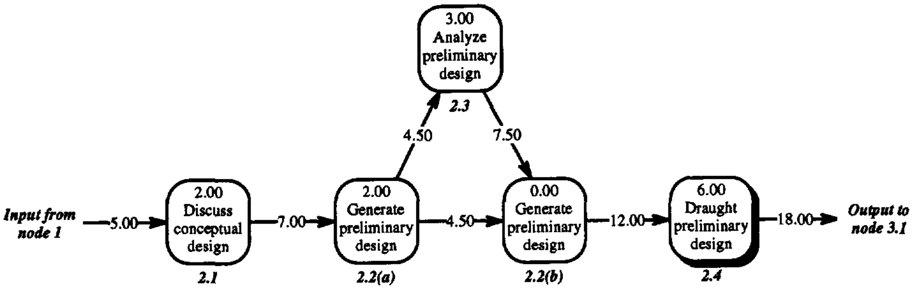
MODELLING COSTS CAD A1		**Dr.man 1**	**Dr.man 2**	**Dr.man 3**	**Dr.man 4**	**Average**	**Working average**
Model preliminary design							**5,6%**
	Study	0,50%	0,75%	1,00%	1,00%	**0,81%**	**0,8%**
	Model geometry	1,75%	1,75%	1,50%	2,00%	**1,75%**	**1,8%**
	Mark sizes	1,00%	0,75%	0,75%	0,50%	**0,75%**	**0,8%**
	Finalize drawings	0,25%	0,25%	0,25%	0,00%	**0,19%**	**0,2%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Model final design							**9,5%**
	Retrieve model	0,25%	0,25%	0,50%	0,25%	**0,31%**	**0,3%**
	Study	0,50%	1,25%	2,00%	1,00%	**1,19%**	**1,2%**
	Model geometry	3,75%	3,00%	2,00%	3,25%	**3,00%**	**3,0%**
	Mark sizes	3,00%	2,00%	2,50%	2,50%	**2,50%**	**2,5%**
	Finalize drawings	0,00%	1,00%	0,50%	0,50%	**0,50%**	**0,5%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Model detailed design							**10,4%**
	Retrieve model	0,25%	0,25%	0,50%	0,25%	**0,31%**	**0,3%**
	Study	0,50%	1,50%	2,50%	1,50%	**1,50%**	**1,5%**
	Model geometry	4,25%	3,50%	3,00%	3,75%	**3,63%**	**3,6%**
	Mark sizes	2,90%	2,40%	1,90%	2,40%	**2,40%**	**2,4%**
	Finalize drawings	0,50%	0,75%	0,50%	0,50%	**0,56%**	**0,6%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**

table 9.9: costs for modelling, to be used for production digraph A2

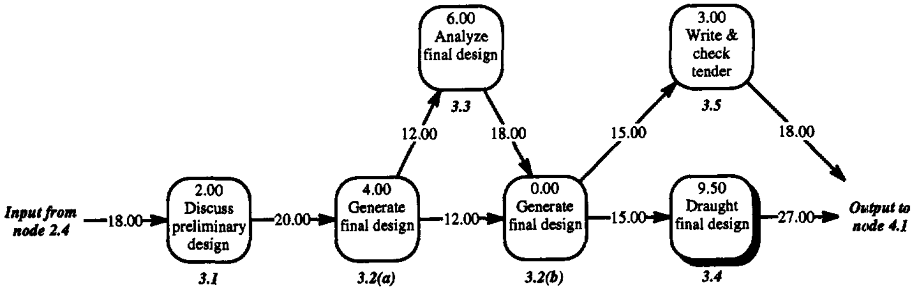
MODELLING COSTS CAD A2		**Dr.man 1**	**Dr.man 2**	**Dr.man 3**	**Dr.man 4**	**Average**	**Working average**
Model preliminary design							**5,6%**
	Study	0,50%	0,75%	1,00%	1,00%	**0,81%**	**0,8%**
	Model geometry	1,75%	1,75%	1,50%	2,00%	**1,75%**	**1,8%**
	Mark sizes	1,00%	0,75%	0,75%	0,50%	**0,75%**	**0,8%**
	Finalize drawings	0,25%	0,25%	0,25%	0,00%	**0,19%**	**0,2%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Model final design							**9,0%**
	Retrieve/adjust model	0,25%	0,25%	0,50%	0,25%	**0,31%**	**0,3%**
	Study	0,50%	1,25%	2,00%	1,00%	**1,19%**	**1,2%**
	Model geometry	3,25%	2,50%	1,50%	2,75%	**2,50%**	**2,5%**
	Mark sizes	3,00%	2,00%	2,50%	2,50%	**2,50%**	**2,5%**
	Finalize drawings	0,00%	1,00%	0,50%	0,50%	**0,50%**	**0,5%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**
Model detailed design							**9,2%**
	Retrieve/adjust model	0,25%	0,25%	0,50%	0,25%	**0,31%**	**0,3%**
	Study	0,50%	1,25%	2,00%	1,00%	**1,19%**	**1,2%**
	Model geometry	3,50%	3,00%	2,50%	3,00%	**3,00%**	**3,0%**
	Mark sizes	2,25%	2,00%	1,75%	2,50%	**2,13%**	**2,1%**
	Finalize drawings	0,75%	0,75%	0,50%	0,50%	**0,63%**	**0,6%**
	Check & administrate	2,00%	2,00%	2,00%	2,00%	**2,00%**	**2,0%**



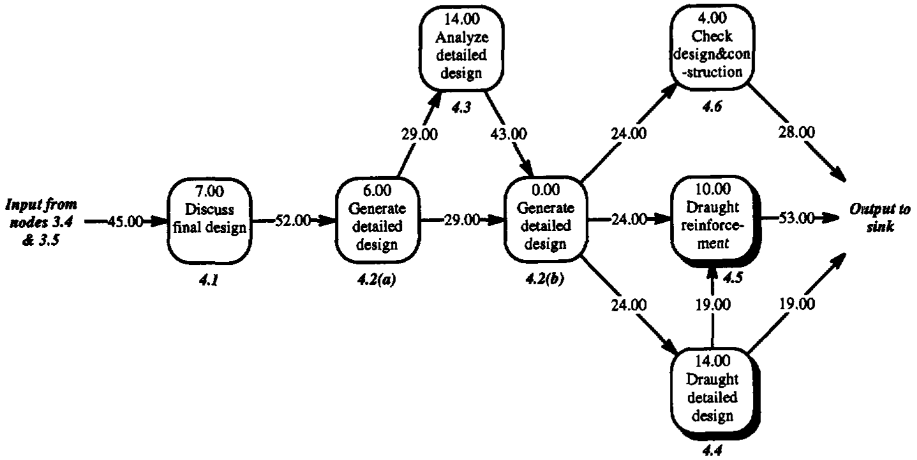
Level 1



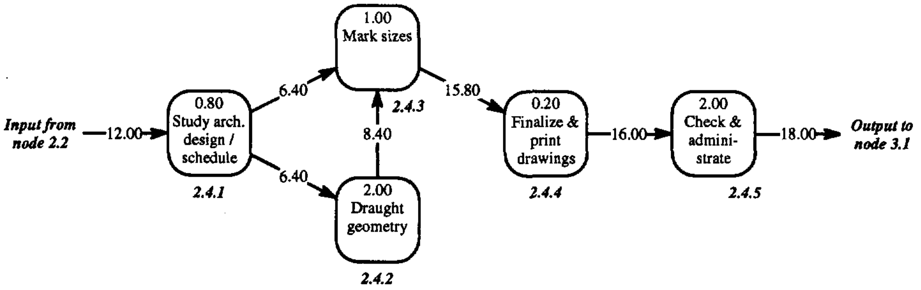
Level 2, Node 2: preliminary design



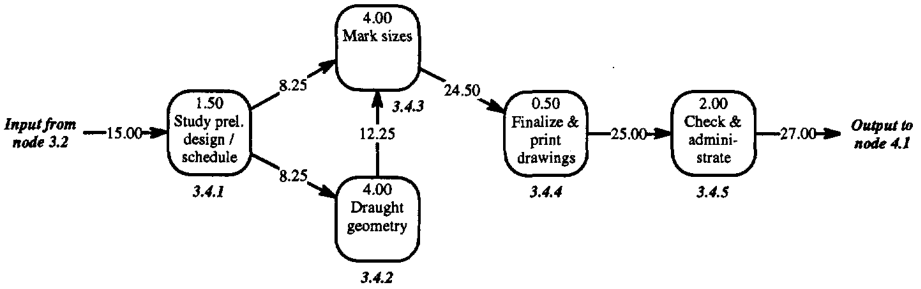
Level 2, Node 3: final design



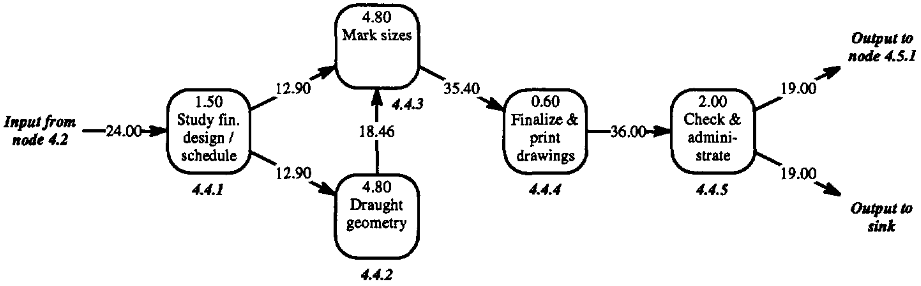
Level 2, Node 4: detailing



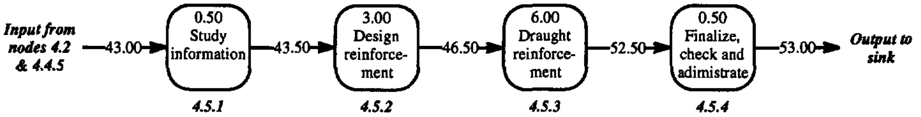
Level 3, Preliminary design, Node 2.4: draught preliminary design



Level 3, Final design, Node 3.4: draught final design

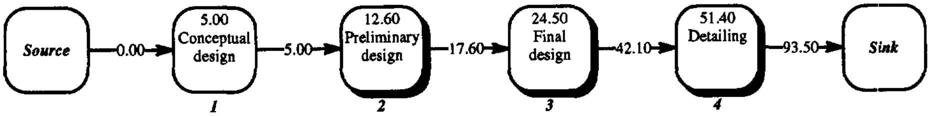


Level 3, Detailing, Node 4.4: draught detailed design

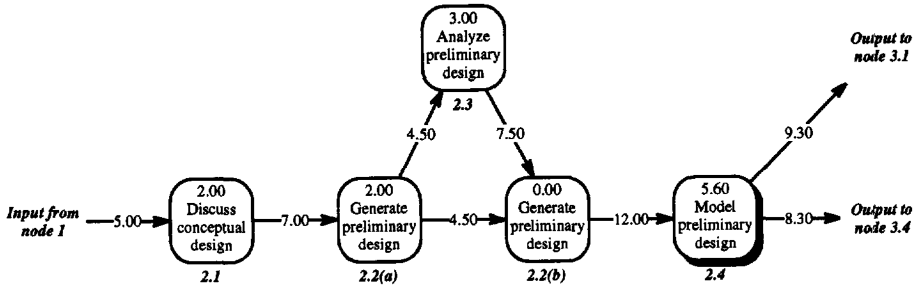


Level 3, Detailing phase, Node 4.5: draught reinforcement

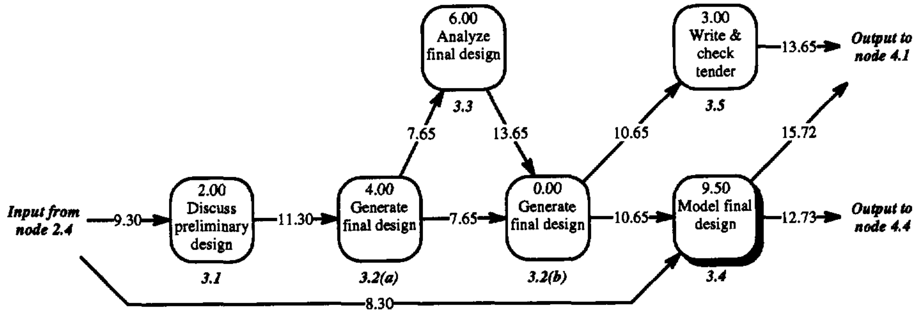
figure 9.2: production digraph A0



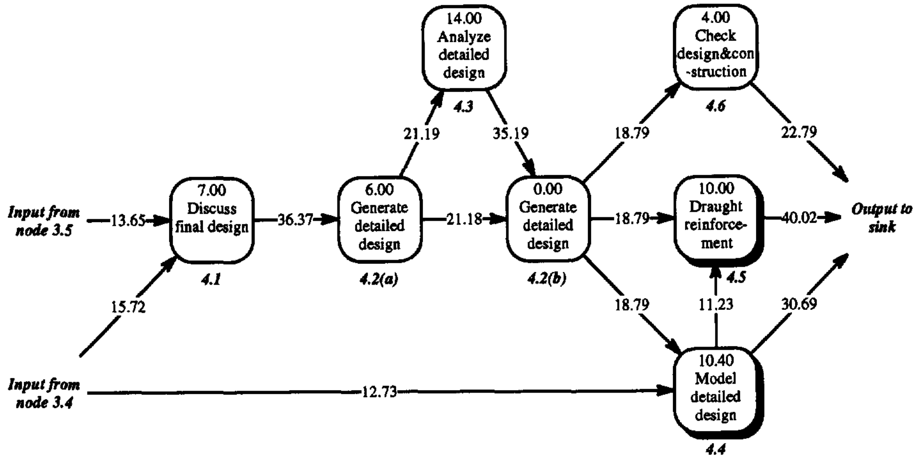
Level 1



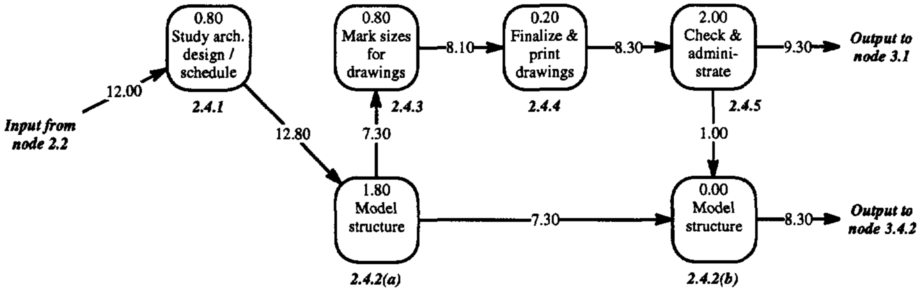
Level 2, Node 2: preliminary design



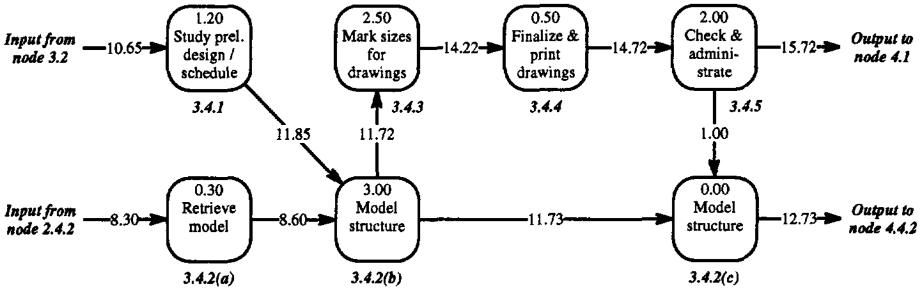
Level 2, Node 3: final design



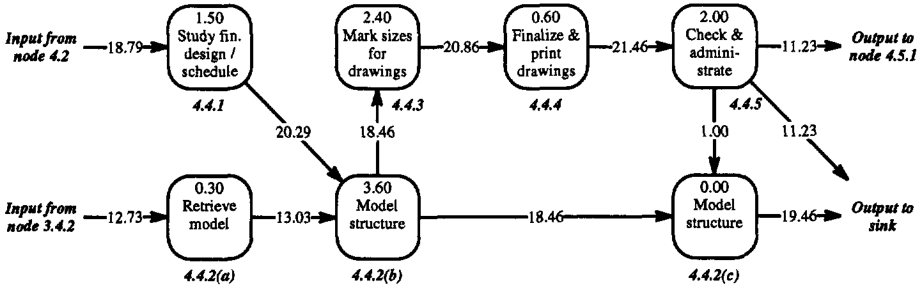
Level 2, Node 4: detailing



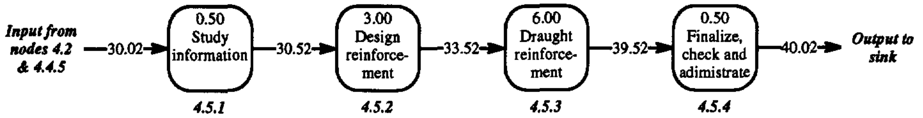
Level 3, Preliminary design, Node 2.4: model preliminary design



Level 3, Final design, Node 3.4: model final design

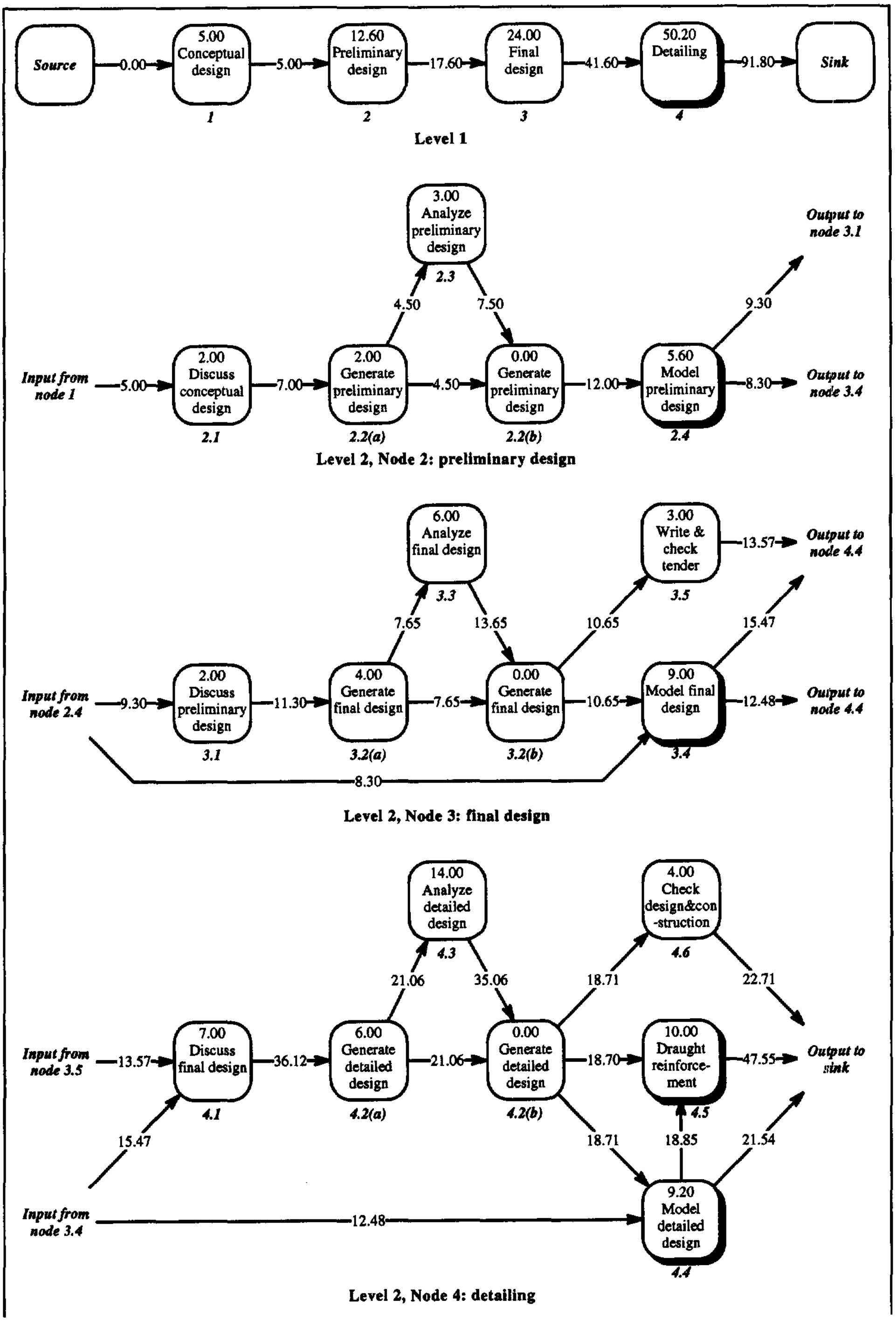


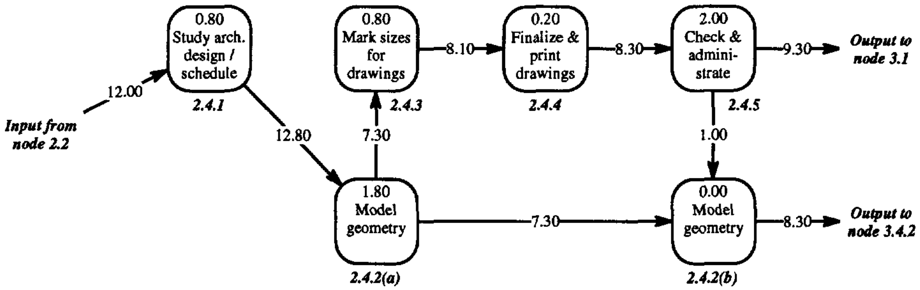
Level 3, Detailing phase, Node 4.4: model detailed design



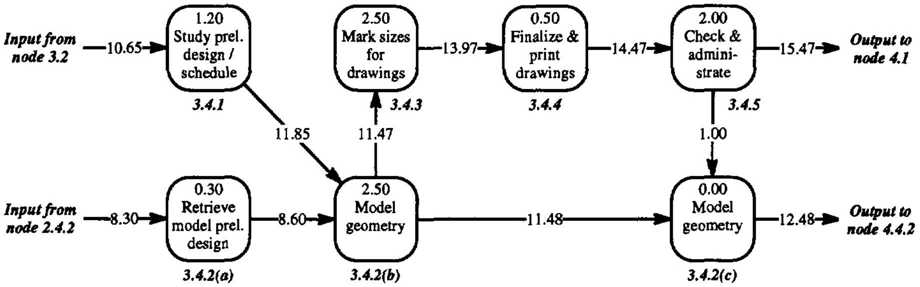
Level 3, Detailing phase, Node 4.5: draught reinforcement

figure 9.3: production digraph A1

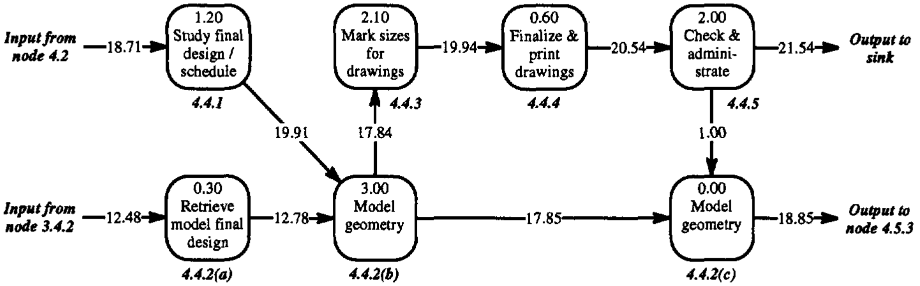

Source
0.00
5.00
Conceptual design
1
5.00
12.60
Preliminary design
2
17.60
24.00
Final design
3
41.60
50.20
Detailing
4
91.80
Sink
Level 1
Input from node 1
5.00
2.00
Discuss conceptual design
2.1
7.00
2.00
Generate preliminary design
2.2(a)
4.50
3.00
Analyze preliminary design
2.3
4.50
7.50
0.00
Generate preliminary design
2.2(b)
12.00
5.60
Model preliminary design
2.4
9.30
Output to node 3.1
8.30
Output to node 3.4
Level 2, Node 2: preliminary design
Input from node 2.4
9.30
2.00
Discuss preliminary design
3.1
11.30
4.00
Generate final design
3.2(a)
7.65
6.00
Analyze final design
3.3
7.65
13.65
0.00
Generate final design
3.2(b)
10.65
3.00
Write & check tender
3.5
13.57
Output to node 4.4
10.65
9.00
Model final design
3.4
15.47
Output to node 4.4
12.48
8.30
Level 2, Node 3: final design
Input from node 3.5
13.57
7.00
Discuss final design
4.1
15.47
36.12
6.00
Generate detailed design
4.2(a)
21.06
14.00
Analyze detailed design
4.3
21.06
35.06
0.00
Generate detailed design
4.2(b)
18.71
4.00
Check design&con-struction
4.6
22.71
18.70
10.00
Draught reinforce-ment
4.5
47.55
Output to sink
18.71
18.85
21.54
Input from node 3.4
12.48
9.20
Model detailed design
4.4
Level 2, Node 4: detailing



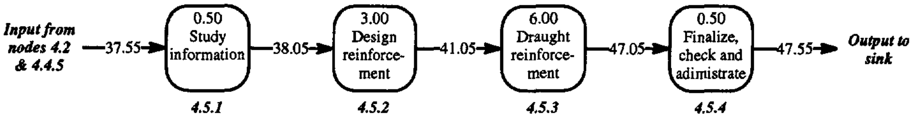
Level 3, Preliminary design, Node 2.4: model preliminary design



Level 3, Final design, Node 3.4:model final design

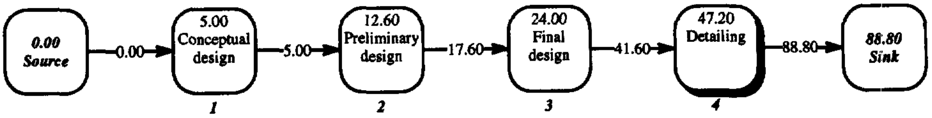


Level 3, Detailing, Node 4.4: model detailed design

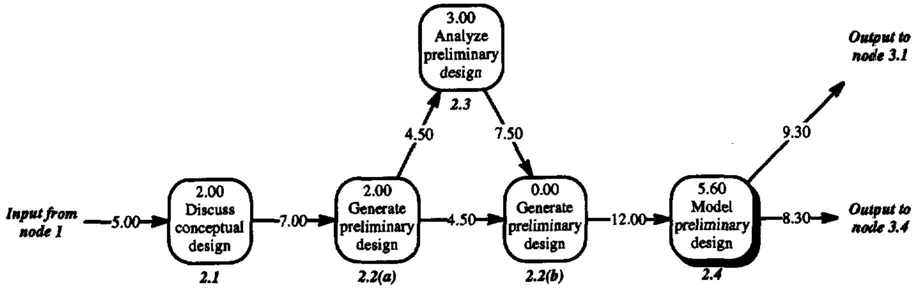


Level 3, Detailing phase, Node 4.5: draught reinforcement

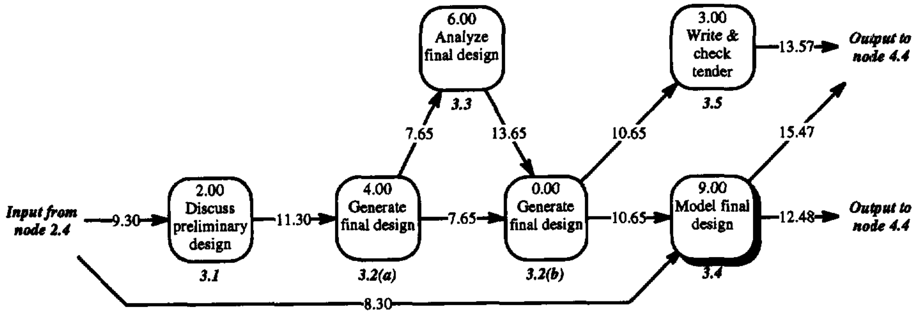
figure 9.4: production digraph A2



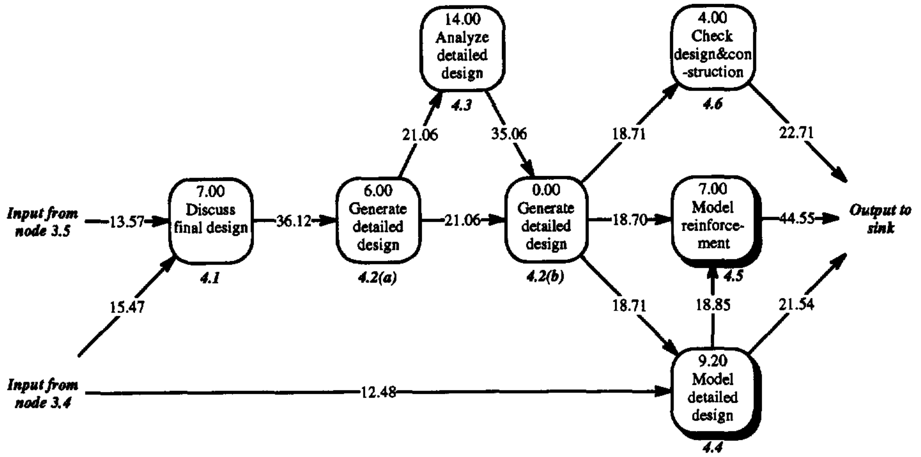
Level 1



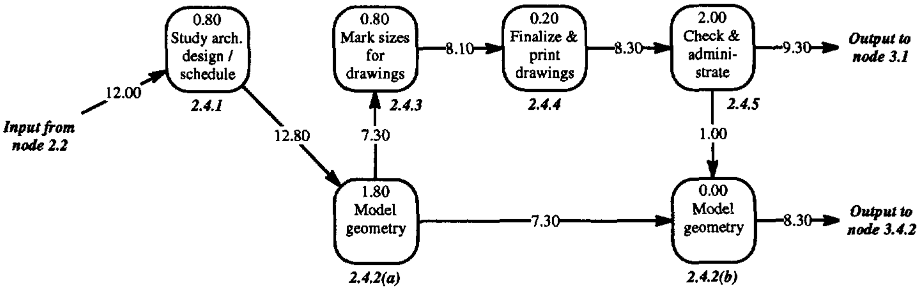
Level 2, Node 2: preliminary design



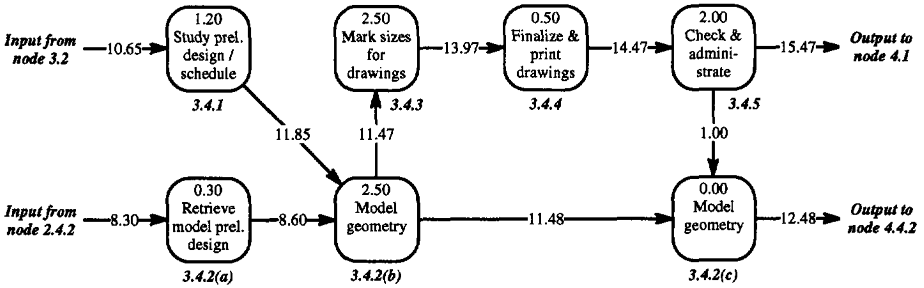
Level 2, Node 3: final design



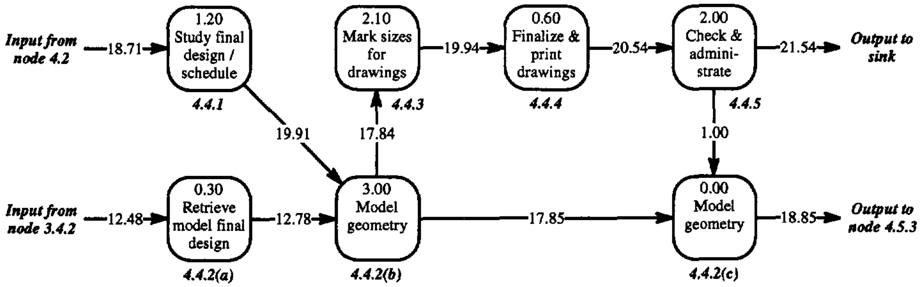
Level 2, Node 4: detailing



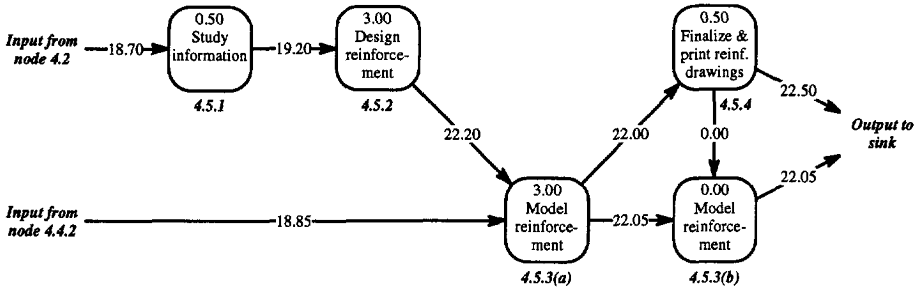
Level 3, Preliminary design, Node 2.4: model preliminary design



Level 3, Final design, Node 3.4:model final design



Level 3, Detailing, Node 4.4: model detailed design



Level 3, Detailing phase, Node 4.5: model reinforcement

figure 9.5: production digraph A3

9.2.5 Analysis of effects (descriptive)

The initial production digraph (A0) is used as a reference for determining the effects of the CAD systems A1 and A2 on the structural design process. The effects are presented by alternative production digraphs (A1-A3). Production digraph A1 presents the effects of the use of CAD system A1, while production digraph A2 presents the effects of the use of CAD system A2. Finally, production digraph A3 presents the effects of an alternative deployment of CAD system A2.

9.2.5.1 Structural effects

The structural effects of deploying CAD system A1 are determined from comparison of the production digraphs A0 and A1. These effects are discussed on the different levels of aggregation of the production digraphs: level 1, level 2, and level 3. Effects are better seen at the lower level of aggregation: level 3.

On the highest level of aggregation (level 1) no structural effects can be determined; these will appear at levels 2 and 3. Effects which can be determined are the reductions in the node-weights *c(2)*, *c(3)*, and *c(4)*. Secondly, the changes in the arc-weights *w(2, 3)*, *w(3, 4)*, and *w(4, sink)*, resulting from the reductions in the node-weights. Finally, arc-weight *w(4, sink)*, representing the input to the sink is lowered with 6,50%. This implies that the total project-costs are reduced by 6,50%.

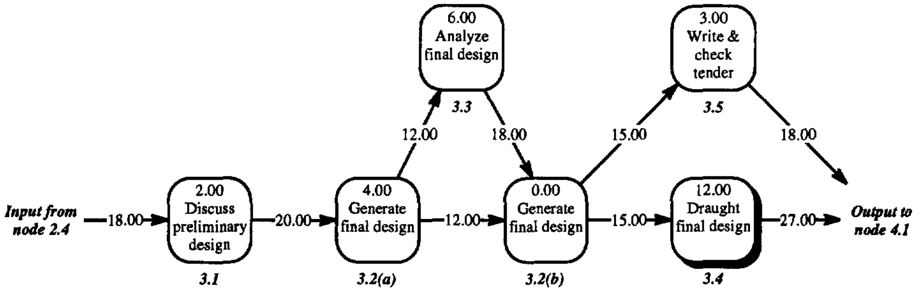
The effects on level 1 can be explained by considering a lower level of aggregation: level 2. On level 2 changes can be identified at nodes 2.4, 3.4, and 4.4. The changes are similar for all these nodes. The nodes are substituted by other nodes due to the use of CAD systems. Together with this substitution arcs are added to connect these node, since they have input-output relations.

These changes are illustrated by comparing node 3 (final design) of production digraphs A0 and A1 (see figure 9.6). Node 3.4 ("draught final design") is substituted by a new node 3.4 ("model final design"). Two arcs are added: the first represents input from (new) node 2.4 ("model preliminary design"), while the second represents output to (new) node 4.4 ("model detailed design"). Nodes 2.4, 3.4, and 4.4 are linked in this way. The practical implication of this is that an initial model of the structure is made (activity 2.4) which is refined in the following activities (3.4 and 3.5).

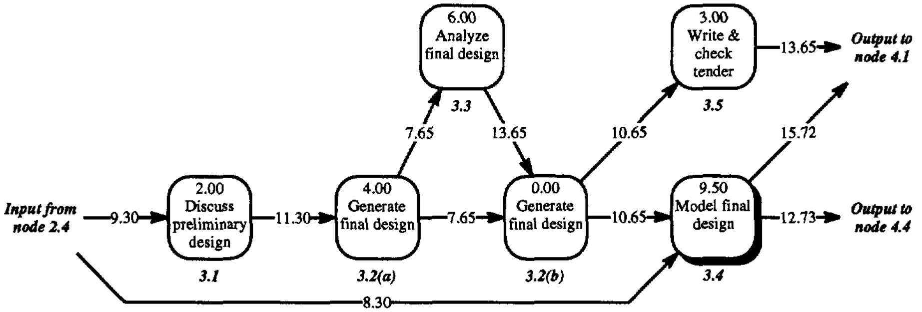
Similar changes can be determined for nodes 2.4 and 4.4; "draught preliminary design" and "draught detailed design" are replaced by "model preliminary design" and "model detailed design" respectively. Node 2.4 has an output to node 3.4, while node 4.4 has both an input from node 3.4 and an output to node 4.5.

The major effects with regard to node-weights and arc-weights at level 2 are:
1. the reductions in the node-weights *c(2.4)*, *c(3.4)*, and *c(4.4)*,
2. the changes in the arc-weights, which represent the output from these nodes.

Note that the other arc-weights at level 2 are changed as well, as a result of changes in previous node-weights and arc-weights in the production digraph.



Production digraph A0, Level 2, Node 3: final design



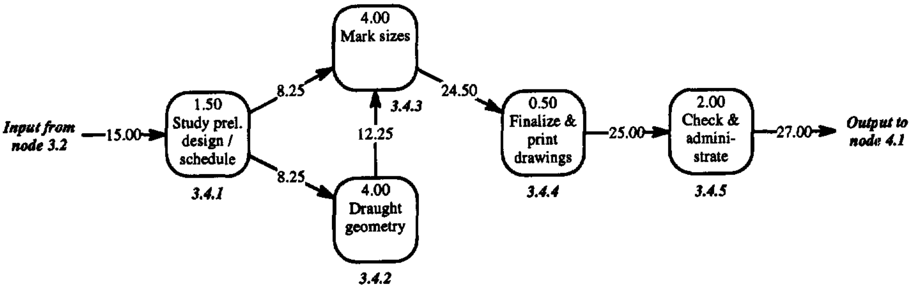
Production digraph A1, Level 2, Node 3: final design

figure 9.6 comparison of node 3 (final design)

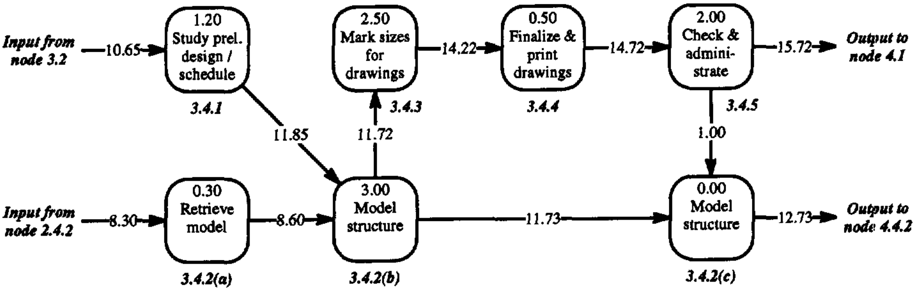
To illustrate the effects at level 3 the A0-sub-digraph "level 3, final design, draught final design" is compared with the A1-sub-digraph "level 3, final design, model final design" (see figure 9.7). The first change which can be identified at this level is the substitution at node 3.4.2: "draught geometry" is substituted by "model structure". This new node consists of three sub-nodes 3.4.2(a-c): retrieve model, model structure, and a dummy-node (model structure). The latter is used to avoid a cycle, and account for input to node 3.4.2 from node 3.4.5. Arcs have been added to represent input from nodes 2.4.2. and 3.4.5. to node 3.4.2. and output from node 3.4.2. to node 4.4.2.

The second change is the substitution at node 3.4.3: "mark sizes" is substituted by "mark sizes for drawings". Together with this changes the arc representing input from node 3.4.1. is deleted. The complete output from node 3.4.1. is re-directed to node 3.4.2.

With regard to node-weights and arc-weights the following changes can be observed. The node-weights *c(3.4.1)*, *c(3.4.2)* and *c(3.4.3)* are reduced. The arc-weight *w(3.4.5, 4.4.1)* is higher than the arc-weight *w(3.4.2, 4.4.2)*, since the additional activities (3.4.3 and 3.4.4) are needed for the first alone. Only half of the node-weight *c(2.4.5)* is distributed to node 3.4.2, through arc-weight *w(2.4.5, 2.4.2.b)*.



Production digraph A0, Level 3, Final design, Node 3.4: draught final design



Production digraph A1, Level 3, Final design, Node 3.4: model final design

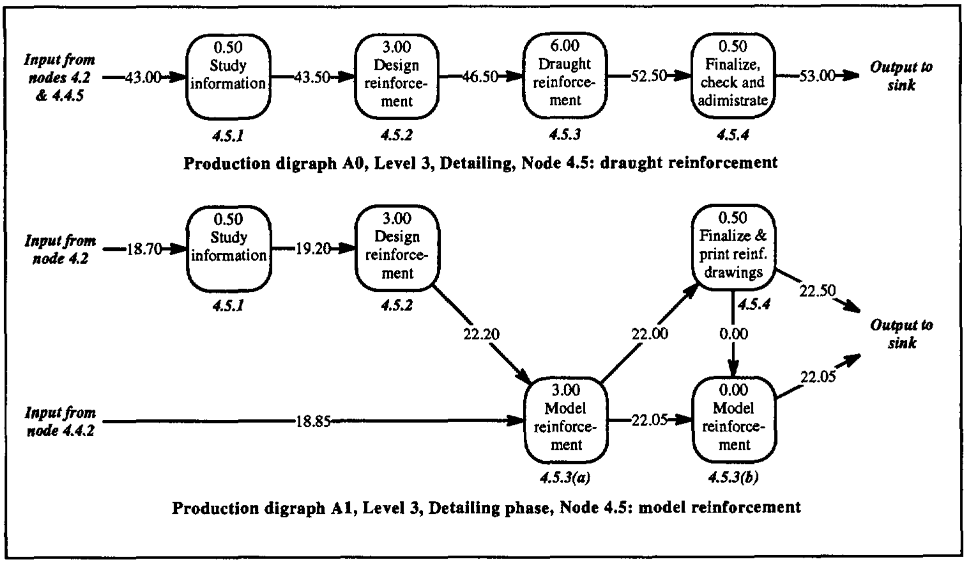
figure 9.7: comparison of node 3.4 (draught / model final design)

Similar changes can be determined at level 3 for "model preliminary design" and "model detailed design". The only difference is that in "model preliminary design" the activity "retrieve model prel. design" is missing, since there is no model to be retrieved at that stage. Changes in node-weights and arc-weights are also similar, but the exact weights differ.

The structural effects of use of CAD system A2 are determined form comparison of the production digraphs A0 and A2. When including production digraph A1 in this analysis it becomes apparent that the structural effects resulting from CAD systems A1 and A2 are similar. The differences in effects refer to the reductions in node-weights, leading to a reduction of the input to the sink (level 1) of 8,20%.

The structural effects of the alternative deployment of CAD system A2 are determined from comparison of the production digraphs A0 and A3. When including production digraph A2 in this analysis it becomes apparent that differences resulting from this alternative deployment occur on level 3 ("model reinforcement") only. On level 1 the overall effect is a reduction of 11.20%.

On level 2 there is a substitution for node 4.5: activity "draught reinforcement" is replaced by activity "model reinforcement". The second change, which can be observed is the reduction of *c(4.5)*. Finally, the arcs are not altered, but the arc-weights are. This can be analyzed in detail at level 3.



Production digraph A0, Level 3, Detailing, Node 4.5: draught reinforcement

Production digraph A1, Level 3, Detailing phase, Node 4.5: model reinforcement

figure 9.8: comparison of node 4.5 (draught / model reinforcement)

Analysis on level 3 shows that node 4.5.3 is altered: activity "draught reinforcement" is substituted by "model reinforcement" (including dummy-node to avoid a cycle). The arc representing input from node 4.4.5. to node 4.5.1. is deleted. A new arc is added representing output from node 4.4.2. to node 4.5.3. The model is input to activity 4.5.3, which van be considered to be another refinement of the model. Node 4.5.3. has a double output: one to node 4.5.4 and another to the sink.

9.2.5.2 Effects attributed to CAD systems

Effects are related to the specific elements of the value adding dimensions of the CAD systems. In particular to the elements of the informational kernel of the CAD software. In tables 9.10-9.12 the effects are attributed to the specific elements of the value adding dimensions of the CAD software. The effects on aggregation level 3 are considered, since they are the most detailed. Tables 9.10-9.12 also provide the total cost-reductions, based on the average of estimates provided by draughtsmen. In addition an interval is provided for the cost-reductions. It is based on the minimum and maximum values of the estimates provided by the draughtsmen (see tables 9.7-9.9).

9.2.6 Predictive analysis

So far the use of the production digraph model for descriptive analysis has been illustrated. The cost-effects of currently deployed CAD systems have been analyzed. The production digraphs clearly show that use of these systems alters the production of drawings by substitution of the draughting-activities by modelling-activities. However, most of the changes in the production digraphs involve modifications of node- or arc-weights. The structural changes were relatively small.

table 9.10: cost-effects related to elements of the value adding dimensions of CAD system A1

Node-number	Cost-effects	Elements of value adding dimensions[10]	Remarks
2.4.2.a	- 0,20%	1, 5, 6, 7	Modelling must be very accurate to account for the precise sizes.
2.4.3	- 0,20%	2	Sizes are derived by the CAD system from the model. Draughtsman indicates which sizes to be included, and on which spot on the drawings. Not many sizes are required.
3.4.1	- 0,30%		Less effort is required for scheduling presentation of the structure on drawings (page-size, scale, etc.) Can be modified when needed.
3.4.2.a	+ 0,30%	3, 4, 5, 8 (model prel. design)	Part of modelling. Convert the graphical entities and symbols to the appropriate scale.
3.4.2.b	- 1,00%	1, 5, 6, 7, 8	The previous model is being refined.
3.4.3	- 1,50%	2	Sizes are derived from the model. The number sizes required is higher.
4.4.1	- 0,30%		Less effort required for scheduling.
4.4.2.a	+ 0,30%	3, 4, 5, 8 (final design)	Convert previous model.
4.4.2.b	- 1,20%	1, 5, 6, 7, 8	The previous model is refined.
4.4.3	- 2,40%	2	All relevant sizes must be specified.
Total	- 6,50%		Interval: 5,60% - 8,85%

table 9.11: cost-effects related to elements of the value adding dimensions of CAD system A2

Node-number	Cost-effects	Elements of value adding dimensions[10]	Remarks
2.4.2.a	- 0,20%	1, 5, 6, 7	Modelling must be very accurate.
2.4.3	- 0,20%	2	Sizes are computed by the CAD system from the model.
3.4.1	- 0,30%		Less effort is required for scheduling.
3.4.2.a	+ 0,30%	3, 4, 5, 8 (model prel. design)	Part of modelling. Convert the graphical entities and symbols to the appropriate scale.
3.4.2.b	- 1,50%	1, 5, 6, 7, 8, 9	Use of graphical symbols of standard construction details.
3.4.3	- 1,50%	2	Sizes are computed by the CAD system.
4.4.1	- 0,60%		Less effort required for scheduling. Standard details are presented on separate sheets.
4.4.2.a	+ 0,30%	3, 4, 5, 8 (final design)	Convert previous model.
4.4.2.b	- 1,80%	1, 5, 6, 7, 8, 9	Use of graphical symbols of standard construction details. All details are required.
4.4.3	- 2,70%	2, 9	Sizes of details are often included in the graphical symbols.
Total	- 8,20%		Interval: 7,25% - 9.00%

table 9.12: cost-effects related to elements of the value adding dimensions of CAD system $A2^{alt}$

Node-number	**Cost-effects**	**Elements of value adding dimensions**[10]	**Remarks**
2.4.2.a	- 0,20%	1, 5, 6, 7	Modelling must be very accurate.
2.4.3	- 0,20%	2	Sizes are computed by the CAD system.
3.4.1	- 0,30%		Less effort is required for scheduling.
3.4.2.a	+ 0,30%	3, 4, 5, 8 (model prel. design)	Part of modelling. Convert the graphical entities and symbols to the appropriate scale.
3.4.2.b	- 1,50%	1, 5, 6, 7, 8, 9	Use of graphical symbols of standard construction details.
3.4.3	- 1,50%	2	Sizes are derived from the model. The number of sizes required is increased.
4.4.1	- 0,60%		Less effort required for scheduling. Standard details are presented on separate sheets.
4.4.2.a	+ 0,30%	3, 4, 5, 8 (final design)	Convert previous model.
4.4.2.b	- 1,80%	1, 5, 6, 7, 8, 9	Use of graphical symbols of standard construction details.
4.4.3	- 2,70%	2, 9	Sizes of details are often included in the graphical symbols.
4.5.3.a	- 3.00%	1, 5, 6, 7, 8 (detailed design), 9	Simple reinforcement for slabs and walls (simple shape, uniform reinforcement, etc.). Symbols can be edited. Material-take-off by the CAD system for production of bar-bending-schedules is not possible.
Total	-11,20%		Interval: 10,25% - 12,00%

The production digraph model has predictive abilities as well. To demonstrate these abilities the effects of the deployment of a hypothetical CAD system (CAD system $_{\text{hypo}}$) is considered. This CAD system combines the elements of the value adding dimensions of CAD system A2 with so-called analysis & design modules. Currently, such modules are available for reinforced concrete beams. In this hypothetical case it is assumed that they are available for all structural elements (details). These modules analyze the element, design its reinforcement, and model the element (including reinforcement). Input to the module consists of the geometry of the element and the loads on the elements. Output is the model which can be manipulated with CAD system A2.

These modules are not expected to alter the first phases of structural design. Changes are most likely to occur in the detailing phase, since elements are detailed in this phase of design. Production digraph A4 shows the expected changes, resulting from use of the modules together with CAD system A2 (see figure 9.8). Expected structural changes, induced by the deployment of this system, are clearly shown in the production digraph. For the node- and arc-weights however detailed analysis is required. In production digraph A4, estimates for node- and arc-weight are provided.

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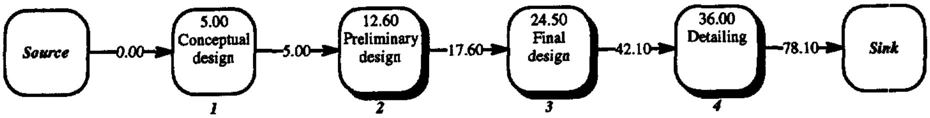
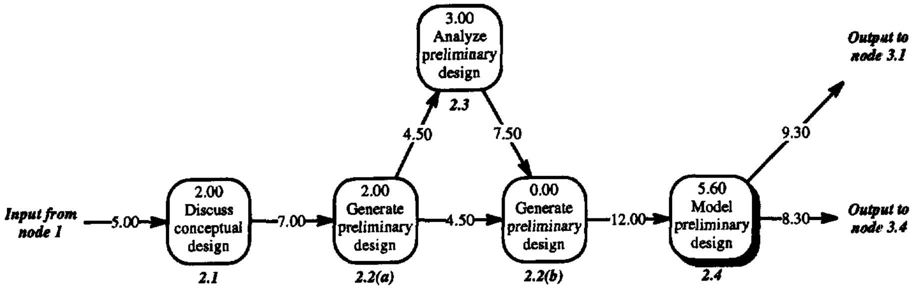
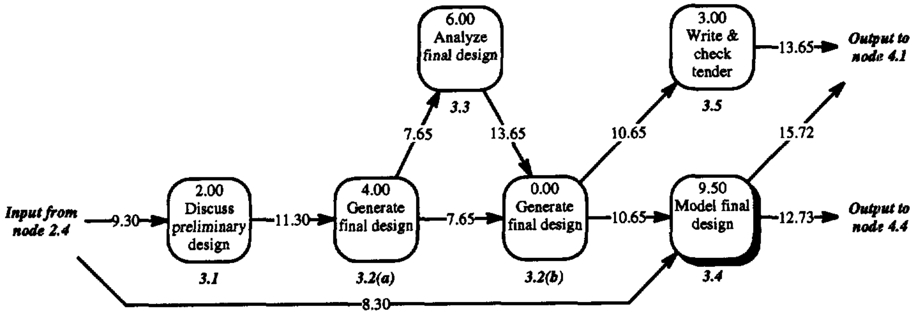
[10] Numbers refer to the elements of the value adding dimensions in table 9.3



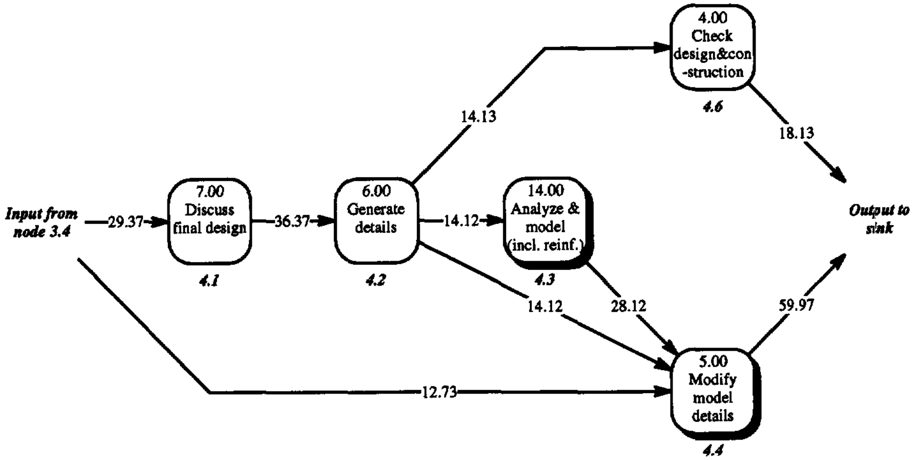
Level 1



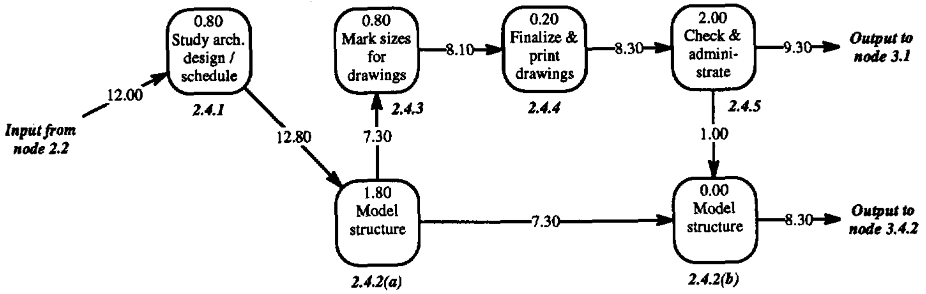
Level 2, Node 2: preliminary design



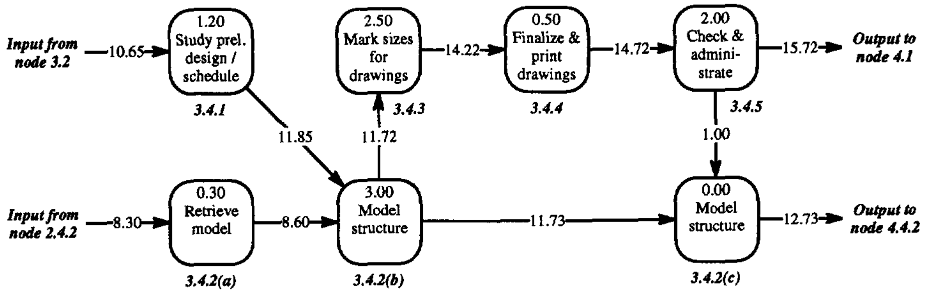
Level 2, Node 3: final design



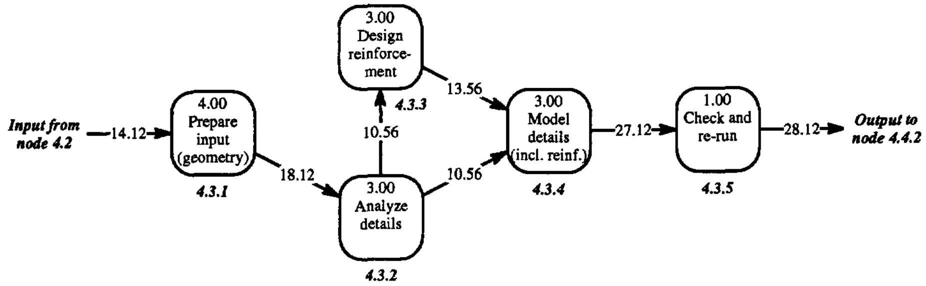
Level 2, Node 4: detailing



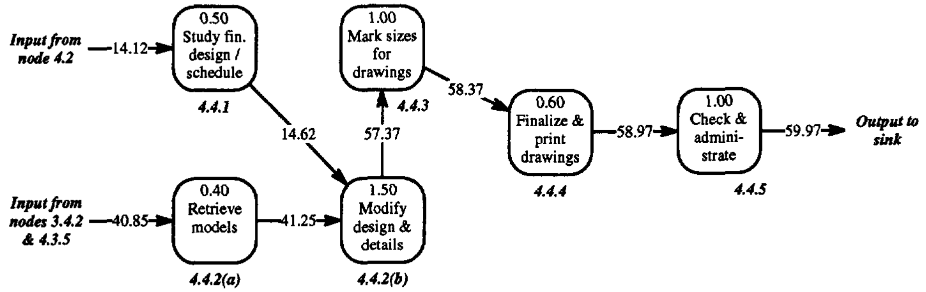
Level 3, Preliminary design, Node 2.4: model preliminary design



Level 3, Final design, Node 3.4: model final design



Level 3, Detailing phase, Node 4.3: analyze & model details



Level 3, Detailing phase, Node 4.4: modify model details

figure 9.9: production digraph A4

Expected changes on level 2 are as follows

1. nodes 4.3, 4.4, and 4.5 in the original production digraph are combined to one new node 4.3 "analyze & model (incl. reinf.)",
2. a new node 4.4 ("modify models details") is added, since it is expected that the output from nodes 4.4 and 4.3.2 must be modified and merged; these modifications are needed, because a part of the structural elements cannot be detailed using the modules and last-minute changes are often required,
3. an arc is added to represent output from node 4.2 to node 4.4.

The activities involved in the "analyze & model (incl. reinf.)" are shown at level three. Except for activities 4.3.1. and 4.3.5, the activities are performed by the modules (automatically). Nodes 4.3.1. and 4.3.5 require the input of human effort in co-operation with the features of the modules.

The activities of node 4.4 "modify model details" do not differ much from those in the production digraph A2. This part of the production digraph remains the same. The only difference is that it deals with modification and a smaller part of the structural elements.

The node- and arc-weights are based on estimates rather than on cost-evaluations. However, the cost-effects are very likely to occur, since the estimates are based on experience of such systems at other engineering consultants. For example, the deployment of such a system for the analysis & design of reinforced concrete beams at engineering consultant 2, and a similar system at another engineering consultant (see Lebbink, 1991).

9.2.7 Conclusion

This case-study clearly shows the relation between the elements of value adding dimensions of CAD systems and their effects on the structural design process. CAD systems reduce the costs for two reasons. First, graphical modelling, using a CAD system, is done more efficiently than draughting, using a draughting board. Partly this results from the procedural information furnished by the CAD systems, and partly from the declarative information in the form of graphical information in the project-files. The latter results in substantial cost-reductions in the later phases of structural design, such as final design and detailing. The production digraph model clearly shows the cost-effects, leading to cost-reductions.

In the second place, project-costs are lowered because dimensions are determined by the CAD system. During draughting, the draughtsmen put a lot of effort in determination and notation of the sizes of the structural components on the drawings. When using CAD systems, this effort is reduced, since these measurements are computed by the CAD system and placed on the drawings on the spot marked by the draughtsmen. So, the only thing the draughtsmen need to do is to select which sizes are needed and to mark the spot where the dimensions should be placed.

This case-study also shows that higher cost-reduction could be achieved by using more advanced CAD systems or an alternative deployment of CAD systems. For example, CAD system A2 results in an increase of the cost-reduction of 2,70%, when compared with CAD system A1. CAD system A2 is more advanced than CAD system A1, since it incorporates a library with graphical symbols of standard construction details. The increase in cost-reduction is attributable entirely to the availability of this library.

CAD system A2 can be deployed for the modelling of reinforcement as well. For simple reinforcement (in slabs, wall, etc.), which is considered in this case, the cost-reduction increases by approximately 3,00%. However, it must be emphasized that this figure must be handled with care, since it is based on the estimate of one (experienced) draughtsman, and is valid for simple reinforcement only.

Throughout this section the average cost-reductions are discussed. Comparison of these averages with the intervals for cost-reductions provided in tables 9.10-9.12 shows that they are quite accurate. In particular for the deployment of CAD system A2 and CAD system $A2^{alt}$.

The cost-reductions can be used to determine upper-bounds for the demand value of the deployment of CAD systems. These upper-bounds can be interpreted as an estimate of the maximum amount of money the engineering consultants might be willing to invest in the deployment of these systems. This amount should be compared to all costs involved in the deployment of CAD systems, such as costs for purchase of the system, training of draughtsmen, maintenance of the system, management, system-control, etc.

Upper-bounds for the demand value of CAD systems can be determined in monetary terms as:

$$\delta_x = \sum_{y=1}^{n} \alpha_{x,y}\ \beta_y\ \Delta$$

with: δ_x: upper-bound for the demand value of CAD system x (in Dfl. per annum),
$\alpha_{x,y}$: reduction of project-costs of project-category y, resulting from the deployment of CAD system x (in %),
β_y: share of project-category y in the annual turnover (in %),
Δ: annual turnover (Dfl. 4.000.000,--),
n: number of project-categories.

Assuming that use of the CAD systems has similar effects on the other project-categories, and no effects on "research and development" results in the following values for $\alpha_{x,y}$ and β_y:

	Project-category 1	**Project-category 2**	**Project-category 3**
β_y	70%	10%	15%
$\alpha_{x,y}$			
CAD system A1	6,50%	6,50%	6,50%
CAD system A2	8,20%	8,20%	8,20%
CAD system $A2^{alt}$	11,20%	11,20%	11,20%
CAD system ^{hypo}	21,90%	21,90%	21,90%

The values can be used to determine the upper-bounds for the demand value of CAD systems for engineering consultant 1:

$\delta_{\text{CAD system A1}} = \{0{,}065 \quad 0{,}70 + 0{,}065 \quad 0{,}10 + 0{,}065 \quad 0{,}15) \quad 4.000.000 =$ Dfl. 247.000,--

$\delta_{\text{CAD system A2}} = \{0{,}082 \quad 0{,}70 + 0{,}082 \quad 0{,}10 + 0{,}082 \quad 0{,}15) \quad 4.000.000 =$ Dfl. 311.600,--

$\delta_{\text{CAD system A2alt}} = \{0{,}112 \quad 0{,}70 + 0{,}112 \quad 0{,}10 + 0{,}112 \quad 0{,}15) \quad 4.000.000 =$ Dfl. 425.600,-

$\delta_{\text{CAD system hypo}} = \{0{,}219 \quad 0{,}70 + 0{,}219 \quad 0{,}10 + 0{,}219 \quad 0{,}15) \quad 4.000.000 =$ Dfl. 832.200,--.

Another way of presenting the cost-reductions is by relating it to the costs of draughting in the initial structural design process. Draughting involved 32,00% of the total project-costs, which is reduced to 11,20%, when CAD system $A2^{alt}$ is used. This implies that approximately 35% (11,20 / 32,00 = 35%) of draughting-costs in projects could be spent on investments in the use of CAD system $A2^{alt}$.

The case-study shows that the effects of a CAD system depend not only on the specific elements of the value adding dimensions, but on the way it is used as well. The optimal way of use of CAD systems could depend on variables, such as organizational, managerial and cultural factors at the engineering consultants. In studying the effects of CAD systems these variables must be considered, and the production digraph model provides an instrument for examining cost-effects of these variables.

Using the production digraphs produced in the case-study, the maximum cost-reduction which can be achieved with this kind of CAD systems can be determined. These CAD systems support draughting mainly. The maximum share of the project cost involved in draughting (read draught geometry and mark sizes, excluding study information, check & administrate, etc.) is approximately 23,60%. This represents the maximum cost-reduction which could be achieved with these type of CAD systems.

The production digraph model can be used to predict the effects of different types of CAD systems as well. In this case-study the use of modules for analysis and detailing of structural elements has been considered. The structural changes can be determined clearly, while determination of weights need some in-depth analysis. Although the weights in production digraph A4 are based on estimates, the model strongly suggests that substantial cost-reductions - approximately 21,90% - could be achieved with the use of these modules.

In addition to studying cost-effects of CAD systems, the production digraphs produced in this case-study could be used for other purposes as well. For example, the information provided by the production digraphs could be used for project-budgeting. That is just what engineering consultants 1 did when faced with a new (complex) project.

9.3 Case 2

9.3.1 Engineering consultant's profile

Case 2 concerns one of the five branch-offices of an engineering consultant, in this chapter referred to as engineering consultant 2. The engineering consultant has been in business for more than 22 years, while the branch-office has 16 years experience in designing structures, mainly in the Netherlands. It is specialized in the design of concrete structures and in the detailing of prefab structural elements, on a commission basis for producers in the prefabricated concrete construction industry. Almost one third of their projects is related to prefabricated concrete construction. A profile of the branch-office is provided in table 9.13.

table 9.13: profile of engineering consultant 2

CASE 2: ENGINEERING CONSULTANT 2				
Number of employees				***28***
Engineering consultants				3
Structural engineers				4
Structural engineers-draughtsmen				12
Draughtsmen				7
Administrative personnel				2
Annual turnover (Dfl.)				***3.300.000,-***
Average number of projects per annum				***100***
Type of project	**Share in turnover**	**Average project size**	**Bandwidth project size**	**Number of projects (finished per annum)**
Structural design of office-buildings	50%	60000	50000 - 70000	25
Structural design of industrial buildings	15%	50000		10
Detailing of prefabricated elements	25%	35000	25000 - 45000	20
Structural design of civil structures	10%	50000		5

The engineering consultant deals with the structural design of several structures, which differ with regard to type and size of the projects (see tables 9.13 and 9.16). The analyses of cost-effects of CAD systems focused on the design and detailing of prefabricated concrete office-buildings on the one hand, and on structural design of (traditional) building and civil structures on the other hand. These categories represent the majority of the projects, all of which are rather small. The average time required for structural design of these structures varies between 6 and 9 months.

9.3.2 Experience with CAD systems

Engineering consultant 2 was one of the first in the Netherlands to use CAD systems in structural design. Together with the other branch-offices and a related technical software developer, a lot of effort has been put in development and use of CAD systems. According to engineering consultant 2, the reason for introducing CAD systems was to maintain and/or improve the firm's competitiveness in the market. The use of CAD systems has supported the consultant's strategy to provide better structural design services to clients at reasonable costs.

The use of CAD systems is based on AutoCAD and is used mainly for the production of drawings. However, standard AutoCAD (release 11 and 12) has been tailored to the specific nature of projects, performed by the branch-office. Additional facilities have been developed, such as the definition of standard settings in layers, libraries of graphical symbols, a set of routines (so-called macro's) for re-scaling of graphical symbols, and predefined structural elements and reinforcement. The software is running on personal computers (MS Dos) which are connected in a local area network (Novell).

At engineering consultant 2, the implementation of CAD systems is complete. CAD systems are available to all staff-members. Current and future investments are likely to focus mainly on upgrading of the current systems. The complete implementation of CAD systems appears to have increased the number of structural engineers-draughtsmen, while reducing the number of draughtsmen.

The engineering consultants's management reported that the main effects of CAD systems' use are cost-reductions, quality-improvements of drawings, improved possibilities for complex geometrical shapes, improved possibilities for optimization, and reduction of effort for marking dimensions on drawings. The cost-reductions are estimated at about 50% of traditional draughting. However the cost-reductions depend on the nature of the project and the participants involved. Furthermore, it was mentioned that a part of possible cost-reductions is invested in quality improvements of drawings.

The managers provided an example of the effects of CAD systems by considering changes in the annual turnover of the branch-office. It was determined that the annual turnover increased by 10% in one year, while the number of employees and the tools used remained the same. This increase is attributed primarily to the use of CAD systems. The skills of the employees working with the CAD systems appear to have resulted prominently in an increased annual turnover.

9.3.3 Classification of CAD systems

Tables 9.15-9.16 describe the specific elements of the value adding dimensions of CAD systems which were identified through interviews with 4 draughtsmen. Currently, two CAD systems are used at the engineering consultant. The first, referred to as CAD system B1, supports production of drawings in general. The second, referred to as CAD system B2, supports the detailing of prefabricated structural elements in particular. CAD system B2 is based on CAD system B1, but is extended with routines and libraries for prefabricated structural elements.

table 9.14: value adding dimensions of components of CAD systems

Value Adding Dimensions	***Personal Computer (stand-alone)***	***Operating system (MS Dos 6.0)***
Kernel **- procedural information (routines for:)** **- declarative information (libraries with:)**		Managing processing, storage, distribution, and presentation. Running software, such as CAD software.
Storage	Cache 256 Kb. Random Access Memory (RAM): 16Mb. Hard-disk local: 40 Mb. Disk drive: 3.5". Hard-disk server: 1.7 Gb. Magnetic tape server (DAT): 2 Gb	
Processing	Intel processor: 80486 DX2, 66 Mhz	
Distribution	Vesa Local Bus (32 bits) Local Area Network: Novell 3.1	
Presentation	SVGA, video-memory: 1 Mb. Black/white monitor (command) 12/14". Colour high resolution monitor 21". Keyboard and mouse. Digitizer and tablet. Printers and plotters.	

table 9.15: value adding dimensions of CAD software

Value Adding Dimensions	***CAD software B1***	***CAD software B2***
Kernel **- procedural information (routines for:)**	1. Modelling of graphical entities; input, edit (copy, move, group, etc.), and presentation. 2. Determining measures from the model. 3. Re-scaling of graphical entities and symbols. 4. Managing project-database and files. 11.Numbering of symbols and generating lists.	1. Modelling of graphical entities; input, edit (copy, move, group, etc.), and presentation. 2. Determining measures from the model. 3. Re-scaling of graphical entities and symbols. 4. Managing project-database and files. 11.Numbering of symbols and generating lists. 12.Modelling of prefab structural elements (including generating material lists, annotating measures, and determining add. information).
- declarative information (libraries with:)	5. Settings (defaults) for model-layers. 6. Symbols, shading, text, etc. 7. Graphical symbols (very limited). 8. Project information stored in project-files. 9. Graphical symbols of (standard) construction details and reinforcement.	5. Settings (defaults) for model-layers. 6. Symbols, shading, text, etc. 7. Graphical symbols (very limited). 8. Project information stored in project-files. 9. Graphical symbols of (standard) construction details and reinforcement. 10.Predefined model of prefab structural elements (including related features).
Storage		
Processing		
Distribution		
Presentation		

9.3.4 Production digraphs of structural design

The case-study at engineering consultants 2 revealed 3 project-categories with respect to activities in structural design. These categories are:

1. detailing of prefabricated structures & elements (for office-buildings),
2. structural design and detailing of concrete office-buildings,
3. structural design of other (e.g. industrial and civil) structures.

Category 1 assumes that structural detailing of prefabricated structures is performed by the consultant. This means that design and detailing of foundation and first floor of office-buildings are excluded. Projects in category 2 include the design and detailing of foundation and first floor. For project-categories 1 and 2, design and detailing is done in close cooperation with contractors, the clients of the engineering consultants. Category 3 assumes that all structural design activities are performed by engineering consultant 2 for other building and civil structures. In this case architects are often the clients.

Table 9.16 shows the importance of the three categories for the engineering consultant. The analyses of cost-effects of CAD systems will focus categories 1 and 2, since both are important to the consultant. These categories account for approximately 75% of the annual turnover. The analyses will consider primarily the structural design and detailing of prefabricated concrete office-buildings.

table 9.16: project-categories of engineering consultant 2

CASE 1: ENGINEERING CONSULTANT 2		
Project-category		***Share in turnover***
1	Detailing of prefabricated structures & elements (for office-buildings)	50%
2	Structural design and detailing of concrete office-buildings	25%
3	Structural design of other (e.g. industrial and civil) structures	25%

table 9.17: production digraphs for engineering consultants 2

Production digraph number	***Project-category***	***Use of CAD system***	***Figure number***
B0	1. Detailing of prefabricated structures & elements (for buildings)	No use	9.10 (1 page)
B1		CAD system B1	9.11 (1 page)
B2		CAD system B2	9.12 (1 page)
C0	2. Structural design and detailing of concrete office-buildings	No use	9.13 (1 page)
C1		CAD system B1	9.14 (1 page)

An overview of production digraphs constructed in this case-study is presented in table 9.17. Production digraph B0 represents the initial production digraph for project-category 1, in which CAD systems are not deployed. The alternative production digraphs are presented by production digraphs B1 and B2; the first results from deployment of CAD system B1, the latter from CAD system B2.

table 9.18: activity-costs for production digraph B0

Costs of selected project		Proj. 1	Proj. 2	Aver.	Sum		Corr.	Sum	**Corrections by managers**	
Conceptual&preliminary design					6%			6%	Conceptual&preliminary design	
	Discuss design	3%	1%	2%			2%		Discuss design	
	Generate design /						1%		Generate design	
	analyze design	3%	3%	3%			2%		Analyze design	
	Check	1%	1%	1%			1%		Check /	
	Administrate								administrate	
Detailing					94%			94%	Detailing	
	Discuss design	2%	2%	2%			2%		Discuss design	
	Generate design /						2%		Generate design	
	analyze design	9%	15%	12%			10%		Analyze design	
	Draught design	65%	60%	63%			63%		Draught design	
	Draught reinforcement	16%	15%	15%			15%		Draught reinforcement	
	Check	0%	0%	0%			2%		Check /	
	Administrate	1%	3%	2%					administrate	
Total		100%	100%	100%	100%		100%	100%		
Project size		30981	27634	29308						

table 9.19: costs of the draughting activities for production digraph B0

DRAUGHTING COSTS		**Dr. man 1**	**Dr. man 2**	**Average**	**Average activity**
Draught elements incl. reinforcement					**40%**
	Study design & analysis	3%	2%	**2%**	
	Draught geometry of elements	12%	13%	**13%**	
	Mark dimensions of elements	14%	10%	**12%**	
	Draught reinforcement	10%	13%	**12%**	
	Finalize, check & administrate	1%	2%	**2%**	
Draught lay-out and foundation					**25%**
	Study design & plan draughting	4%	2%	**3%**	
	Draught lay-out geometry	6%	6%	**6%**	
	Mark lay-out dimensions	5%	8%	**7%**	
	Draught foundation geomtry	4%	4%	**4%**	
	Mark foundation dimensions	4%	3%	**4%**	
	Finalize, check & administrate	2%	2%	**2%**	
Draught reinforcement lay-out and foundation					**15%**
	Study information	2%	0%	**1%**	
	Design reinforcement	2%	4%	**3%**	
	Draught reinforcement	10%	10%	**10%**	
	Finalize, check & administrate	1%	1%	**1%**	

The initial production digraph for project-category 2 is represented by production digraph C0. This shows the process without CAD systems' deployment. The alternative production digraph is presented by production digraph C1, which shows the effects of the deployment of CAD system B1.

table 9.20: costs for modelling, to be used for production digraph B1

MODELLING COSTS, CAD B1		**Minimum**	**Maximum**	**Average**	**Average activity**
Model elements incl. reinforcement					**24,40%**
	Study design & analysis	2,00%	2,00%	**2,00%**	
	Model geometry of elements	6,00%	8,40%	**7,20%**	
	Mark dimensions of elements	3,60%	6,00%	**4,80%**	
	Model reinforcement of elements	7,20%	9,60%	**8,40%**	
	Finalize, check & administrate	2,00%	2,00%	**2,00%**	
Model lay-out and foundation					**17,80%**
	Study design & plan draughting	3,00%	3,00%	**3,00%**	
	Model lay-out geometry	4,80%	3,60%	**4,20%**	
	Mark lay-out dimensions	2,40%	3,60%	**3,00%**	
	Model foundation geometry	2,40%	3,20%	**2,80%**	
	Mark foundation dimensions	2,40%	3,20%	**2,80%**	
	Finalize, check & administrate	2,00%	2,00%	**2,00%**	
Model reinforcement lay-out and foundation					**12,00%**
	Study information	1,00%	1,00%	**1,00%**	
	Design reinforcement	3,00%	3,00%	**3,00%**	
	Model reinforcement	6,00%	8,00%	**7,00%**	
	Finalize, check & administrate	1,00%	1,00%	**1,00%**	

table 9.21: costs for modelling, to be used for alternative graph B2

MODELLING COSTS, CAD B2		**Minimum**	**Maximum**	**Average**	**Average activity**
Model elements incl. reinforcement					**18,40%**
	Study design & analysis	2,00%	2,00%	**2,00%**	
	Model elements incl. reinforcement	10,80%	18,00%	**14,40%**	
	Finalize, check & administrate	2,00%	2,00%	**2,00%**	
Model lay-out and foundation					**16,60%**
	Study design & plan draughting	3,00%	3,00%	**3,00%**	
	Model lay-out geometry	2,40%	3,60%	**3,00%**	
	Mark lay-out dimensions	2,40%	3,60%	**3,00%**	
	Model foundation geometry	2,40%	3,20%	**2,80%**	
	Mark foundation dimensions	2,40%	3,20%	**2,80%**	
	Finalize, check & administrate	2,00%	2,00%	**2,00%**	
Model reinforcement lay-out and foundation					**12,00%**
	Study information	1,00%	1,00%	**1,00%**	
	Design reinforcement	3,00%	3,00%	**3,00%**	
	Model reinforcement	6,00%	8,00%	**7,00%**	
	Finalize, check & administrate	1,00%	1,00%	**1,00%**	

The structure of the production digraphs is based on the initial model, as presented earlier in chapter 6. However, since the design and detailing is based on an existing design or a predefined design-concept, only the two final design phases are included. This was also determined in the interviews with the managers. The main activities, relations, and arc-weights (cost-relations) were reviewed and modified by the managers, structural engineers, and draughtsmen.

table 9.22: activity-costs for production digraph C0

Costs of selected project		Proj. 1	Proj. 2	Proj. 3	Proj. 4	Aver.	Sum		Corr.	Sum	**Corrections by managers**	
Design							26%			26%	Design	
	Discuss design	3%	3%	2%	1%	2%			2%		Discuss design	
	Generate design /								2%		Generate design	
	analyze design	13%	14%	9%	11%	12%			10%		Analyze design	
	Draught design	11%	9%	13%	8%	10%			10%		Draught design	
	Check	1%	2%	1%	0%	1%			2%		Check /	
	Administrate	0%	2%	0%	2%	1%					administrate	
Detailing							74%			74%	Detailing	
	Discuss design	3%	3%	2%	1%	2%			2%		Discuss design	
	Generate design /								2%		Generate design	
	analyze design	21%	16%	23%	20%	20%			18%		Analyze design	
	Draught design	32%	31%	33%	39%	34%			34%		Draught design	
	Draught reinforc.	14%	17%	16%	15%	16%			16%		Draught reinforc.	
	Check	1%	2%	0%	1%	1%			2%		Check /	
	Administrate	1%	1%	1%	2%	1%					administrate	
Total		100%	100%	100%	100%	100%	100%		100%	100%		
Project size		17454	258097	117072	27291	104979						

table 9.23: costs of the draughting activities for production digraph C0

		Dr.man 1	**Dr.man 2**	**Dr.man 3**	**Dr.man 4**	**Average**	**Average activity**
Draught design							**12%**
	Study design & analysis	2%	1%	1%	0%	**1%**	
	Draught structure geometry	4%	6%	3%	6%	**5%**	
	Mark structure dimensions	3%	4%	6%	4%	**4%**	
	Finalize, check & administrate	3%	1%	2%	2%	**2%**	
Draught detailed design							**36%**
	Study design & plan draughting	2%	2%	0%	3%	**2%**	
	Draught structure geometry	15%	16%	20%	16%	**16%**	
	Mark structure dimensions	18%	14%	15%	14%	**16%**	
	Finalize, check & administrate	1%	4%	1%	3%	**2%**	
Draught reinforcement							**16%**
	Study information	2%	0%	0%	1%	**1%**	
	Design reinforcement	1%	5%	3%	0%	**2%**	
	Draught reinforcement	10%	10%	12%	15%	**12%**	
	Finalize, check & administrate	3%	1%	1%	0%	**1%**	

The node-weights (activity costs) are based on analyses of cost-evaluations; two cost-evaluations for project-category 1, and four for project-category 2. The calculated node-weights (table 9.18 and 9.22 left) were checked and modified (table 9.18 and 9.22 right), because:

1. activities in the cost-evaluations did not match with those of the graph,
2. features of some selected projects disturbed the activity-costs.

Draughting activities were analyzed in detail, during interviews with draughtsmen, since it was expected that they were affected by the use of the CAD systems. Node-weights were estimated by draughtsmen: two draughtsmen provided estimates for project-category 1 and four draughtsmen for project-category 2. Averages of these estimates (see table 9.19 and 9.23 respectively) were used as node-weights of the draughting-activities.

table 9.24: costs for modelling, to be used for production digraph C1

MODELLING COSTS, CAD B1		Minimum	Maximum	Average	Aver. act.
Model design					9,80%
	Study design & analysis	1,00%	1,00%	1,00%	
	Model structure geometry	3,50%	4,50%	4,00%	
	Mark structure dimensions	2,40%	3,20%	2,80%	
	Finalize, check & administrate	2,00%	2,00%	2,00%	
Model detailed design					28,00%
	Study design & plan draughting	2,00%	2,00%	2,00%	
	Model structure geometry	11,20%	14,40%	12,80%	
	Mark foundation dimensions	9,60%	12,80%	11,20%	
	Finalize, check & administrate	2,00%	2,00%	2,00%	
Model reinforcement					12,40%
	Study information	1,00%	1,00%	1,00%	
	Design reinforcement	2,00%	2,00%	2,00%	
	Model reinforcement	7,20%	9,60%	8,40%	
	Finalize, check & administrate	1,00%	1,00%	1,00%	

Effects of CAD systems are presented in the alternative production digraphs B1-B2 and C1. Node-weights for these production digraphs were estimated by draughtsmen: two draughtsmen provided estimates for project-category 1 and four draughtsmen for project-category 2. Averages of these estimates (see table 9.20 and 9.21 for production digraphs B1-B2, and table 9.24 for production digraph C1) were used as node-weights of the draughting-activities.

9.3.5 Analysis of effects (descriptive)

The initial production digraphs are used to determine the effects of CAD systems A2 and B2. First the effects of the CAD systems on project-category 1 are discussed. The effects are determined from comparison of production digraphs B0-B2. Then the effects of the CAD systems on project-category 2 are discussed, which can be seen by comparing production digraphs C0-C1.

9.3.5.1 Structural effects

Project-category 1

Comparing the production digraphs B0 and B1 on the highest level of aggregation (level 1) reveals no structural changes. One effect which can be determined is the reduction in the node-weight *c(2)*. In addition, the arc-weight *w(2, sink)* is reduced as well as a result of the reduction in node-weight *c(2)*. This arc-weight, representing the total project-costs, shows a reduction of 25,80%. This implies that use of CAD system B1 reduces the process-costs with 25,80%.

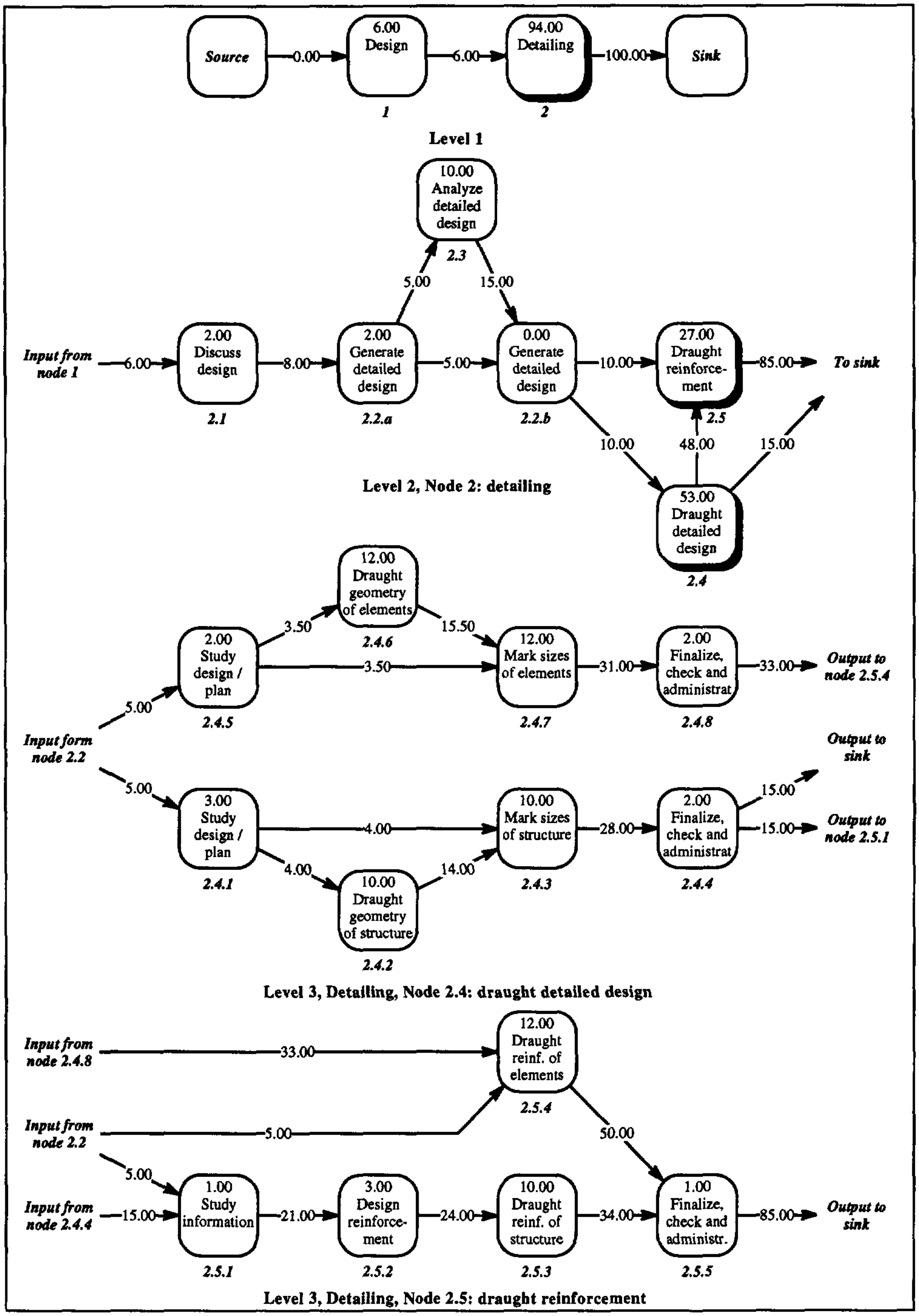


figure 9.10: production digraph B0

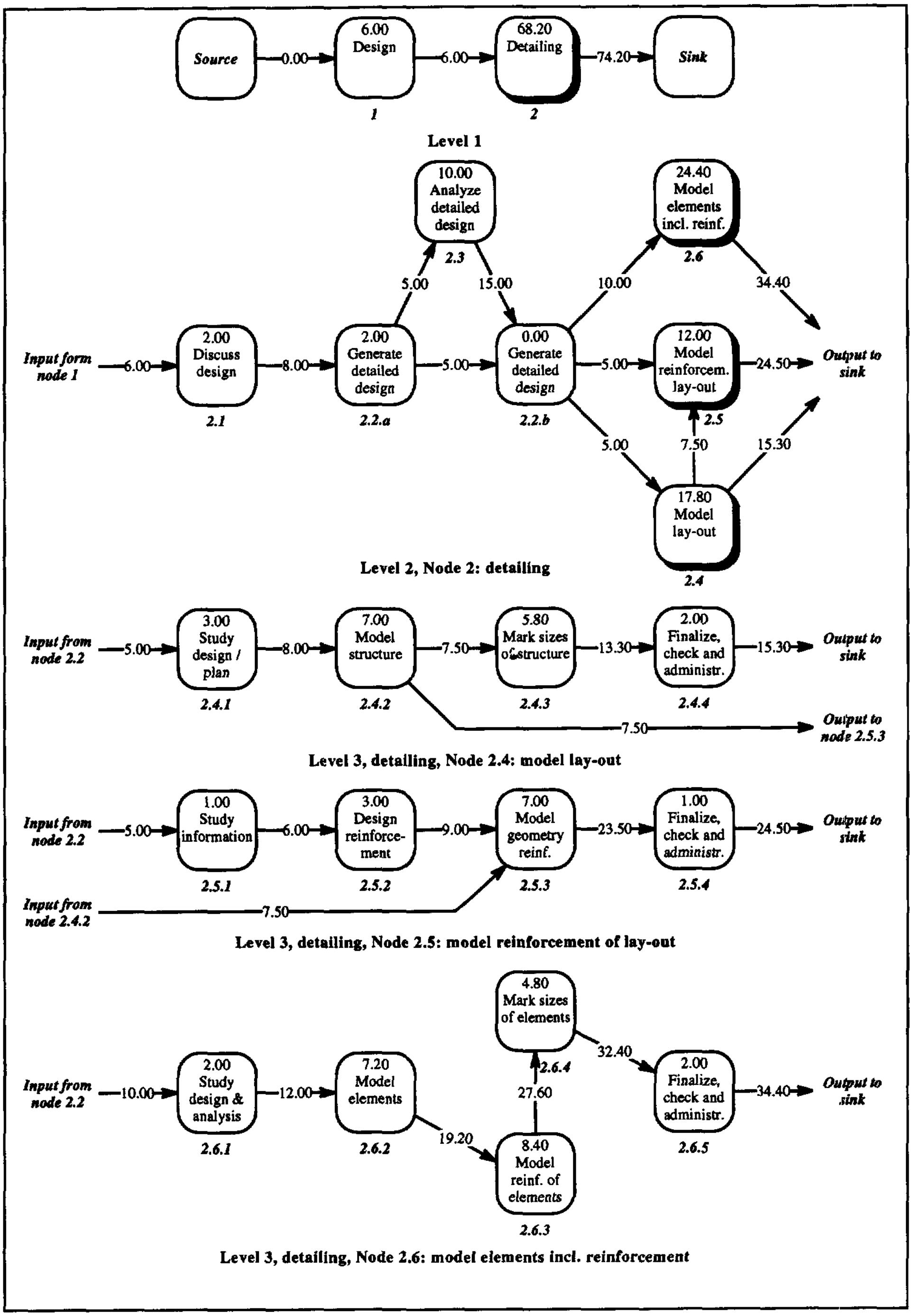


figure 9.11: production digraph B1

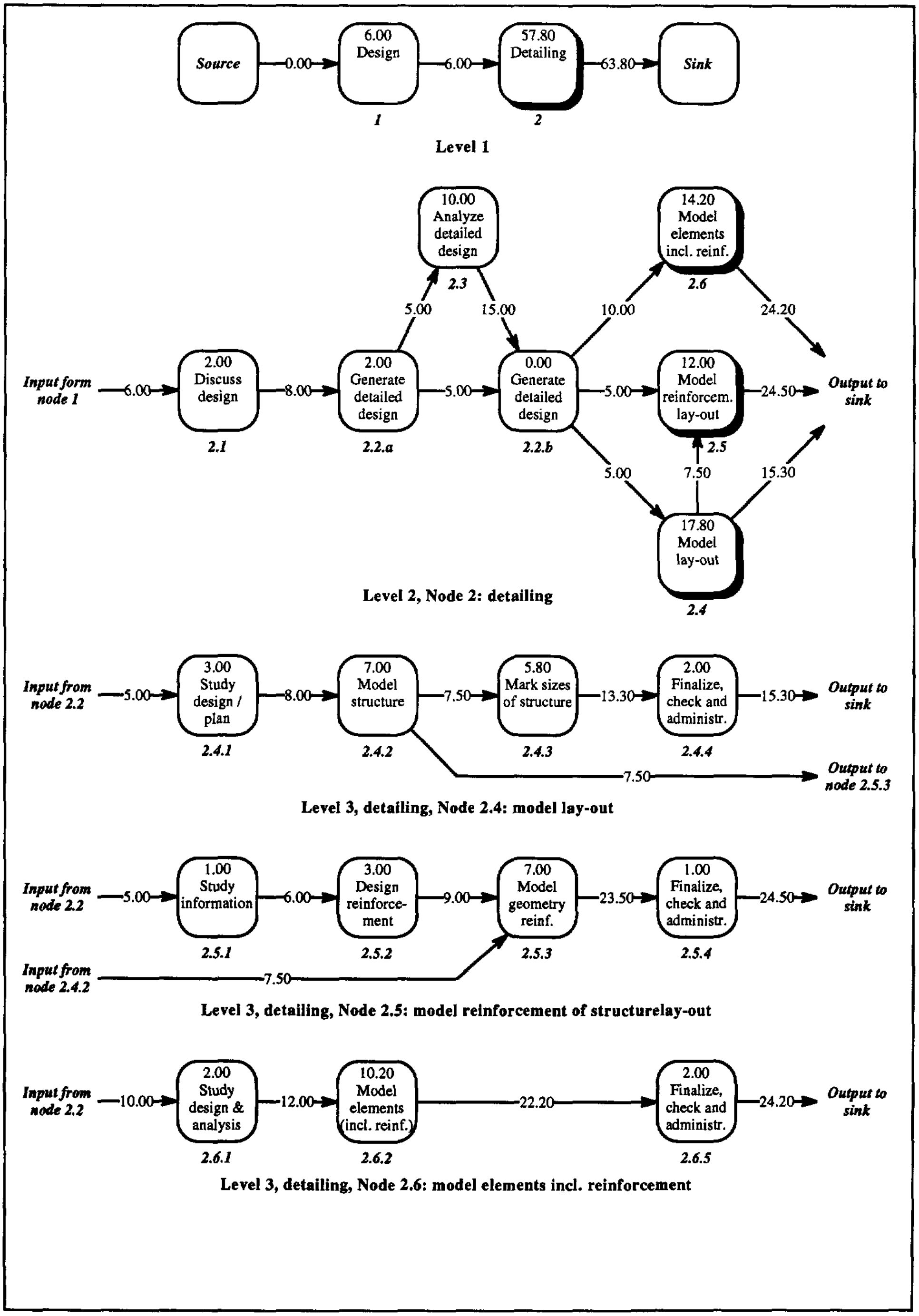


figure 9.12: production digraph B2

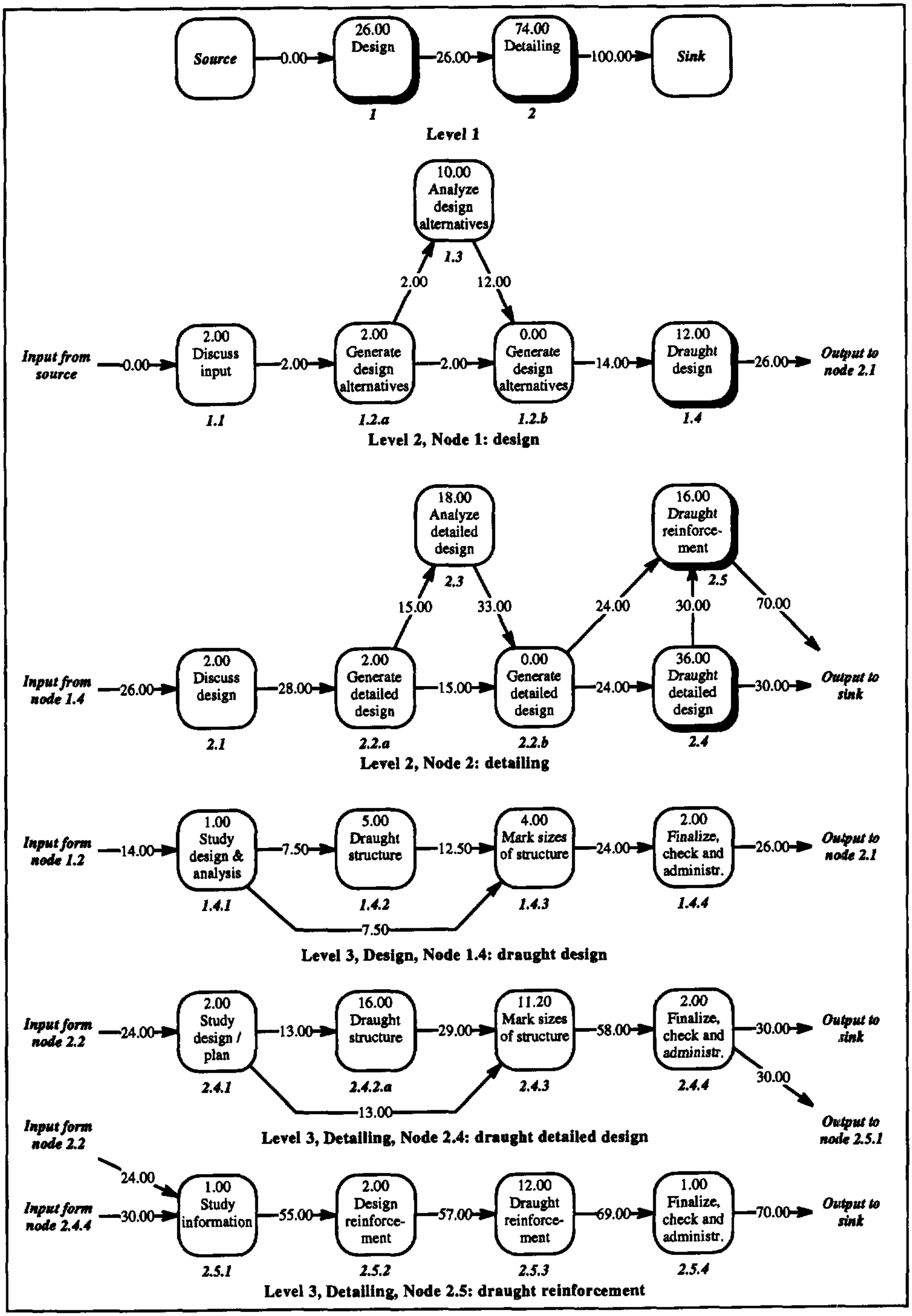


figure 9.13: production digraph C0

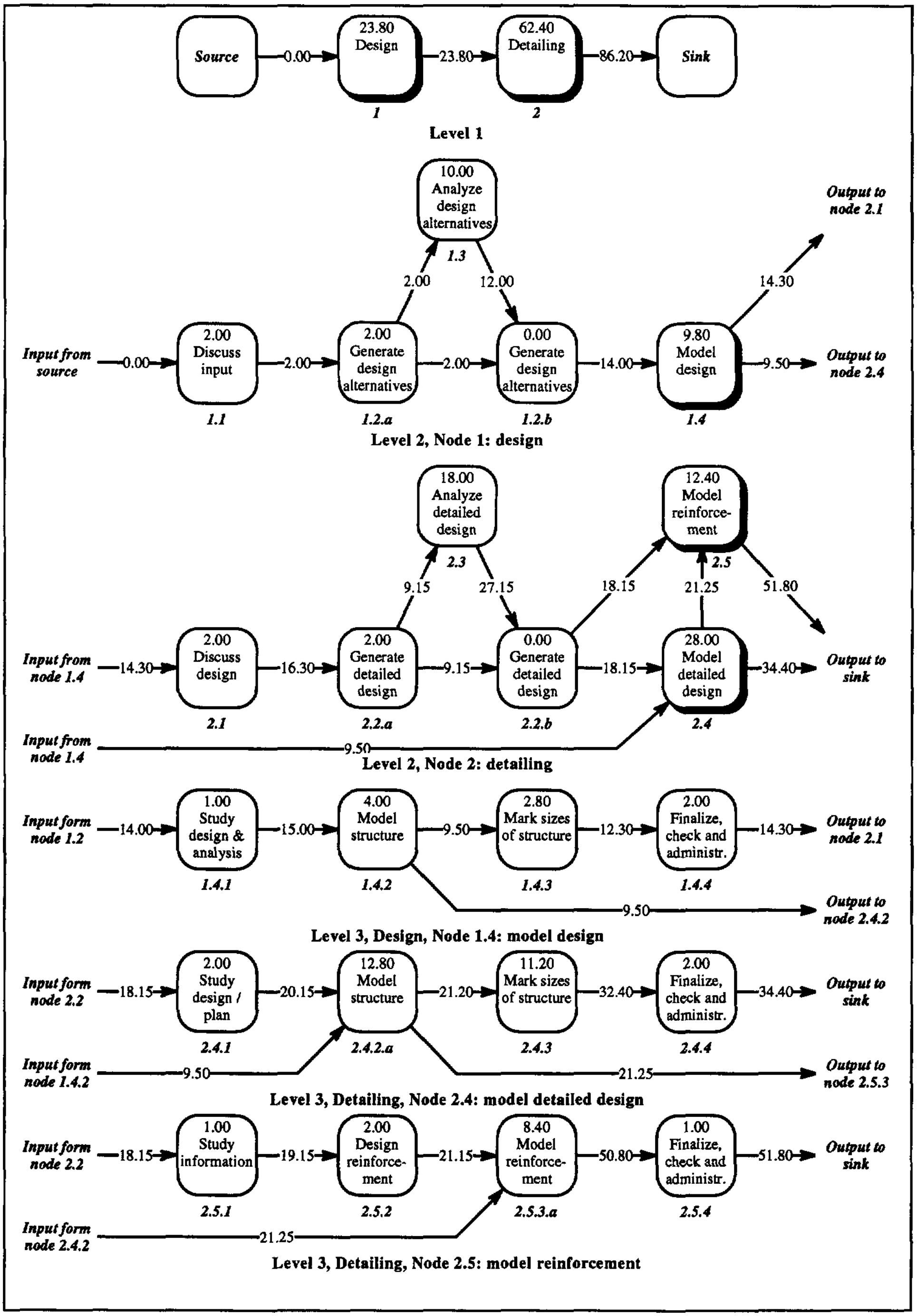


figure 9.14: production digraph C1

Considering node 2 at level 2 shows the addition of a new node (2.6), resulting from rather complex structural changes. Both node 2.4 and nodes 2.5 of production digraph B0 are split into two parts, resulting into 2.4.x, 2.4.y, 2.5.x and 2.5.y. The parts 2.4.y and 2.5.y are combined to one node. This node is substituted by node 2.6 in production digraph B1. The parts 2.4.x. and 2.5.x are substituted by nodes 2.4 and 2.5 of production digraph B1.

As a result of the substitutions, arcs are added to connect node 2.2 with node 2.6, and node 2.6 to the sink. The substitutions also result into reductions of the node-weights. The sum of the node-weights of nodes 2.4-2.6 of production digraph B1 are lower than the sum of the node-weights of nodes 2.4-2.5 of production digraph B0.

The complex structural changes referred to above are shown clearer at level 3. It is shown that within node 2.4 the (sub-)nodes 2.4.1-2.4.4 are removed, and within node 2.5 the (sub-)node 2.5.4. These (sub-)nodes combined and replaced by the nodes 2.6.1-2.6.5. The modelling of elements (including reinforcement) is integrated, and separated from the modelling of the remaining parts of the structure. Modelling of reinforcement is now done just after the modelling of the elements. Furthermore the arc between 2.6.1. and 2.6.4. is removed, since node 2.6.4 does not need an input from node 2.6.1.

With the use of CAD system B1 the modelling is done more efficient. The sum of the node-weights of nodes 2.6.1-2.6.5 of production digraph B1 are lower than the sum of the node-weights of nodes 2.4.5-2.4.8 and 2.5.4 of production digraph B0.

Other structural changes are substitutions of nodes 2.4.2 and 2.5.3. Together with the substitution an arc is added to connect these two nodes, since node 2.5.3 requires input from node 2.4.2. In addition the arc between nodes 2.4.1 and 2.4.3 is removed, since node 2.4.3 no longer requires input from node 2.4.1.

Node-weights are reduced as a result of the substitutions, since activities are performed more efficient, using CAD system B1. Production digraph B1 shows reductions for node-weights *c(2.4.2)*, *c(2.4.3)*, and *c(2.5.3)*. These changes result in changes in the subsequent arc-weights as well.

Comparing production digraphs B0, B1, and B2 shows that effects of CAD system B2 are quite similar to those of CAD system B1, except for the additional effects on node 2.6. Level 3 of production digraph B2 shows that nodes 2.6.2-2.6.4 are combined to one new node 2.6.2, as a result of the use of CAD system B2. At the same time the node-weight is reduced substantially. Resulting from this increase in efficiency the overall project-costs are reduced with an additional 10,20% to a total of 36,00%.

Project-category 2

Comparing the production digraphs C0 and C1 on the highest level of aggregation (level 1) reveals no structural changes either. Effects which can be determined are reductions of the node-weights *c(1)* and *c(2)*. In addition, the arc-weights *w(1, 2)* and *w(2, sink)* are reduced as well, as a result of the reductions of the node-weights. The total project-costs are reduced with 13.80% as a result of the use of CAD system B1.

The structural changes at level 2 and 3 are similar to the structural changes, discussed in case-study 1 (section 9.2). Nodes 1.4.2, 2.4.2, and 2.5.3 are substituted by new nodes. These new nodes are connected by arcs, since node 2.4.2 requires input from node 1.4.2, and node 2.5.3 from node 2.4.2. Furthermore, the arc between node 1.4.1 and node 1.4.3 is deleted, since node 1.4.3 no longer requires input from node 1.4.1. The same holds for the arc between node 2.4.1 and 2.4.3.

Due to the use of CAD system B1 the node-weights *c(1.4.2)*, *c(1.4.3)*, *c(2.4.2)*, *c(2.4.3)*, and *c(2.5.3)* are reduced. Arc-weights are changed as a result of changed relations between the nodes, and changes in the node-weights (compare production digraphs C0 and C1).

The additional elements of the value adding dimensions of CAD system B2 (compared with CAD system B1) do not alter the production digraph C1. These elements are only useful for prefabricated structures or (structural) elements. The structures within project-category 2 do not include these elements, so the additional elements of CAD system B2 are useless for the design and detailing of these structures.

9.3.5.2 Effects attributed to CAD systems

In tables 9.25-9.27 the effects are attributed to the specific elements of the value adding dimensions of the CAD software. The effects on aggregation level 3 are considered, since they are the most detailed. Tables 9.25-9.27 also provide the total cost-reductions, based on the average of estimates provided by draughtsmen. In addition an interval is provided for the cost-reductions. It is based on the minimum and maximum values of the estimates provided by the draughtsmen (see tables 9.19-9.21 and 9.23-9.24).

9.3.6 Conclusion

This case-study also proves that the cost-effects of CAD systems on structural design processes can be determined, using the production digraph model. The analysis reveals not only the cost-effects, but attribute them to the specific elements of value adding dimensions of CAD systems. In addition this case-study clearly shows that the effects depends on the characteristics of the process as well. Use of CAD system B1 results different effects for the two project-categories. The additional elements of the value adding dimensions of CAD system B2 (compared with CAD system B1) are only useful for project-category 1; they do not result any effect for project-category 2.

Similar to the CAD systems in case-study 1, CAD system B1 reduces project-costs because graphical modelling is done more efficiently than draughting. Efficient modelling is due to:

1. procedural information, furnished by the CAD systems, such as:
    a. routines and procedures for input, edit, and output of graphical entities,
    b. routines for computing of sizes of the structure are reduced, based on the graphical model;
2. declarative information in the form of:
    a. graphical information in the project-files (e.g. drawing-files, files of previous projects).
    b. graphical symbols of standard construction elements and reinforcement.

table 9.25: cost-effects related to elements of value adding dimensions of CAD system B1 (project-category 1)

Node-number	Cost-effects	Elements of value adding dimensions[11]	Remarks
2.4.2.	- 3,00%	1, 5, 6, 7, 9	Modelling must be accurate to account for the precise sizes.
2.4.3	- 4,20%	2	Sizes are derived by the CAD system from the model.
2.6.2 (for 2.4.6)	- 4,80%	1, 5, 6, 7, 9, 11	Efficient modelling of elements due to edit-features
2.6.3 (for 2.5.4)	- 3,60%	1, 5, 6, 7, 9, 11, 8 (model elements)	Use of model of elements and the graphical symbols for reinforcement.
2.6.4 (for 2.4.7)	- 7,20%	2	Sizes are derived by the CAD system from the model.
2.5.3	- 3,00%	1, 5, 6, 7, 9, 8 (model structure)	Use of model of structure and the graphical symbols for reinforcement.
Total	- 25,80%		Interval: 24,40% - 38,40%

table 9.26: cost-effects related to elements of value adding dimensions of CAD system B2 (project-category 1)

Node-number	Cost-effects	Elements of value adding dimensions[11]	Remarks
2.4.2.	- 3,00%	1, 5, 6, 7, 9	Modelling must be accurate to account for the precise sizes.
2.4.3	- 4,20%	2	Sizes are derived by the CAD system from the model.
2.6.2 (for 2.4.6, 2.5.4, and 2.4.7)	- 25,80%	1, 2, 5, 6, 10, 11, 12	Efficient modelling of elements due to predefined model of prefabricated elements.
2.5.3	- 3,00%	1, 5, 6, 7, 9, 8 (model structure)	Use of model of structure and the graphical symbols for reinforcement.
Total	- 36,00%		Interval: 29,60% - 46,40%

table 9.27: cost-effects related to elements of value adding dimensions of CAD system B1 (project-category 2)

Node-number	Cost-effects	Elements of value adding dimensions[11]	Remarks
1.4.2	- 1,00%	1, 5, 6, 7, 9	Modelling must be accurate to account for the precise sizes.
1.4.3	- 1,20%	2	Sizes are derived by the CAD system from the model.
2.4.2	- 4,20%	1, 3, 5, 6, 7, 9, 8 (model design)	The model of design is being refined, after conversion of graphical entities and symbols to the appropriate scale.
2.4.3	- 4,80%	2	Sizes are derived by the CAD system from the model.
2.5.3	- 3,60%	1, 5, 6, 7, 9, 8 (model structure)	The previous model is being refined.
Total	- 14,80%		Interval: 7,10% - 31,50%

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[11] Numbers refer to the elements of the value adding dimensions in table 9.15

The influence of the project-characteristics on cost-effects can be demonstrated clearly by considering the effects as shown in production digraphs B1 and C1. In both cases CAD system B1 is deployed, but the cost-reductions are higher in the first case. This difference results from the (high level of) uniformity of the prefabricated structural elements (including the reinforcement). Uniformity facilitates efficient modelling and reduces the design-effort required to design and detail these elements.

CAD system B1 facilitates accurate modelling of reinforcement to enable the listing of the reinforcement (initial bar-bending-schedules). However, the ability to list the reinforcement is not often used, and was not considered in this case-study. When this ability is used, more effort is required for accurate modelling of the reinforcement. In that case it is expected that the cost-reductions will be slightly lower than those determined in this case-study.

In addition to the reasons just mentioned CAD system B2 reduces project-costs, since it makes good use of the uniformity of the prefabricated structural elements. Generic models of these elements are predefined, which are used to model the elements through input of values for a limited set of parameters. This way of design (detailing) is often referred as parametric design, and is possible only for rationalized and standardized products.

Comparison of production digraphs B1 and B2 clearly indicates that better cost-effects can be achieved by using more sophisticated CAD systems. Sophistication refers to functional rather than technological sophistication. CAD system B2 is more sophisticated (tailored for this specific purpose) than CAD system B1. Use of CAD system B2 results an additional cost-reduction of 10,20% over use of CAD system B1.

Throughout this section the average cost-reductions are discussed. Comparison of these averages with the intervals for cost-reductions provided in tables 9.25-9.27 shows that they are not very accurate. In all cases the interval for cost-reductions is large. However, the order of magnitude of cost-reductions is well represented by the average cost-reduction.

The cost-reductions determined in this case-study can be used to determine upper-bounds for the demand value of the deployment of CAD systems. These upper-bounds can be interpreted as an estimate of the maximum amount of money the engineering consultants might be willing to invest in the deployment of these systems. This amount should be compared to all costs involved in the deployment of CAD systems, such as costs for purchase of the system, training of draughtsmen, maintenance of the system, management, system-control, etc.

Upper-bounds for the demand value of CAD systems can be determined in monetary terms as:

$$\delta_x = \sum_{y=1}^{n} \alpha_{x,y} \, \beta_y \, \Delta$$

with: δ_x: upper-bound for the demand value of CAD system x (in Dfl. per annum),
$\alpha_{x,y}$: reduction of project-costs of project-category y, resulting from the deployment of CAD system x (in %),
β_y: share of project-category y in the annual turnover (in %),
Δ: annual turnover (Dfl. 3.300.000,--),
n: number of project-categories.

Assuming that use of the CAD systems has similar effects on project-category 3 as determined for project-category 2 results in the following values for $\alpha_{x,y}$ and β_y:

	Project-category 1	**Project-category 2**	**Project-category 3**
β_y	50%	25%	25%
$\alpha_{x,y}$			
CAD system B1	25,80%	13,80%	13,80%
CAD system B2	36,00%	13,80%	13,80%

The values can be used to determine the upper-bounds for the demand value of CAD systems for engineering consultant 2:

$$\delta_{\text{CAD system B1}} = \{0{,}258 * 0{,}50 + 0{,}138 * 0{,}25 + 0{,}138 * 0{,}25\} * 3.300.000 = \text{Dfl. } 653.400,\text{--}$$

$$\delta_{\text{CAD system B2}} = \{0{,}360 * 0{,}50 + 0{,}138 * 0{,}25 + 0{,}138 * 0{,}25\} * 3.300.000 = \text{Dfl. } 821.700,\text{--}$$

9.4 Case 3

9.4.1 Reinforcement-subcontractor's profile

Case 3 concerns a division of an organization. This division is responsible for the production, transport and fixing of reinforcement bars (so-called rebars). It represents one of the six largest reinforcement-subcontractors in the Netherlands specialized in cutting and bending of rebars in factories. A profile of this reinforcement-subcontractor is provided in table 9.28. The other division of the organization is engaged in the business of other steel-products.

This research focuses primarily on the production and transport of rebars. Table 9.29 stretches the current production and transport of rebars within the division. Staff-members involved in this process are listed in the table. In addition, costs incurred by the production of bar-bending-schedules, scheduling of production of rebars, production of rebars, and transport of rebars are provided. The remainder of this case-description deals with (costs of) production of bar-bending-schedules.

9.4.2 Experience with information systems

This reinforcement-subcontractor (RS) does not use CAD systems. However, RS did participate in several research projects dealing with the use of CAD/CAM systems in construction. These projects focused in particular on effects of CAD systems on the scheduling, production, and fixing of reinforcement. Exchange of information from CAD systems to CAM systems, so-called PDI (Product Data Interchange) is expected to improve scheduling, production and fixing of reinforcement.

The organization has developed an information system (CAM system) to support management, scheduling and production of rebars. The information system is centred on a database of rebars-information. This database contains the bar-bending-schedules produced by bar-bending-schedulers. The reinforcement-drawings are used to produce the bar-bending-schedules.

The information system is still under development. One of developments focuses directly on the input of information from CAD systems, one appearance of PDI. Information on the reinforcement, readily available in CAD systems, can be stored on a diskette according to a specific format. This format is referred to as WUF, the Dutch acronym for "Wapenings-Uitwisseling-Formaat" (Reinforcement Exchange Format).

The effects of the deployment of the WUF-diskette is considered in this case-study. The WUF-diskette enables the transfer of information concerning reinforcement from CAD systems at the engineering consultants to CAM systems at the reinforcement-subcontractor. The WUF-diskette represents one form of PDI.

table 9.28: profile of reinforcement-subcontractor

REINFORCEMENT-SUBCONTRACTOR			
Annual turnover (Dfl., VAT excluded) ***Quantity of reinforcing steel per annum (tons)***			***21.000.000,-*** ***15.000 - 20.000***
Costtype		**Percentage of turn-over**	**Amount (Dfl.)**
Material		40%	8.400.000,-
Production & transport of rebars (including overhead)		12%	2.520.000,-
Fixing of reinforcement		45%	9.450.00,-
Profits / risks		3%	630.000,-
Number of projects per annum			***150 - 200***
Projecttype	**Percentage of turn-over**	**Average projectsize (Dfl.)**	**Project-duration (months)**
Construction of houses	5%	10.000 - 5.000.000	6 - 24
Construction of offices	45%		
Construction of civil structures	45%		
Construction of special structures	5%		

table 9.29: profile of division production & transport of rebars

DIVISION: PRODUCTION & TRANSPORT OF REBARS		
Number of employees		***32***
Managing director / manager		2
Bar-bending-schedulers		3
Production-schedulers		4
Shop-floor-employees		21
Administrative personnel		2
Annual turnover (Dfl.)		***2.520.000,-***
Costtype	**Percentage of turn-over**	**Amount (Dfl.)**
Production of bar-bending-schedules	12.5%	315.000,-
Scheduling production of rebars	12.5%	315.000,-
Production of rebars (cut, bend, etc.)	65.0%	1.638.000,-
Transport rebars to site	10.0%	252.000,-

During the interviews it was determined that the production of bar-bending-schedules is affected by the use of CAD systems in structural design. It is the first activity of the production processes, where the information provided by structural design is processed. Other activities may be affected as well, but that depends on information processing in this activity. The analysis in this research will be restricted to the cost-effects of the different possible deployments of the WUF-diskette in the production of bar-bending-schedules.

9.4.3 Classification of information commodities

Information commodities used for the production of bar-bending-schedules are reinforcement-drawings. Traditionally these drawings, the output of the structural design process, serve as input for realization of reinforcement in construction. The reinforcement is represented schematically on drawings, according to national or international conventions which are prescribed in design-codes. The representation shows the shape and location of the rebars, while the dimensions and number of rebars are implicit. These can be derived from additional information provided on the drawing, e.g. concrete cover, sizes of the structure. Other properties of the rebars, such as the quality of the rebars, are provided on the drawings as well.

For a long time CAD systems did not change this situation, since the output of the structural design remained the reinforcement-drawings. Drawings produced using CAD systems were represented on paper according to the same conventions for representation of rebars. However, improvements often mentioned include better editing-possibilities of drawings and clarity of drawings produced with CAD systems. The latter facilitates improved understanding of the reinforcement.

CAD-CRETE systems are used not only to produce reinforcement-drawings, but to determine the properties and sizes of rebars as well. During modelling of the rebars, information is specified (or determined) and stored in a database. This information can be used to produce bar-bending-schedules on paper, which can be used for the production of rebars. However, these bar-bending-schedules, according to conventions in design codes, must be interpreted and input into the reinforcement-subcontractor's information system manually.

Recently a reinforcement-exchange-format, called WUF, was developed in the Netherlands. This format enables PDI, in particular the exchange of declarative information of rebars on diskette from CAD-CRETE systems to the CAM system of the RS. This information is converted by the RS and imported into its CAM system.

It must be mentioned that a WUF-diskette does not contain all the information on rebars, needed for scheduling, production and fixing. For example, the diskette does not include information concerning the location of rebars in the structure. That type of information is still represented on drawings. Furthermore, currently the drawings are still the formal contract documents. This means that drawings are still required when using the WUF-diskette. In particular, the drawings are required for fixing of the rebars and in some cases for production of rebars as well.

table 9.30: value adding dimensions of drawings and the WUF-diskette

Value Adding Dimensions	*Reinforcement drawings*	*WUF-diskette*
Kernel **- procedural information (routines for:)**		
- declarative information (libraries with:)	1. Shape of rebars. 2. Location of rebars. 3. Concrete cover on rebars. 4. Sizes the concrete structure.	1. Shape of rebars. 2. Properties and sizes of rebars. 3. Number of rebars.
Storage	5. Paper / calque	4. Diskette, according to WUF
Processing		
Distribution		
Presentation	6. Symbolic representation, according to design code: (NEN 3870).	

Presently, the WUF-diskette is used together with drawings, that differ slightly from traditional reinforcement-drawings. On the drawings - related to the WUF-diskette - the rebars are labelled, in contrast to unlabelled rebars on traditional drawings. These labels (bar-codes) are used to identify rebars and to find the relevant information on the WUF-diskette.

The effects of this information commodity - termed the WUF-diskette - on the production of bar-bending-schedules were analyzed. The effects are determined by comparing the traditional situation (using drawings only) with the new situation in which the WUF-diskette is used. Table 9.30 lists the elements of the value adding dimensions of the traditional reinforcement-drawings and the WUF-diskette.

The WUF-diskette (with related drawings) is still in an experimental phase. It can be deployed in several different ways, which depend on organizational conditions. Conditions concerning responsibilities alter the use of the WUF-diskette at the reinforcement-subcontractor. Also, agreements on what to include in the WUF-diskette determine the way it is used.

9.4.4 Production digraphs

The production digraphs for the process of production of bar-bending-schedules are based on direct observations, rather than on interview-data. The main activities had to be determined from observations, since previous analyses of the production of bar-bending-schedules were rather poor. The activities are performed in a sequential order; cost-relations between the activities can be identified easily.

The activity costs (node-weights) are based on measurements taken during the observations and during the experiments. The time needed for each activity was measured. Table 9.31 provides an example of the result of measurements during the experiments. These measurements were used to determine the costs of each activity. It is assumed that the only relevant costs are labour-costs, and that time is a proxy for costs.

table 9.31: results of time-measurements for simple reinforcement (production digraph D0)

Case-study 3, part 1	**Experiment**		**Traditional**				**WUF-diskette**
Simplen reinforcement	**Reinforcement top**		**Net time in seconds**				**No deployment**
BAR-BENDING -SCHEDULES	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***Barcodes***
General for whole drawing	330				75	300	
Bar-bending-schedule 1							
general	180		1125	60	480		
barcodes 1-2		120		120			10
barcodes 11-13		30		30			3
barcodes 14-22	60	150		150			9
barcodes 23-24		30		30			2
barcodes 25-28		45		45			4
barcodes 29-32		45		45			4
barcodes 33-36		30		45			4
barcodes 37-39		30		15			3
barcodes 40		75	45	15			1
barcodes 41		30	15	15			1
barcodes 42	30	30		30			1
barcodes 43	15	15		15			1
barcodes 44-45		15		30			2
barcodes 46	45	20		15			1
barcodes 47		60		45			1
barcodes 48		15		15			1
Total	330	740	1185	720	480		48
Average	**7**	**15**	**25**	**15**	**10**		
Bar-bending-schedule 2							
general	90		750	90	405		
barcodes 49-56		90		60			8
barcodes 57-64		60		90			8
barcodes 65		15		30			1
barcodes 66-71		60		90			6
barcodes 72		15		45			1
barcodes 73-77		60		75			5
barcodes 78-79	30	30		15			2
barcodes 80-81		45		15			2
barcodes 82		15		15			1
barcodes 83-85		15		30			3
barcodes 86		15		15			1
barcodes 87		45		30			1
barcodes 88		15		15			1
barcodes 89		15		15			1
Total	120	495	750	630	405		41
Average	**3**	**12**	**18**	**15**	**10**		
Bar-bending-schedule 3							
general			210		225		
barcodes 90-96		30		105			7
barcodes 97-103		45		120			7
barcodes 104-109		45	80	90			6
Total	0	120	290	315	225		20
Average	**0**	**6**	**15**	**16**	**11**		
Total	**780**	**1355**	**2225**	**1665**	**1185**	**300**	

Material-costs are not included in these analysis, for two reasons. First, the production of bar-bending-schedules is considered. In this process material is not handled, so material-costs are not relevant. Second, previous experiments showed that use of the WUF-diskette hardly affects the quantity of the material (see Tongeren & Chandansingh, 1993). Based on this experiment it is expected that the material-costs will not be affected.

The effects of three different deployments of the WUF-diskette were considered in this case-study:

1. WUF-diskette^{alt1}: deployment of the WUF-diskette, requiring checking of the rebars at the RS,
2. WUF-diskette^{alt2}: deployment of the WUF-diskette, requiring determination and processing of additional rebars at the RS,
2. WUF-diskette^{alt3}: deployment of the WUF-diskette, requiring neither checking of the rebars nor determination and processing of additional rebars at the RS.

Table 9.32 provides an overview of the production digraphs constructed in this case-study. Initial production digraphs were constructed: production digraph D0 for simple reinforcement and production digraph E0 for complex reinforcement, both without deployment of the WUF-diskette. These production digraphs are based on the costs provided in table 9.33, and are used to analyze the effects of the different deployments of the WUF-diskette.

table 9.32: production digraphs for the production of bar-bending-schedules

Production digraph number	***Description***	***Deployment of WUF-diskette***	***Figure number***
D0	1. Simple reinforcement: top reinforcement of a slab	No deployment	9.15
D1		WUF-diskette^{alt1}	9.16
D2		WUF-diskette^{alt3}	9.17
D3		WUF-diskette^{alt4}	9.21
E0	2. Complex reinforcement: bottom reinforcement of a slab with curved beams	No deployment	9.18
E1		WUF-diskette^{alt2}	9.19
E2		WUF-diskette^{alt3}	9.20

The production-costs of bar-bending-schedules is determined by the complexity of reinforcement and the number of rebars. Two types of complexity of reinforcement were considered: simple reinforcement and rather complex reinforcement. As simple reinforcement was considered the top-reinforcement of a slab. As complex reinforcement was considered the bottom-reinforcement of the same slab. The bottom of the slab includes some straight and curved beams.

For comparison the production of bar-bending-schedules for the simple reinforcement is used as reference. The total costs is indexed at 100, and the costs of the activities are expressed with respect to the total costs, expressed as percentages. The costs for the production of bar-bending-schedules for the complex reinforcement are expressed relative to this index.

table 9.33: production-costs for bar-bending-schedules, to be used for production digraphs D0 and E0

Production of bar-beding-schedules							
SIMPLE REINFORCEMENT (D0)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General	330				75	300	
Barcodes	450	1355	2225	1665	1110		***109***
Average per barcode	4	12	20	15	10		
Total (time in seconds)	***7510***						
General	4,4%				1,0%	4,0%	
Barcodes	6,0%	18,0%	29,6%	22,2%	14,8%		***109***
Total (index-percentages)	***100%***						
COMPLEX REINFORCEMENT (E0)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General	555				75	300	
Barcodes	980	1847	3035	2425	1843		***119***
Average per barcode	8	16	26	20	15		
Total (time in seconds)	***11060***						
General	555				75	300	
Barcodes	898	1692	2780	2221	1688		***109***
Total (corrected time in sec.)	***10209***						
General	7,4%				1,0%	4,0%	
Barcodes	12,0%	22,5%	37,0%	29,6%	22,5%		***109***
Total (index-percentages)	***136%***						

table 9.34: production-costs for bar-bending-schedules, to be used in production digraphs D1, D2, E1, and E2

Production of bar-beding-schedules							
SIMPLE REINFORCEMENT (D1)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General					1,0%	4,0%	
Barcodes	46,0%		4,5%		4,5%		***109***
Total (index-percentages)	***60%***						
SIMPLE REINFORCEMENT (D2)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General					0,5%	4,0%	
Barcodes							***109***
Total (index-percentages)	***5%***						
COMPLEX REINFORCEMENT (E1)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General	19,5%				0,5%	4,0%	
Barcodes							***109***
Total (index-percentages)	***24%***						
COMPLEX REINFORCEMENT (E2)	***Study/check***	***Annotate***	***Determine***	***Note***	***Input/modify***	***Administrate***	***# of codes***
General					0,5%	4,0%	
Barcodes							***109***
Total (index-percentages)	***5%***						

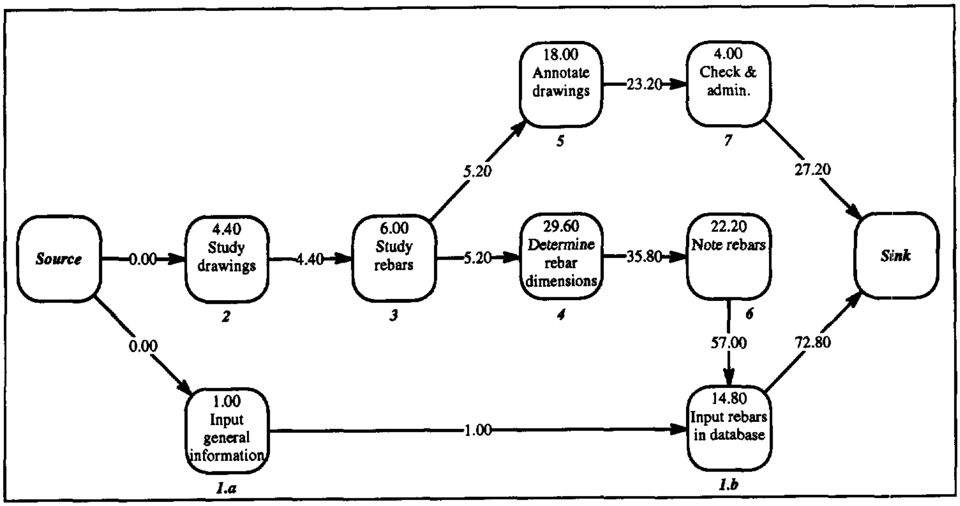

figure 9.15: production digraph D0

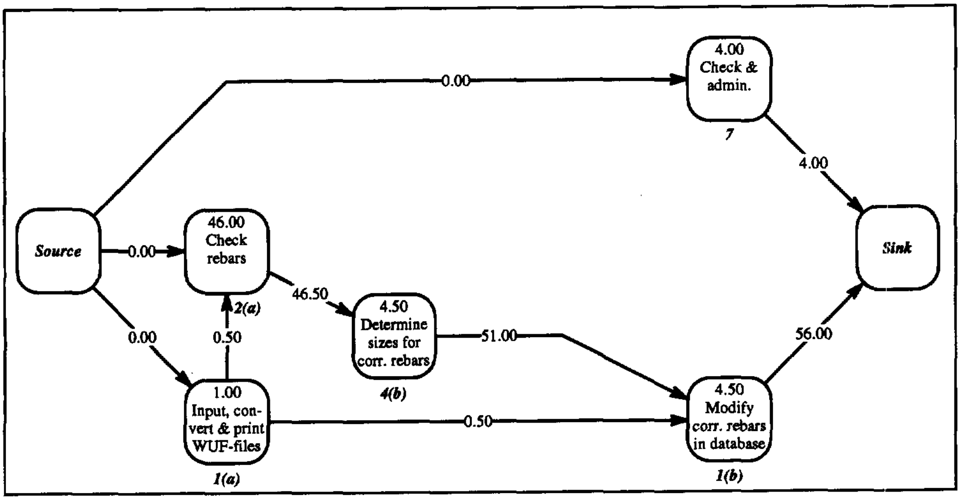

figure 9.16: production digraph D1

Since the number of barcodes differ for the both cases, the production-costs for bar-bending-schedules for the complex reinforcement had to be corrected to allow proper comparison. These corrections are based on the calculated averages of the activity costs for a single barcode (see table 9.33). The table shows that production of bar-bending-schedules for the complex reinforcement requires an additional 36,00% (average) of the costs compared to the simple reinforcement.

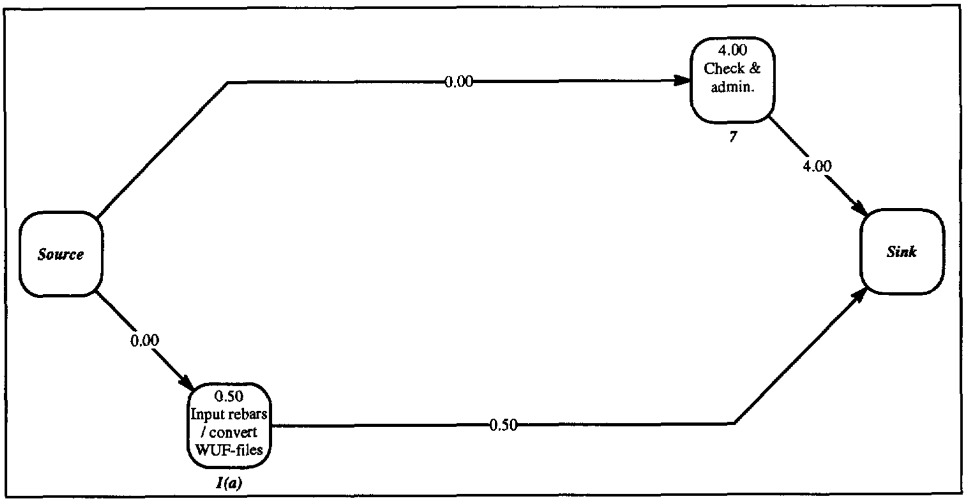

figure 9.17: production digraph D2

Production digraph D1 shows the effects of deployment WUF-diskette^{alt1} on production digraph D0, while production digraph D2 shows the effects of deployment WUF-diskette^{alt3}. Production digraph E1 shows the effects of deployment WUF-diskette^{alt2} on production digraph E0. Finally, production digraph E2 shows the effects of deployment WUF-diskette^{alt3} on production digraph E0. The figures used in these production digraphs are listed in table 9.34 as well.

9.4.5 Analysis of effects

9.4.5.1 Descriptive analysis

Effects of WUF-diskette^{alt1} can be determined by comparing the production digraphs D0 and D1. Nodes 2, 3, 4, 5, and 6 of production digraph D0 are deleted, since these activities are no longer required. Nodes 2(a) ("check rebars") and 4(b) ("determine sizes for corrected rebars") are added in D1, since this deployment of the WUF-diskette requires checking of rebars. Node 1(a) ("input general information") is substituted by a new node 1(a) ("input, convert & print WUF-files. In addition, node 1(b) ("input rebars in database") is replaced by a new node 1(b) ("modify corrected rebars in database"). Node 1(a) has output to both node 2(a) and node 1(b), while node 1(b) requires input from node 4(b) as well.

Costs are reduced, since node-weights *c(2)*, *c(3)*, *c(4)*, *c(5)*, and *c(6)* do not appear in production digraph D1. In addition node-weight *c(1(b))* is lowered substantially, since only a limited number of rebars need to be modified. The overall costs are still lowered despite the high node-weights *c(2(a))* and *c(4(b))*. In particular node-weights *c(2(a))* indicates that still substantial costs are involved in this deployment of the WUF-diskette. That is why the overall cost-reduction is only 40,00%.

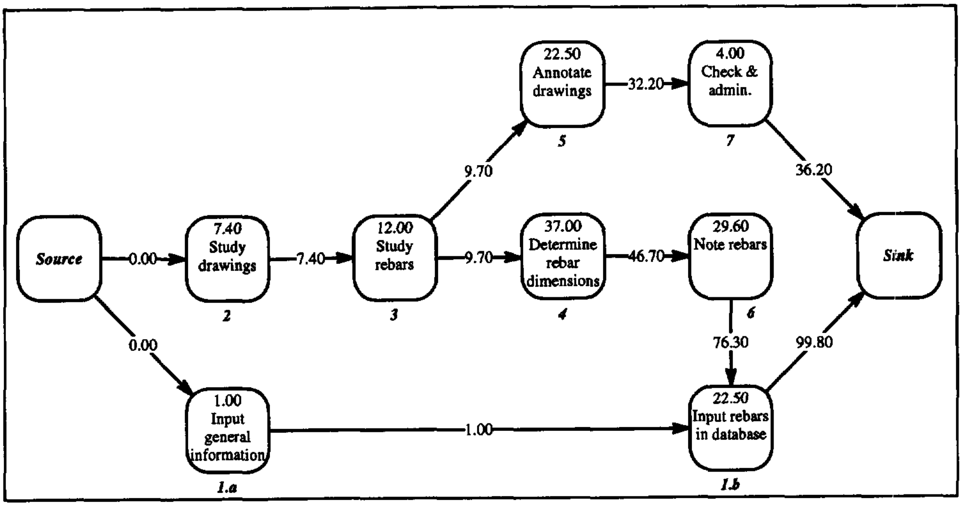

figure 9.18: production digraph E0

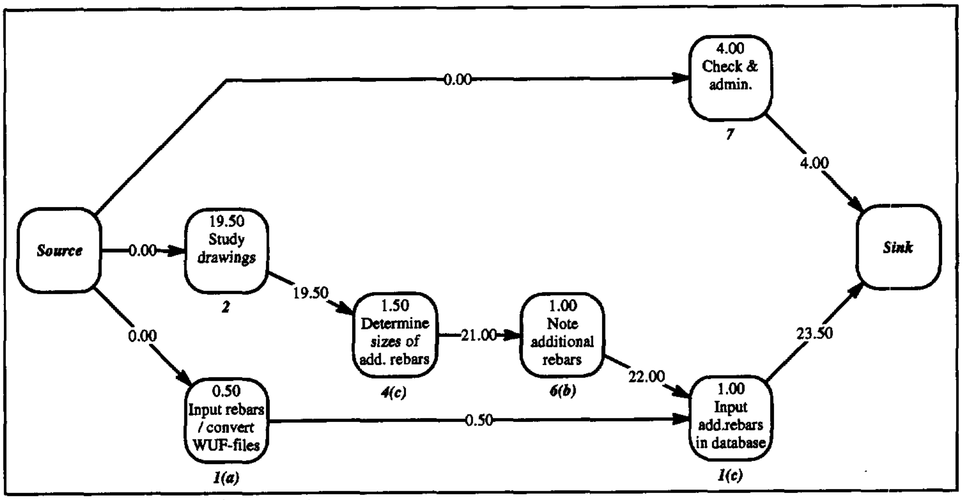

figure 9.19: production digraph E1

Effects of WUF-diskette^{alt3} for simple reinforcement can be determined by comparing the production digraphs D0 and D2. It can be seen that nodes 2, 3, 4, 5, and 6 of production digraph D0 are deleted. Node 1(a) ("input general information") is substituted by a new node 1(a) ("input & convert WUF-files"). Costs are reduced dramatically, since node-weights *c(2)*, *c(3)*, *c(4)*, *c(5)*, and *c(6)* do not appear in production digraph D2. The overall cost-reductions, resulting from this deployment of the WUF-diskette increases up to 95,50%.

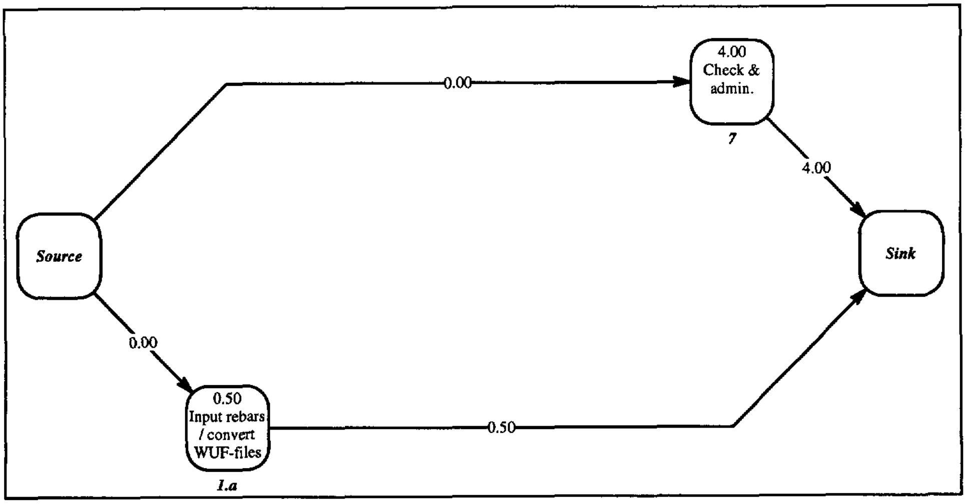

figure 9.20: production digraph E2

Effects of WUF-diskette^{alt2} on complex reinforcement are determined by comparing the production digraphs E0 and E1. Comparison shows that nodes 3 and 5 are deleted. Nodes 4 and 6 are split into two parts; the first dealing with rebars, the second with so-called additional rebars. The nodes dealing with the rebars are deleted, since these activities are no longer required. The nodes dealing with the additional rebars (node 4(c) and 6(b)) are shown in production digraph E1. In addition node 1(a) is substituted by node 1(a) ("input & convert WUF-files").

An arc is added between node 6(b) and 1(c), since node 1(c) requires input from node 6(b). The node-weights of nodes 4(c), 6(b), and 1(c) are lowered, since these activities are required only for the additional rebars. The node-weight *c(1)* is also lower than node-weight *c(1(a))*. However, as can be seen from node-weight *c(2)*, more costs are required for activity 2 "study drawings". The overall cost-reductions, resulting from this deployment of the WUF-diskette for complex reinforcement is approximately (108,50/136=) 80,00%.

Effects of WUF-diskette^{alt3} for the complex reinforcement is similar to the effects for the simple reinforcement (compare D0, D2, E0, and E2). In production digraph E2 only nodes 7 and 1.a are retained. The only costs incurred are for these activities. The production-costs are reduced from 136,00% to 4,50%, as a result of this deployment of the WUF-diskette.

9.4.5.2 Predictive analysis

The production digraphs constructed provide possibilities for predictive analysis of the different deployments of the WUF-diskette. In the case-study, the effects of the deployment of the WUF-diskette, requiring both checking of the rebars, and determination and processing of additional rebars at the RS was not considered. However, with the insight gained from the available production digraphs the effects of this deployment, referred to as WUF-diskette^{alt4} can be predicted.

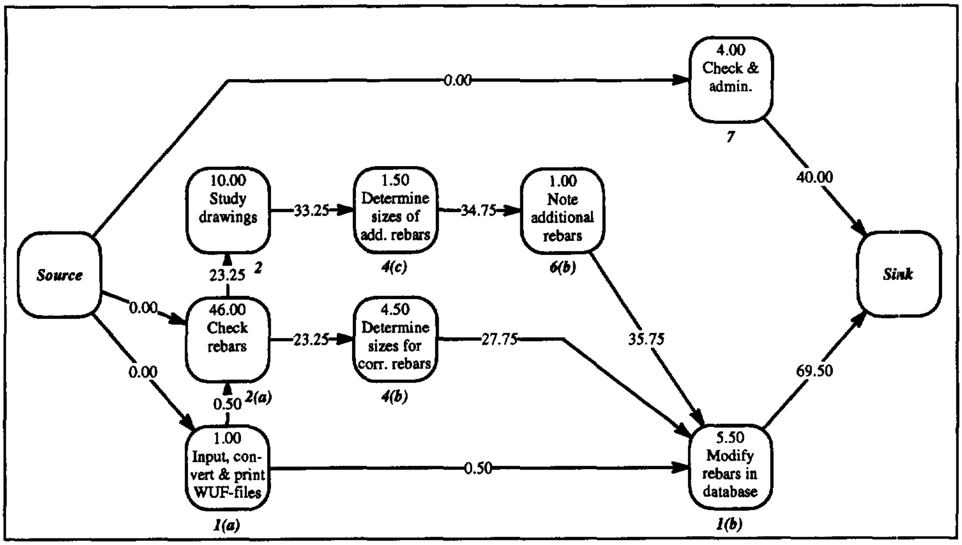

figure 9.21: production digraph D3

Production digraph D3 represents the predictive analysis of the effects of WUF-diskette^{alt4} for the simple reinforcement. The production digraph can be constructed as a combination of the structural changes of the production digraphs E1 and D1. In addition to the changes already seen in the production digraphs separately, an arc is added between node 2(a) an node 2. Node 2(a) ("check rebars") provides input to node 2 ("study drawings"), enabling lowering of node-weight *c(2)*. The node-weights used in production digraph D3 are estimates based on the other production digraphs. Comparison with production digraph D0 shows that WUF-diskette^{alt4} results in cost-reduction of 26,50%. It is expected that for complex reinforcement the reduction will be even less.

9.4.6 Conclusion

The production digraph model illustrates the cost-effects of use of the WUF-diskette in a clear way. The production digraphs show that the different deployments of WUF-diskette have completely different cost-effects. The different deployments are determined by project-organization, arrangements concerning liabilities, etc., rather than on the WUF-diskette itself. This process that the effects of an information commodity depends not only on its elements of the value adding dimensions, but on the mode of deployment as well.

Deployment of WUF-diskette^{alt2} reveals that the separate processing of the additional rebars requires more costs for study of the drawings (compare production digraphs E0 and E1). In the initial process, the additional rebars are processed with the other rebars. Insight in the reinforcement is gained during the processing of the other rebars, which is used for processing of the additional rebars. When WUF-diskette^{alt2} is deployed, more study is required to gain the same insight for appropriate processing of the additional rebars.

The results show that the use of the WUF-diskette at the reinforcement-subcontractor can result in cost-reduction up to 95,00% of the production-costs of bar-bending-schedules. However, deployment WUF-diskette^{alt4} would yield much lower cost-reduction of approximately 26,50%. An intermediate cost-reduction of 40,00% can be achieved with the deployment WUF-diskette^{alt1}. If WUF-diskette^{alt2} is deployed, cost-reductions of approximately 80,00% can be achieved.

Cost-reductions, based on the experiments, matched very well with the estimates of the cost-reductions, provided by the bar-bending-schedulers. The cost-reductions can be used to determine upper-bounds for the demand value of the different deployments of the WUF-diskette. These upper-bounds can be interpreted as an estimate of the maximum amount of money the reinforcement-subcontractor might be willing to invest in the deployment. This amount should be compared to all costs involved in the deployment of the WUF-diskette, such as development-costs for additional features of the CAM system, maintenance of the system, management, system-control, etc.

Upper-bounds for the demand value of CAD systems can be determined in monetary terms as:

$$\delta_x = \alpha_x \, \Delta$$

with: δ_x: upper-bound for the demand value of WUF-diskette deployment x (in Dfl. per annum),

α_x: reduction of production-costs of bar-bending-schedules, resulting from WUF-diskette deployment x,

Δ: annual production-costs of bar-bending-schedules (Dfl. 315.000,--),

For simple reinforcement the values for α_x are summarized below:

Simple reinforcement	**WUF-diskette^{alt1}**	**WUF-diskette^{alt3}**	**WUF-diskette^{alt4}**
α_x	40,00%	95,50%	26,50%

The values can be used to determine the upper-bounds for the demand value of the different WUF-diskette deployment for the reinforcement-subcontractor:

$\delta_{\text{WUF-diskette alt1}} = 0{,}400 * 315.000 =$ Dfl. 126.000,--

$\delta_{\text{WUF-diskette alt3}} = 0{,}955 * 315.000 =$ Dfl. 300.825,--

$\delta_{\text{WUF-diskette alt4}} = 0{,}265 * 315.000 =$ Dfl. 83.475,--

Chapter 10
Conclusions

This last chapter of the thesis describes the implications of this research. Conclusions are provided concerning the cost-effects of CAD systems and the approach taken in this research for modelling cost-effects of CAD systems. Finally, some conclusions are provided concerning the applicability of the approach to other fields.

10.1 Introduction

The purpose of this research is to support strategic management of CAD systems in structural design and construction. For investment-decisions, management needs insight into actual and likely effects of CAD systems and related information commodities. Knowledge of economic effects of both existing CAD systems and alternative CAD systems is needed. Moreover, an analytic framework for comparison of the effects and usefulness of CAD systems (and related information commodities) for structural design and construction processes in general is essential for the analysis of investment-decisions.

The aim of this research has been to develop and test an approach to the analysis of the cost-effects of CAD systems on structural design and construction processes. This thesis provides an approach to analyze and compare the effects of different CAD systems (and related information commodities), based on the production digraph model. CAD systems are classified according to the value-added model of information commodities.

Section 10.2 describes conclusions relating to the cost-effects of CAD systems on structural design and construction processes. These conclusions are based on the case-studies performed in this research at two engineering consultants and one reinforcement-subcontractor. This research shows that cost-effects of deployment of CAD systems can be estimated in quantitative terms.

Section 10.3 confirms that the production digraph model is a useful analytical tool for modelling costs of and cost-relations between activities of structural design and construction. Together with a classification of CAD systems, according to the value-added model, it provides an analytical basis for comparison of the cost-effects of these systems.

Section 10.4 discusses generic conclusions concerning the applicability of the approach to analyze the effects of information commodities on production processes. These conclusions are based on findings in this research. First, this research showed that the approach is applicable not only to CAD systems, but to other information commodities (e.g. drawings, WUF-diskettes, etc.) as well. Secondly, the research findings show that the approach is applicable to both structural design and construction processes. The conclusions are reinforced by other applications of the approach.

10.2 Cost-effects of CAD systems

This research shows that cost-effects can be determined quantitatively. For a business-unit deploying a CAD system cost-reductions can be determined, which represent estimated upper-bounds for the demand value (or benefits) of the deployment of the system. The cost-reductions are determined as percentages of project-costs. With additional information concerning distribution of project-costs and annual turnover the cost-reduction can be expressed in monetary terms.

These upper-bounds can be interpreted as an estimate of the maximum amount of money the engineering consultants might be willing to invest in the deployment of these systems. This amount should be compared to all costs involved in the deployment of CAD systems, such as costs for purchase of the system, training of draughtsmen, maintenance of the system, management, system-control, etc.

Cost-effects are determined and attributed to the specific elements of the value adding dimensions of CAD systems. This facilitates appropriate analysis of the different cost-effects of different CAD systems. Attributing cost-effects to the specific elements of value adding dimensions enables both descriptive and predictive analysis of cost-effects of these systems.

The specific elements of the value adding dimensions of CAD systems are important, but cost-effects are determined by their deployment. Different deployments of a specific CAD system may result in different cost-effects. A specific deployment of a CAD system depends on process-characteristics, which are related to aspects as project-organization, rationalization of the process and product, liabilities, etc.

Resulting from deployment of CAD systems, reductions varying from 6,50% to 36,00% of the structural design costs have been found. The WUF-diskette can be seen as the result of the use of a specific CAD system in the structural design process. Deployment of the WUF-diskette results in reductions in the production-costs of bar-bending-schedules, which vary from 26,50% to 95,00%.

The cost-reductions are based on averages of estimates, provided by experienced staff-members within the organizations, and measurements. However, they provide accurate estimates of the order of magnitude of the cost-effects of different CAD systems, since:

1. the intervals for cost-reductions were relatively small (see sections 9.2.7. and 9.3.6),
2. the measurements during the experiments, and the estimates of the staff-members matched very well (see section 9.4.6).

10.2.1 CAD-effects on structural design

This research proves that significant cost-reductions can result from use of CAD systems in structural design. For current systems, cost-reductions up to 36,00% can be found. However, it must be clear that cost-reductions depend on the nature of the structural design process, the specific elements of the value adding dimensions of the CAD system, and the deployment of the CAD system.

The deployment of CAD systems is restricted by process-characteristics, such as project-organization, rationalization of products & processes, and liabilities. Often a specific cost-effective deployment of a CAD system cannot be realized in practice, since it is hindered by current process-characteristics. Often it is required to deploy the CAD system in a specific way. For example, project-organization hinders the deployment of computer-based concurrent engineering, since current organization is focused on paper- or document-based communication between project-participants. Deployment of CAD systems calls for a re-orientation on the current project-organization.

Based on comparison of the case-studies it can be concluded that the cost-reductions increase with the level of sophistication of the CAD system. So-called standard CAD systems reduce costs by approximately 6,50%, because graphical modelling is done more efficiently than draughting on a draughting-board. Efficient modelling is due to:

1. procedural information, furnished by the CAD systems, such as:
    a. routines and procedures for input, edit, and output of graphical entities,
    b. routines for computing of sizes of the structure are reduced, based on the graphical model;
2. declarative information in the form of:
    a. graphical information in the project-files (e.g. drawing-files, files of previous projects).

More sophisticated systems result from enhancing the standard CAD systems by adding specific features. One such enhancement often seen is the addition of declarative information in the form of graphical symbols of standard construction elements and reinforcement (e.g. libraries with standard symbols and details). Such enhanced CAD systems result in an increase of the cost-reductions, which depends on the process it is deployed in as well. Cost-reductions between 8,20% and 13,80% for the design of structures, and approx. 25,80% for the detailing of prefabricated structure are determined.

Even higher cost-reductions, up to 36,00% and more, can be achieved by deploying more sophisticated CAD systems. Sophistication refers to functional enhancement rather than technological enhancement of CAD systems. Systems, which support parametric design, are examples of such CAD systems. These systems use generic models of structural elements to model the elements, based on input of a limited set of parameters. These kinds of systems are often referred to as object oriented design systems.

For sophisticated CAD systems, such as those facilitating parametric design, rationalization of products and processes is a prerequisite. A certain level of uniformity of the structural elements or objects is required to define generic models. Prefabricated structural elements are examples of rationalized products with a high level of uniformity. For these kinds of elements it is possible to define generic models, which support the achievement of high cost-reductions in the structural detailing of these elements.

It is expected that deployment of CAD systems in the future will result in increased cost-reductions, because:

1. more sophisticated CAD systems are expected, providing features which will increase efficiency; examples of sophisticated systems are object oriented CAD systems and integrated CAD/CAM systems,
2. employees will get more familiar with the use of CAD systems and deploy these systems more efficient.

10.2.2 CAD-effects on construction

This research shows that the deployment of CAD systems in structural design has impacts on construction-costs as well. In case-study 3 the effects of CAD systems on the construction process of reinforcement has been analyzed, resulting in the determination of cost-effects in quantitative terms. This analysis goes beyond the qualitative descriptions of expected effects commonly found in the literature. The production digraph model enables us to provide quantitative estimates of cost-reductions. Significant cost-reductions can be gained, ranging from 26,50% up to 95,00% of the production-costs of bar-bending-schedules.

Effects on construction-costs occur due to the use of information provided by CAD systems, which is transferred to the CAM systems. The transferring of information between information systems is often referred to as Product Data Interchange (PDI). The WUF-diskette enables the transfer of information concerning reinforcement from CAD systems at the engineering consultants to CAM systems at the reinforcement-subcontractor. So, the WUF-diskette represents one form of PDI. Other forms of PDI can be used, for example, by connecting the CAD systems and CAM systems in a computer-network or by telephone line. The exchange format (WUF) can be used in those forms of PDI as well.

This case-study shows that the WUF-diskette can be deployed differently at the reinforcement-subcontractor. Each deployment results in different cost-effects on the production of bar-bending-schedules. The different deployments are influenced by factors mentioned before, such as project-organization, liabilities, etc. During development and testing of WUF, Tongeren & Chandansingh (1994) already concluded that problems are not of technological nature, but related to the deployment of WUF. Indeed, this case-study clearly shows that cost-effects depend on the deployment rather than on the WUF-diskette itself.

Based on these findings, a generalization can be drawn for the effects of PDI, which must be treated as a hypothesis rather than as a conclusion. Cost-effects of PDI on construction depend partly on the technological sophistication (so-called PDI-state). Cost-effects depend primarily on organizational issues associated with the deployment of PDI in construction.

10.3 Modelling

The research shows that this approach used supports decision-making concerning investments in CAD systems, since it facilitates analysis of cost-effects of CAD systems on structural design and construction processes. Analyses with the production digraph model pinpoint effects and relate these to the value adding dimensions of CAD systems. The effects can hardly be illustrated better than with production digraphs, since changes in the structure of the process, the costs of activities, and the cost-relations are shown explicitly.

The case-studies proved that cost-effects are determined mainly by the deployment of CAD systems. One of the strong points of the production digraph model is that it facilitates analysis of the different deployments of a CAD system. Especially in the third case the modelling abilities with respect to the different deployments of an information commodity were demonstrated.

The case-studies proved that the approach has a wide applicability. Firstly, it was shown that the approach applies not only to CAD systems, but to related information commodities as well (e.g. drawings, WUF-diskettes, communication channels, etc.). Secondly, the case-studies showed that the production digraph model can be used to analyze cost-effects in structural design processes as well as in construction processes.

Critical for the reliability of the cost-effects is the determination of the relevant activities, the relevant activity-costs, and the cost-relations. The relevant activities and relations were determined partly from previous research and partly from observations during the case-studies. The activities were checked and modified with several employees and managers.

In contrast to the node-weights (activity costs), the arc-weights (cost-relations) were hard to determine. During the case-studies it was found that employees at the firms were not used to thinking in terms of cost-relations, related to information, between activities. Often an arbitrary, equal distribution was applied for assigning arc-weights. For example, if the output of an activity is distributed over two arcs, the arc-weights assigned are equal to half of the output. Only in some cases was it possible to identify differences in arc-weights with any degree of certainty.

One possible explanation for applying an arbitrary, equal distribution for assigning arc-weights, is the fact that structural engineers and draughtsmen are used to think in traditional information products rather than in the value adding dimensions of information commodities. Arc-weights assigned are based on their observation that a product (e.g. a drawing) is used in different activities. Which elements of the value adding dimensions of an information commodity is used in which activity is not considered.

This touches upon an important issue in the deployment of information systems in structural design and construction. The current focus on paper- or document-based communication between project-participants obstructs deployment of new developments, such as computer-based concurrent engineering. Proper assessment of innovative developments requires an understanding of the nature of the value adding dimensions of an information commodity.

In this research the weights of the arcs were assigned by staff-members. However, during case-study 3 it was found that the arc-weight can be determined from a detailed analysis of the (sub-)activities and related costs. If the analysis is detailed enough it is possible to relate a sub-activity to a specific arc (and the activity using this output). The costs of this activity is then assigned to this arc.

Determination of activity costs (node-weights) proved not to be difficult, but required a lot of recalculation of cost-evaluations. This is due to the fact that costs are not administrated according to the relevant activities (ABC). Is was very stimulating to see that the activity-costs, determined to construct production digraphs, were used by the engineering consultants for project-budgeting. When costs are administered according to the activities identified, more appropriate analyses of cost-effects of CAD systems and other information commodities can be done at these firms in the future.

The application of this approach in the case-studies showed that the accuracy of the structural effects and the cost-reductions improve, when:

1. the relevant activities within the process are clear or relatively easy to determine; e.g. the activities in production of bar-bending-schedules (case-study 3) were clearer than the activities in structural design process (case-studies 1 and 2),
2. the relevant cost-information is based on both measurements, and estimates of staff-members; e.g. measurements and estimates in case-study 3 provided more accurate cost-information than the estimates in case-studies 1 and 2.

10.4 Generalization

This research supports the idea that the production digraph model can be used to analyze cost-effects of any information commodity on any production process. In the case-studies two production processes were considered: the structural design process and (a part of) the construction process. In addition several (types of) information commodities were considered: CAD system, WUF-diskette, and reinforcement-drawings.

This conclusion is supported by related research as well. In particular, Bellin (1991) demonstrated the suitability of the approach to model the effects of CASE-tools on the software engineering process. Currently, the production digraph model is being used and extended to analyze the effects of information commodities based on artificial intelligence (AI).

Appendices

Appendix 1: Checklist questions, initiation

For all case-studies:

When did the organization start its activities.
What are the organization's specializations.
Which staff-members are occupied (function, number, and education).
What is the annual number of projects.
Who are your clients, and what is their share in the annual turnover.
Describe the nature of projects and their share in the annual turn-over.
What were the annual turn-overs for the last four years (Dfl.).
What is the average project-size (Dfl.).
What is the average project-time (months).
Which experience does the organization have with the use of CAD systems and related products, systems, and services.
Can you describe the development of use of CAD systems within your organization.
What were the reasons to start with the use of CAD systems.
What did the organization gained from the use of CAD systems.
What are the features of the CAD systems currently deployed.
Can you estimate the cost-reductions resulting from the use of CAD system.

Additional questions for reinforcement-subcontractor:

What were the annual turn-overs for the last four years (tons of reinforcement).
Can you breakdown the costs of reinforcement according to the different process-activities.
What are the production-costs of bar-bending-schedules.
Can you breakdown the production-costs of bar-bending-schedules.
What is the annual number of bar-bending-schedules produced.
What is the annual number of bar-codes (in the bar-bending-schedules).

Appendix 2: Checklist questions, determination of production digraphs

Interviews with managing structural engineers and structural engineers:

Does the initial production digraph represent all relevant activities.
Does the initial production digraph represent all cost-relations between activities.
Which activities and cost-relations are missing in the structure of the production digraph.
Can you estimate the node-weights (activity-costs).
Can you estimate the arc-weights (cost-relations).
How can more accurate estimates of the weights be gained.
Which nodes and arcs are expected to be altered by the use of CAD systems.

Interviews with draughtsmen:

Which sub-activities can be determined.
What are the cost-relations between these sub-activities.
Can you provide estimates for the node-weights.
Can you provide estimates for the arc-weights (cost-relations).
How can more accurate estimates of the weights be determined.
Which are the important elements of the value adding dimensions of CAD systems.
Which changes result from the use of CAD systems.
Which structural effects can be determine structural effects.
Which node- and arc-weights are affected.
Can you estimate the new node- and arc-weights.
Can you relate the effects to the specific elements of the value adding dimensions of CAD systems.

Appendix 3: Checklist questions, evaluation

Interviews with managing structural engineers and structural engineers:

Do you agree with the estimates of the draughtsmen.
What do you think about the differences represented by the different production digraphs.
What is your opinion on the utility of the approach.
Do you have any questions or suggests. on this or related topics.

Interviews with draughtsmen:

Do you agree with the estimates of the weights presented by the production digraphs.
Are changes resulting from the use of CAD systems shown well enough.
What is your opinion on the effects of CAD systems resulting from the use of CAD systems, and presented by the different production digraphs.

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Summary

The purpose of this research is to support strategic management of CAD systems in structural design and construction. For investment-decisions, management needs insight into actual and likely effects of CAD systems and related information commodities. Knowledge of economic effects of both existing CAD systems and alternative CAD systems is needed. Moreover, an analytic framework for comparison of the effects and usefulness of CAD systems (and related information commodities) for structural design and construction processes in general is essential for the analysis of investment-decisions.

The aim of this research has been to develop and test an approach to the analysis of the cost-effects of CAD systems in structural design and construction processes. This thesis provides an approach to analyze and compare the effects of different CAD systems (and related information commodities), based on the production digraph model. CAD systems are classified according to the value-added model of information commodities.

Chapter 1 describes the relevance of this research by defining the problem, the aim and scope, and the research approach. This thesis reports on the economic effects of CAD systems in structural design and construction. The outline of the thesis is provided at the end of this chapter.

Chapter 2 reviews literature on economic analysis of IT, and focuses on micro-economic aspects. Current methods are evaluated and problems in analysis of IT are identified. The chapter concludes that micro-economic analysis of IT requires consideration of the use of IT-applications in business processes.

Chapter 3 discusses the notion of information and value of information. Information is analyzed with respect to its role in (production) processes. Furthermore, the concept of information commodities - the appropriate element for economic analysis - is defined, and its value-adding attributes are discussed. This chapter concludes that CAD systems are information commodities. This facilitates analysis of the value of CAD systems.

Chapter 4 describes the effects of CAD systems on production processes. In particular, the production digraph model is used to determine the cost-effects of CAD systems in production processes. Some costing issues are also discussed, since the model is designed for the analysis of cost-effects.

Chapter 5 discusses the specific characteristics of the building process. The several phases and activities of structural design and construction of concrete structures are determined. These are required for specifying the production digraphs.

Chapter 6 discusses the objectives of the production digraph model of structural design and construction. This model is applied to structural design and construction to analyze production-costs. The procedure for specifying a production digraph is provided as well.

Chapter 7 pinpoints the different types of CAD systems considered in this research. Not only are the general (draughting) systems considered, but the more specific applications (e.g., detailing of reinforcement, quantity take-out, engineering and analysis) are included as well. A sharp distinction between CAD systems and other computer-based engineering tools (e.g. expertsystems, knowledge-bases systems) is hard to make.

Chapter 8 describes the case-study process, designed to verify the modelling approach to analysis of cost-effects of CAD systems. Three case-studies were selected: two at engineering consultants and one at a reinforcement-subcontractor. The case-study process followed in the first two cases differs from that of the third.

Chapter 9 reports on the results of the case-studies. The first two cases analyzed the cost-effects of CAD systems in structural design. The third case analyzed the cost-effects of the so-called "WUF-diskette" in construction of reinforcement.

Finally, chapter 10 discusses the implications of this research. Conclusions are provided concerning the cost-effects of CAD systems and the approach taken in this research for modelling cost-effects of CAD systems. Finally, conclusions are provided concerning the applicability of the approach to other production domains.

Samenvatting

De Economische Waarde van CAD systemen in het Constructief Ontwerp- en Uitvoeringsproces; een modelmatige aanpak

Dit onderzoek beoogt het strategisch management van Computer Aided Design (CAD) systemen in het constructief ontwerp- en uitvoeringsproces te ondersteunen. Managers hebben behoefte aan inzicht in de verwachte en behaalde effecten van CAD systemen, ten behoeve van het nemen van investeringsbeslissingen. Kennis van de economische effecten van zowel bestaande als verwachte systemen is dan vereist. Daartoe is een generiek analytisch raamwerk voor het vergelijken van de effecten van CAD systemen (en verwante informatie-leverende goederen) in het ontwerp- en uitvoeringsproces van constructies onontbeerlijk.

Het doel van dit onderzoek was: het ontwikkelen en valideren van een benadering voor de analyse van de kosten-effecten van CAD systemen in ontwerp- en uitvoeringsprocessen. Dit proefschrift biedt een mogelijke benadering voor het analyseren en vergelijken van de effecten van verschillende CAD systemen, gebaseerd op het productie-graaf-model. Daartoe worden CAD systemen geclassificeerd aan de hand van het zogenaamde waarde-toevoegend-model van informatie-leverende goederen.

Hoofdstuk 1 beschrijft de relevantie van dit onderzoek door het probleem, het doel en de onderzoeksaanpak te definiëren. Dit proefschrift rapporteert over de economische effecten van CAD systemen in het constructief ontwerp- en uitvoeringsproces. Aan het eind van dit hoofdstuk is de opzet van het proefschrift beschreven.

Hoofdstuk 2 evalueert de literatuur over de economische analyse van Informatie Technologie (IT). Hierbij wordt vooral de micro-economische analyse beschouwd. De huidige methoden en problemen in de analyse van IT zijn geëvalueerd. Geconcludeerd wordt dat voor micro-economische analyse van IT, het gebruik van informatie systemen in processen moet worden beschouwd.

Hoofdstuk 3 bespreekt de begrippen "informatie" en "waarde van informatie". De rol van informatie in (productie) processen wordt geanalyseerd. Daarnaast worden zogenaamde informatie-leverende goederen - de meest geschikte elementen voor economische analyse - gedefinieerd. Tenslotte wordt aangetoond waarom CAD systemen als informatie-leverende goederen beschouwd kunnen worden. Dit maakt het mogelijk de waarde van CAD systemen te analyseren.

Hoofdstuk 4 beschrijft de effecten in productie processen ten gevolge van CAD systemen. Het productie-graaf-model wordt geïntroduceerd, waarmee kosten-effecten van CAD systemen in productie processen kunnen worden bepaald. Omdat het model gebruikt wordt voor het analyseren van kosten-effecten worden tenslotte enkele kosten-begrippen besproken.

Hoofdstuk 5 behandelt de specifieke kenmerken van het constructie-proces. De verschillende fasen en activiteiten van het ontwerp- en uitvoeringsproces van betonconstructies worden besproken. Deze zijn nodig voor het construeren van productie-grafen.

Hoofdstuk 6 beschrijft de doelstelling van de productie-grafen van het ontwerp- en uitvoeringsproces. Het productie-graaf-model wordt hier gebruikt voor het modelleren van productiekosten van ontwerp en uitvoering van betonconstructies. De generieke procedure voor het construeren van productie-grafen wordt eveneens gegeven.

Hoofdstuk 7 definieert de verschillende CAD systemen die worden beschouwd in dit onderzoek. Hierbij worden niet alleen de algemene (teken-) systemen beschouwd, maar ook de specifieke applicaties (bijvoorbeeld applicaties voor het detailleren van wapening, het bepalen van materiaal-hoeveelheden, het ontwerpen en het analyseren). Hierbij wordt geen onderscheid gemaakt tussen CAD systemen en andere IT-gereedschappen (zoals expertsystemen en kennissystemen).

Hoofdstuk 8 beschrijft het case-study proces. De case-studies zijn opgezet om te testen of de benadering voor het modelleren van de kost-effecten van CAD systemen voldoet. Drie case-studies zijn uitgevoerd: twee bij raadgevend ingenieursbureau's en één bij een wapeningscentrale. Het proces voor de eerste twee case-studies verschilt ten opzichte van het proces voor de derde case-studie.

Hoofdstuk 9 presenteert de resultaten van de case-studies. In de eerste twee case-studies werden de effecten van CAD systemen in het constructief ontwerpproces geanalyseerd. In de derde case-studies worden de effecten van de zogenaamde WUF-diskette in het wapeningsproces in wapeningscentrales geanalyseerd.

Hoofdstuk 10 tenslotte, bediscussieert de implicaties van het onderzoek. De conclusies hebben betrekking op de effecten van CAD systemen en de gevolgde benadering voor het modelleren van de kosten-effecten van CAD systemen. Tenslotte zijn ook conclusies beschreven over de geschiktheid van de benadering voor andere takken van industrie en wetenschap.

Curriculum vitae

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