PRODUCTION CONTROL IN CONSTRUCTION

Different Approaches to Control, Use of Information and Automated Data Processing

B. Melles
J.W.F. Wamelink
PRODUKTIEBEHEERSING IN DE UITVOERENDE BOUW

verschillende typen van beheersing, informatiegebruik en
automatisering bij de realisatie van bouwopdrachten

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ter verkrijging van de graad van doctor
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op gezag van de Rector Magnificus, prof. ir. K.F. Wakker,
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To our wives
PREFACE

This thesis represents the culmination of research activities carried out under the auspices of the Delft University of Technology in the Netherlands which have dealt with "production control in the construction industry". This project was part of a joint program supported by the Applied Mechanics Section and the Design & Construction Management Section of the Civil Engineering Faculty. The Industrial Engineering and Management Science Faculty of the Eindhoven University of Technology in the Netherlands also participated in this research.

Prof.dr.ir. J. Blauwendraad supervised the research work carried out in connection with this project. He was assisted by a Advisory Group in which prof.dr.ir. J.W.M. Bertrand (Eindhoven Technical University), dr.ir. R. Kwikkers (TNO-IPL), ir. J.C.B. Robers (Twijnstra Gudde NV, Management Consultants), prof.ir. Ch.J. Vos (Delta Marine Consultants BV, Delft University of Technology) and prof.dr.ir. J.C. Wortmann (Eindhoven University of Technology) participated.

This research project was organized as a joint effort from its initiation. Proposals and ideas for this study were contributed and developed equally by both authors. With respect to the preparation of the final report and the defence of this research, B. Melles has been responsible for Part 1, Chapter 3; Part 2, Chapter 5 and the sub-sections dealing with the decision system per type discussed in Sections 6.3 through 6.7 in Part 2; the Intermezzo in Part 2; Part 3, Chapter 3 and Part 4, Chapter 3. J.W.F. Wamelink has been responsible for Part 1, Chapter 4; the sub-sections dealing with data analysis and automated information systems per type in Sections 6.3 through 6.7 in Part 2; Part 2, Section 6.8; Part 3, Chapter 2 and Part 4, Chapter 4. The responsibility was shared for the preparation of Part 0; Part 1, Chapters 1 and 2; Part 2, Chapters 1 through 4 and Appendix I; Part 3, Chapter 1 and Part 4, Chapters 1 and 2.

The initiation and execution of a research project is not a simple task. The challenges encountered by the researcher are not restricted to problems of a scientific nature. The availability of ample support is important. We wish to mention several names in this connection, without overlooking the many other individuals who also contributed significantly to this project.

To start with, we owe a considerable amount of thanks to our thesis supervisor,
Preface

prof.dr.ir. J. Blaauwendraad. He inspired us to complete our research particularly when difficulties were encountered; he also help us tremendously in controlling the level of our ambitions. Our other thesis advisors, prof.dr.ir. J.W.M. Bertrand and prof.dr.ir. J.C. Wortmann, supported us in the development and careful formulation of our approaches to decision systems and management information systems for production control. Both of our wives demonstrated great patience in providing a continual and flexible support. Patience and understanding was also exhibited by the staff of INFOCUS Management Consultants BV when we were unavailable for dealing with matters of business.

We also wish to express our gratitude to our sponsors, Baan Info Systems BV (1988-1989) and the Technology Foundation (STW) (1990-1993), for their financial support for this research project.

Delft, November 1993

Bert Melles
Hans Wamelink
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SUMMARY

As a result of changes in the construction industry such as smaller profit margins and increasingly demanding clients, more interest has been shown for improving the control of the production process in recent years. The research described in this book is closely linked with this effort to realize improvements in production control. Production control in this context is interpreted as a complex whole of decision functions and information processing functions which, together, ensure that the construction process produces a product which satisfies the requirements of the client.

The construction industry is different from other industries. This becomes apparent when a number of characteristics are considered. The most important characteristics in this respect are that:

- a new "production company" (construction site) is created for each construction order; this production company therefore exists only for a short period of time and has a temporary character;
- a large number of joint agreements (subcontracting and the establishment of consortia) are generally arranged for each construction order; and
- the design activities (carried out by architects and engineers) and the production activities (carried out by the construction company) are generally not carried out by a single contractor.

This combination of characteristics is unique to the construction industry. This means that the production control requirements and methods in the construction industry are also different from the other sectors of industry. A great deal of attention is traditionally focused on project control (project management). Nevertheless, this does not always lead to satisfactory results. The planning and recording methods which have been specially developed for the construction industry tend to work well in some situations but are inadequate in other situations. The suitability of any given method of production control appears to be dependent upon the specific type of construction order. This observation has formed the basis for one of the most important objectives of this study, which is answering the question of -

"which characteristics of a given construction order in the construction industry are the key determinants for the applicability of a certain form of control?"
A similar question can be asked with respect to production companies in general. This has been the subject of research in the field of industrial engineering, leading to the definition of typologies as the theoretical basis for different control approaches. An analysis of these typologies shows that they are not really applicable to a situation in the construction industry for a number of reasons. The most important reason is that these typologies do not take the particular characteristics of the construction industry (as mentioned above) into account.

As a result, it has been necessary to develop a new typology for production control in construction. The individual construction orders as well as their interrelationships form the basis of this new typology. This is a unique aspect of the research presented here which is not found in previously published studies carried out in the construction industry. Using this newly developed typology, construction orders are differentiated based upon the following distinguishing characteristics:

- the internal availability of scarce resource capacities (equipment, personnel);
- the employment period of the internal resource capacities;
- the number of crew assignments per construction order;
- the variety and quantity of materials consumed and resource capacities utilized;
- the information requirements which are dependent upon crew assignments.

By using these distinguishing characteristics to analyze the various sectors in the construction industry, five different types of control situations have been identified. Subsequently, design rules for the decision system as well as the management information system have been defined for each type. With respect to the decision system, the interrelationships and the content of the decision functions are then described. Concerning the management information system, the data model and the way in which the information system can contribute to reducing the uncertainties in the production process are described per type of control. Attention is also focused on the general architecture of the management information system which could be used when automating these functions.

The following five basic types of construction orders and associated types of control have been identified in this study:

**A. Unique project**

The "unique project" type refers to large, complex construction orders in which many different types of materials and resource capacities are found. The average project duration is on the order of one to four years. Various components of such construction orders require the employment of specialized and highly qualified
personnel. Generally, a great deal of uncertainty is still present when the construction activities are initiated. This type of construction order is found primarily in the commercial building sector and in the case of civil works.

This type of complex construction order needs to be controlled at various hierarchical levels. Special attention must be paid to coordinating the allocation of the scarce resource capacities across multiple construction orders. The complexity of the construction order and the relatively long project duration emphasize the need for an adequate project coordination to ensure that the relationships between the activities, the progress of activities and the consequences of any disruptions are carefully managed. A significant amount of attention must be focused also on the mobilization of workers, equipment and materials. Adequate instructions for performing the necessary tasks must be available at the construction site. The design of the management information system is influenced to a large extent by the vast amount of unique data that needs to be processed and transformed into decision information.

B. Subcontracting project

The "Subcontracting Project" type of construction order can be characterized as being less complex than a "unique project" since this generally involves smaller and simpler projects of limited duration. This type is found in the commercial building sector and the residential construction sector in connection with companies which operate in a flexible fashion. This essentially means that whenever the portfolio of orders is such that the demand for a certain resource capacity exceeds the available capacity, it is then possible to make use of external resource capacity through subcontracting. The implication here is that the resource capacities required by this type of project are not extremely scarce. In comparison with the number of control levels required for the "unique projects", this type of project has one level less, namely, there is no need for coordinating the allocation of resource capacities across multiple construction orders. As a result, there is no need to take other construction orders (projects) into account, thus, leading to an important simplification of the management information system.

C. Standard project

The identifying characteristic of this type of construction order is that resource capacities are used which are relatively easy to find externally (and, thus, are not scarce resources), with the consequence that these resource capacities are neither scheduled nor allocated in advance of the time at which they are needed. In addition, no assignment-dependent information is needed in connection with performing the required tasks at the construction site since only routine methods and techniques are
involved. Uncertainty is not a problem, which means that the management information system can be simplified enormously. This type of construction order can be found within most sectors of the construction industry.

D. Work order production

The "work order production" type of construction order can be characterized as being small-scale, simple and well-defined. This type of construction order occurs primarily in connection with small-scale jobs and the smaller road construction and concrete construction orders. The work crews assigned to this type of construction order are always able to complete the total construction order independently.

An explicit coordination of the activities involved in the construction order is not required in this case since a single work crew is assigned to carry out the total construction order. A good coordination across all of the construction orders is, nevertheless, extremely important in view of the limited availability of workers qualified to carry out this type of work and the short duration of the construction order. Poor coordination would otherwise lead to under-utilized resource capacity.

E. Mass production project

The "mass production project" type of construction order occurs in the dredging sector. The activities in this case are similar for all of the construction orders and extremely scarce resource capacities are utilized. This means that the coordination of multiple construction orders of this type is of great importance.

The formulated design rules have been translated into concrete, practical situations in the form of two case studies which illustrate how changes in the distinguishing characteristics can lead to a different type of control and a different type of support from a management information system.
SAMENVATTING

Door veranderingen in de bouwnijverheid, zoals krappere marges en veeleisende opdrachtgevers staat een betere beheersing van het produktieproces de laatste jaren steeds meer in de belangstelling. Het in dit boek beschreven onderzoek sluit zich bij dit streven naar een betere produktiebeheersing aan. Produktiebeheersing wordt daarbij opgevat als een complex geheel van beslissings- en informatieverwerkings-functies die er gezamenlijk voor zorgen dat het bouwproces tot een produkt leidt dat aan de wensen van de klant voldoet.

De uitvoerende bouw is een branche in de industrie welke zich onderscheidt van andere branches door een combinatie van kenmerken. De belangrijkste hiervan zijn:

- het voor iedere bouwopdracht opnieuw opzetten van een "produktie-bedrijf" (bouwplaats), hetgeen daardoor een zeer tijdelijk karakter heeft;
- het groot aantal samenwerkingsverbanden per bouwopdracht (onderaanneming en consortiumvorming);
- en het doorgaans niet in één hand zijn van ontwerp (architecten, constructeurs) en uitvoering (uitvoerend bouwbedrijf);

Door deze combinatie van kenmerken is de wijze van produktiebeheersing in de uitvoerende bouw anders dan in andere delen van de industrie. Van oudsher wordt veel aandacht besteed aan projectbeheersing (project-management). Echter, niet altijd met het juiste resultaat. De ontwikkelde plannings- en registratiemethoden voor de bouw voldoen in de ene situatie wel en in de andere niet. De toepasbaarheid van een methode van produktiebeheersing blijkt afhankelijk te zijn van de specifieke produktiesituatie.

Deze constatering heeft ten grondslag gelegen aan een belangrijk doel van het onderzoek, de beantwoording van de vraag:

"welke eigenschappen van een produktiesituatie in de bouw bepalen de toepasbaarheid van een bepaalde vorm van beheersing"

In de technische bedrijfskunde voor produktiebedrijven wordt iets soortgelijks onderkend en worden verschillen in beheersing theoretisch onderbouwd met typologieën. Na bestudering van deze typologieën bleken zij om een aantal redenen
Samenvatting

niet toepasbaar voor de situatie in de uitvoerende bouw. De belangrijkste reden is dat de typologieën geen rekening houden met de eerdere genoemde bijzondere kenmerken van de bouwbranche.

Een en ander heeft geleid tot de ontwikkeling van een eigen typologie voor produktiebeheersing in de uitvoerende bouw. Onderwerp van deze typologie zijn niet alleen de bouwopdrachten individueel, maar ook hun onderlinge relatie. Op dit punt onderscheidt het onderzoek zich van eerder uitgevoerd onderzoek in de bouwnijverheid. Binnen de ontwikkelde typologie worden bouwopdrachten onderscheiden op basis van de volgende typerende eigenschappen:

- de schaarste van de bedrijfseigen capaciteiten (materieel, personeel);
- de inzetdura van de bedrijfseigen capaciteiten;
- het aantal ploegtaken per bouwopdracht;
- de diversiteit en hoeveelheid gebruikte materialen en ingezette capaciteiten;
- de behoefte aan ploegtaakgebonden informatie.

Door analyse van sectoren in de bouwbranche met behulp van deze typerende eigenschappen blijken er vijf verschillende beheersingstypen te bestaan. Per type zijn ontwerpregels opgesteld voor zowel het beslissingssysteem als het bestuurlijk informatiesysteem. Met betrekking tot het beslissingssysteem wordt ingegaan op de samenhang en invulling van beslissingsfuncties. Met betrekking tot het bestuurlijk informatiesysteem wordt per beheersingstype stilgestaan bij het gegevensmodel en de wijze waarop het informatiesysteem een bijdrage kan leveren aan de reductie van onzekerheden in het produktieproces. Aandacht wordt tevens besteed aan de applicatie-architectuur van mogelijke automatisering.

De volgende vijf basis-beheersingstypen worden in het onderzoek onderscheiden:

A. Uniek project

Het type "uniek project" kenmerkt zich als grote, complexe bouwopdrachten, waarin veel verschillende materialen en capaciteiten gebruikt worden. De gemiddelde doorlooptijd is orde grootte 1 tot 4 jaar. Verschillende onderdelen van deze bouwopdrachten vereisen de inzet van specialistisch, hoog gekwalificeerd personeel. Over het algemeen bestaat er bij aanvang van de bouwopdracht nog veel onzekerheid. Dit type bouwopdrachten komt vooral voor in de utiliteitsbouw en de droge waterbouw.

Een dergelijke complexe bouwopdracht dient beheerst te worden op verschillende hiërarchische niveaus. Door de schaarste van de capaciteiten dient gezorgd te worden
voor een goede afstemming met andere bouwopdrachten. De complexheid van de bouwopdracht en de lange doorlooptijd maken een adequate projectcoördinatie nodig, waarbij de relaties tussen activiteiten, de voortgang en de consequenties van verstoringen nauwkeurig worden bijgehouden. Veel aandacht dient ook besteed te worden aan de mobilisatie van mensen, materieel en materialen. Op de bouwplaats moeten goede instructies beschikbaar zijn voor de bewerkingen die uitgevoerd worden. De inrichting van het bestuurlijk informatiesysteem wordt in grote mate beïnvloed door het grote aantal unieke gegevens dat verwerkt dient te worden tot beslissingsinformatie.

B. Uitbestedingsproject

Het type uitbestedingsproject kenmerkt zich ten opzicht van een uniek project door een kleinere complexiteit. Het zijn over het algemeen kleinere en minder moeilijke werken met een beperkte doorlooptijd. Dit type komt voor in de utiliteitsbouw en de woningbouw bij bedrijven die zich flexibel willen opstellen. Op het moment dat de orderportefeuille de beschikbaarheid van capaciteit nodig maakt, zijn zij in staat deze in te huren of aan te trekken. Dit betekent dat de benodigde capaciteiten niet erg schaars zijn bij dit type bouwopdracht. Een en ander betekent voor de beheersing dat ten opzicht van het type “uniek project” één beheersingsniveau ontbreekt, n.l. de afstemming van inzet van capaciteiten over bouwopdrachten heen. Dit betekent dat met andere bouwopdrachten (projecten) geen rekening gehouden hoeft te worden, hetgeen ook een belangrijke vereenvoudiging van het bestuurlijk informatiesysteem tot gevolg heeft.

C. Standaardproject

Kenmerkend voor dit type bouwopdrachten is dat er gewerkt wordt met capaciteiten die eenvoudig inhuurbaar (en dus niet schaars) zijn, hetgeen tot gevolg heeft dat de inzet van capaciteiten zeer kort voor het moment dat zij benodigd zijn ingepland kunnen worden. Daarnaast is geen taakgebonden informatie benodigd bij het uitvoeren van bewerkingen op de bouwplaats als gevolg van het feit dat het hier gaat om bekende technieken. Onzekerheid treedt niet op, waardoor het bestuurlijk informatiesysteem sterk vereenvoudigd kan worden. Dit type bouwopdracht komt in de meeste sectoren van de bouw voor.

D. Werkorderproduktie

Het type werkorderproduktie kenmerkt zich als kleinschalige, eenvoudige en goed
afgebakende bouwopdrachten. Het komt voor bij klantenwerk (klussenbus) en de kleinschalige wegenbouw en betonbouw. Ze worden allen gekenmerkt door het feit dat de ploegen de gehele bouwopdracht volledig zelfstandig uitvoeren.

Door deze koppeling van een ploeg aan de gehele bouwopdracht is een expliciete coördinatie binnen de bouwopdracht niet noodzakelijk. Wel is een goede afstemming van de bouwopdrachten onderling van groot belang. Dit laatste wordt veroorzaakt door de schaarste van het personeel en de korte doorlooptijd. Een slechte afstemming zou dan leiden tot leegloop.

E. Massaproject

Het type massaproject komt voor in de baggersector. De werkzaamheden binnen dit type bouwopdracht zijn voor alle bouwopdrachten gelijksoortig. Er worden zeer schaarse capaciteiten ingezet. Hierdoor is met name de afstemming van bouwopdrachten op elkaar van groot belang.

In de vorm van twee cases zijn de opgestelde ontwerpregels vertaald naar concrete situaties in de praktijk, waarbij geïllustreerd wordt hoe verandering van de typende eigenschappen leidt tot een andere vorm van beheersing en van de noodzakelijke ondersteuning met een bestuurlijk informatiesysteem.
PART 0: INTRODUCTION
1 MOTIVATION AND OBJECTIVE OF THIS RESEARCH

1.1 Motivation for this Research

Improving the control of production in the construction industry is a subject of major interest within construction companies as well as in the scientific community. This topic also received a great deal of attention in the sixties. Research and practical experience in the past have focused on the introduction of network techniques for activity scheduling, performing time-motion studies and the creation of production planning departments within construction companies.

The interest in these topics waned in the early seventies, probably due to the belief that the limits of the practical application of production control in construction had already been reached. It was assumed that further enhancements to this research might lead only to further misunderstandings between production, project planning and project management rather than further improvements in productivity.

At the end of the eighties it was apparent that there was renewed interest in this subject. Two important stimuli were:

1. the increased possibilities for using information technology effectively within the construction industry;

2. the successes reported in other industries and/or by foreign construction companies (e.g., in Japan) in the area of production control. In particular, the introduction of Total Quality Management has become popular; this approach supports the realization of a systematic improvement of the total business process.

The success of theories for production control in other industrial sectors has also been a source of inspiration for this research. Why have various forms of production with associated control approaches been identified in other industrial sectors but not in the construction industry? To what extent might these other approaches be applicable within construction companies? What are the particular advantages of each of these approaches?
The scientific research dealing with production control in the other industrial sectors typically falls within the specific area of industrial engineering which focuses on manufacturing operations. By applying the theory which has been developed within this specific area of management science to the construction industry, an effort has been made to reach a better understanding of production control so that a more direct approach can also be followed in construction companies to improve production control.

This research complements other scientific research initiatives which are current topics of discussion within various international scientific organizations (for example, Working Commission 65 on "Organization and Management of Construction" of the International Council for Building Research, Studies and Documentation (CIB). The intention of the approach followed here is to extend the normal boundaries of the traditional research carried out in this area.

1.2 Objective and Scope of this Research

The objective of this research has been:

*to provide a theoretical basis for construction companies in their efforts to improve the control of production activities. The starting point for this has been the theory developed within the area of industrial engineering for manufacturing companies.*

The research here remains limited to the control of processes which deal with the actual realization of construction work (by construction companies). This research is intended, on the one hand, to provide a theoretical basis for construction companies in their efforts to improve the control of production activities, resulting in design rules for the establishment of an adequate production control. In connection with this and the aforementioned theoretical framework, attention is focused here on the decision-making aspects and the related information requirements. The intention of this research is also to provide an indication of how various alternatives for production control could be realized in practice in existing situations. This practical application provides a better evaluation of the feasibility of the ideas presented here.
2 STUDY APPROACH AND STRUCTURE OF THIS THESIS

2.1 Study approach

The approach followed to carry out the research in this study consists of three phases. These phases are presented in the form of a diagram in Figure 2.1.

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**Figure 2.1: The Three Phases of the Study Approach**

It should be mentioned that the division of this study into phases has not led to the observance of strict boundaries between the phases as suggested in Figure 2.1. There has been a certain amount of interaction and overlapping activities between the phases.
A brief description of these phases is presented in the remainder of this chapter.

**Orientation**

The initial orientation phase was carried out during the first years of this study (1988-1990). A variety of subjects were reviewed during this phase and a significant portion of the time was spent on analyzing the approaches to production control which were currently being used in the construction industry [Melles & Wamelink-1990,a]. This resulted in the development of several models which could be used as the basis for further analysis. Many of these models were developed based upon eight different research projects which were lead by the authors.

In addition to this, reference theories concerning decision systems and management information systems for production control were established. The important assumptions for the further development of theories on decision systems and management information systems for production control in the construction industry were documented at this point. Finally, a review of the methods and techniques employed by manufacturing companies for the purpose of production control was carried out. Here, also, a portion of the research was performed in connection with two research projects which were supervised by the authors.

**Theory Formulation**

Design rules for decision systems and management information systems for production control were established during this phase for use in the construction industry. This was carried out by combining a selection of the assumptions formulated in the reference theories, the collected knowledge of production control methods used by manufacturing companies and knowledge of the approaches to production control currently used in the construction industry.

**Application**

Various details of the design rules were defined based upon two practical situations formulated as case studies.
2.2 Structure of this thesis

This thesis is organized in four parts. The basic approach followed in carrying out this study is described as part of the general introduction in Part 0.

A review of the various schools of thought in the field of management science is then presented in Part 1. Using this as a basis, a suitable approach for analyzing production control situations in the construction industry is then identified. This approach is closely related to the method normally followed with respect to production control in the field of industrial engineering. Special attention is paid to the theories developed by a number of researchers at the Eindhoven University of Technology. Their ideas have been incorporated in the model developed here for describing and explaining the production control issues in the construction industry.

The discussion in Part 2 builds upon this foundation by recognizing, first of all, that a further analysis of the model developed in Part 1 leads to the identification of a number of different production situations in manufacturing companies from an industrial engineering point-of-view. Each of these production situations can be characterized by a different form of production control. A Typology can be defined to make a distinction between the various types of production situations based upon a specific set of distinguishing characteristics. In order to develop this typology, a number of existing typologies are subsequently evaluated in Part 2 to determine to what extent they might be applicable to situations in the construction industry. The conclusion is that none of the existing typologies is adequate for use in distinguishing between the different types of construction orders. A new typology is, therefore, defined here. In addition, a number of design rules are formulated for determining which production control approach should be used for each of the different types of construction orders. In connection with this, a production control system is viewed as a combination of a decision system and a management information system.

The typology developed here is then applied to two different case study situations in Part 3.

The results of the study are evaluated in Part 4.
PART 1: PRODUCTION CONTROL THEORY
1 INTRODUCTION

In the past production control in construction has been the subject of research studies a number of times. A variety of objectives have been formulated and many different approaches have been followed over the years.

A theoretical framework is presented in this part of the book to provide a basis for the subsequent research. The reasons for making certain choices during the course of this research effort are explained in combination with a retrospective review of the reasons behind the approaches used in the past for production control.
2 PRODUCTION CONTROL: OBJECTIVE, DEFINITION AND MODELLING

2.1 Introduction

Production control can be studied and described from various points of view. The purpose of this chapter is to establish which points of view exist and which are suitable for use as part of this research effort (Sections 2.2 and 2.3). The subject of what may be understood by the term "production control" is introduced in Section 2.4. Certain aspects are discussed subsequently in more detail in Chapters 3 and 4.

2.2 Defining the Terminology

A construction company's primary objective is to carry out a construction order to produce a construction work. Each construction work can be seen as the ultimate result of a given production process. The production process in a company can also be referred to as the primary business process. The primary business process is the process which is performed in order to achieve the primary business objective of a company.

The production process within a construction company is defined here as being:

the process by which materials are transformed into construction works through the use of resource capacities under certain conditions.

The conditions referred to in this definition are related to the requirements associated with the product, itself, as well as requirements associated with the process of producing the product. Examples of such requirements are the quality of the product and the period of time within which the product must be completed by the contractor. In addition, it is important for the continuity of the construction company that the cost of the product is kept as low as possible.

It is necessary that other processes are carried out in addition to the production process within a company in order to ensure that the production process is performed in conformance with the stated conditions. This whole set of processes is referred to as production control:
Production control consists of the processes which are related to the coordination of all of the aspects of the production process such that the stated conditions pertaining to the production process are satisfied.

Various types of processes may be included in this set. Some of the processes may deal with decisions concerning the utilization of equipment, for example. Other processes may be included which need to be carried out in order to capture the data which is needed by the decision-maker.

2.3 Production Control Research

Production control has been a subject of study in companies for many years. The ways in which these studies are carried out and the ideas concerning which factors are most significant with respect to production control have changed over the course of time. The various approaches which can be used to study the subject of production control are reviewed in Sub-section 2.3.1 prior to discussing the production control research in the construction industry in Sub-section 2.3.2. Subsequently, in Sub-section 2.3.3, the final choice is described regarding the approach selected for the research performed here.

2.3.1 Research from various points of view

Botter [Botter-1988] has provided an extensive description of several different approaches in his book "Industry and Organization" (Dutch: "Industrie en Organisatie"). One of the first scientific researchers involved in the field of production control was F.W. Taylor [Taylor-1911]. Taylor has been mentioned as the "father of scientific management." The essence of this theory is that productivity can be improved by linking reward schemes to the achievement of norms with respect to performance. The performance norms should be based upon time-motion studies and the analysis of procedures. The philosophy behind this scientific management approach can be characterized as being rather "technocratic". Many of the researchers in this field, indeed, have a mathematical or technical (engineering) background.

Botter sees the socio-psychological proponents (around 1930) as a reaction to this scientific management approach. This approach can be characterized as one in which socio-psychological factors (such as motivation and recognition) are taken into account in evaluating performance, in addition to technical and physical factors. Herzberg and McGregor are two of the well-known researchers who advocate this approach. In 't Veld expresses the essence of this new approach as follows [Malotaux & In 't Veld-1987]: "man is a social creature who can be persuaded to be more productive when one takes into account that his productivity is influenced by his
relationships with other workers (i.e., human relations).

In 't Veld explains further that this approach also does not always lead to the most ideal situation within a company: "in the meantime this human relations approach has degenerated in practice in some companies into the idea that the factory should be one, big, happy family in which conflicts are to be avoid under all circumstances."

The contribution of the humanities suggests that a totally different approach should be followed. This approach is based upon the premise that better insights into the existence and growth of modern organizations have been attained by considering this within the context of the general social developments during the last centuries. This approach has not been considered any further within the scope of this research.

An approach which deserves some serious attention is the "management process" approach. Using this approach, a clear distinction is made between the production process (the primary business process), on the one hand, and the management functions, on the other hand. A top-down as well as a bottom-up approach can be identified within this context. The proponents of a top-down approach believe that the design of the control function dictates how the production process must then be structured. Those who support the bottom-up approach, on the other hand, believe that the control of the production process is dependent upon the inherent structure of the production process.

In addition, within these two different points of view, two different schools of thought can be identified: the "universal school" and the "contingency school". The universal school assumes that any properly developed theory will always be valid and applicable within a certain environment. The generalists who follow this school of thought tend to concentrate on the formulation of generally applicable principles and methods. This approach was supported by a large number of researchers in the fifties and sixties. After 1965, however, this approach received a great deal of criticism, leading to the formulation of the "contingency theory". The proponents of this newer school of thought tend more towards the opinion that a theory is only valid under certain conditions. This became an extremely popular approach in the eighties. A good example of this approach is the typology study carried out by Van Rijn [Van Rijn-1986]. Bertrand, Wortmann and Wijngaard, in their book "Production Control: a Structural and Production-oriented Approach", also indicate that a careful evaluation is always necessary with respect to techniques and methods to be used [Bertrand et al.-1990,a].

The last important approach considered to be relevant for this study is the so-called systems approach. Systems theory is used in various sciences, including organizational research. The application of systems theory to organizational issues is described by In
't Veld in his book "Analysis of Organizational Problems" (Dutch: "Analyse van Organisatieproblemen" [In 't Veld-1987]). In 't Veld states that systems theory can be useful in studies involving improvement of the organization as a whole and the underlying interrelationships. Systems theory is less suited to situations in which only isolated efficiency improvements are anticipated.

A split between the generalists and the proponents of the contingency school can also be identified with respect to the applications of systems theory.

2.3.2 Production control research in the construction industry

Many of the approaches described in the previous sub-section can be identified in the literature which has been published on the subject of controlling construction processes. Gilbreth, one of the followers of the scientific approach of Taylor (scientific management), studied the methods and procedures used in the construction industry [Taylor-1911]. Specifically, he researched the use of various methods for laying bricks. His analysis showed that the number of movements required to lay each brick to construct an outside wall could be reduced from an average of 18 (in the worst case) to only 4.5.

A large number of time-motion studies were carried out in the Netherlands in the sixties. The Research Institute for Labour Economy in the Building Trade [Dutch: Stichting Arbeidstechnisch Onderzoek Bouwnijverheid (SAOB)] was responsible for a significant number of contributions in this area. This approach was also followed by researchers such as Twijnstra [Twijnstra-1969]. Twijnstra believes that time-motion studies provide the required basis for designing procedures in such a way that the time and cost consequences can be recognized directly. It is clear that scientific management has provided the basis for this approach.

A technical approach such as that used by Taylor is characteristic of virtually all of the scientific research which has been carried out with respect to production control in construction. The industrial community (including the management consultants) has pointed out that it is necessary to also include other, non-technical factors as part of a more organizational approach. An example of this was the introduction of the "MANS" philosophy (MANagement New Style) in the construction industry in The Netherlands in the mid-eighties.

The "management process" approach described in the previous sub-section (in which a clear distinction is made between the production process and the control of this process) is particularly prevalent in the English-language literature. The work of Koskela [Koskela & Tyrväinen-1990] is an example. Koskela refers to "controllability
analysis" in this context. This technique can be used to map out a production process and its related control system as optimally as possible. With this approach, Koskela can be seen as one of the researchers who follows a bottom-up approach. He explains that he derived this approach from studying research reports from manufacturing companies. The management process approach became popular primarily in the eighties.

More use has been made of a systems theory approach in previous research [Melles & Wamelink-1990,a]. Similar to the studies carried out by Koskela, the primary business process was used also as the starting point. The systems theory approach is suited particularly well for following a systematic approach to resolving control issues in a situation in which the aspects of many subsystems need to be considered (e.g., multiple production units within a construction company).

2.3.3 Chosen methods and perspective

As indicated in Sub-section 2.3.1, production control research can be carried out in a variety of ways. Each different approach has its own advantages and disadvantages and can be used with different degrees of success depending upon the particular situation (time and place).

It is normal to assume that an effort will be made to combine several approaches within any given research project in order to be able to take advantage of the positive characteristics of more than one method.

The objective of the research presented here implies that an approach is needed which highlights various aspects of a construction company as an integral whole. As mentioned in Sub-section 2.3.1, systems theory may provide a good basis in this type of situation. Systems theory could be used as the basis for identifying the various subsystems which exist within a construction company. A clear idea of the aspects which need to be investigated can be obtained in this way. In addition, this method was used as the basis for the preliminary study (see Part 0) and has been used also as the basis for previous research in the area of Industrial Engineering for manufacturing plants. One of the objectives of this research is to draw upon related research experience in these areas. Specifically, reference can be made to the previously mentioned work of Bertrand, Wijngaard and Wortmann and of Van Rijn (both carried out at the Eindhoven University of Technology).

The use of systems theory implies modelling reality. Models are useful for providing insights, but they are never an identical copy of the real situation. Certain aspects are purposefully left out. Systems theory is used here to derive a basic model of a real-
world situation for the purpose of gaining insights into the various aspects of the decisions and information systems within construction companies. This basic model is then used to identify and derive a number of general characteristics. The primary business process defines the basic structure of the model. As a result, this approach can be characterized as one which provides a bottom-up description. Nevertheless, the question always remains of to what extent any detailed model (by definition developed by a modeller based upon his own subjective interpretation of reality) can be considered to be an accurate bottom-up representation of a real-world situation.

2.4 A Basic Model for Production Control

2.4.1 Derivation

Production control within a construction company can be viewed as a complex, composite activity. In many instances it is only possible to study this activity when the scope of the study is restricted to a limited number of aspects or certain simplifications are assumed to be true.

One method which can be used to identify a consistent set of basic premises for this purpose is to view the construction company as a system. In this way the fundamental assumptions are provided by systems theory. This theory is not only useful for dealing with organizational issues, but has also proven to be a successful approach in other specific areas. Because of the broad applicability of systems theory, it is not surprising to discover that a large number of definitions of the term "system" can be found in the literature.

Mesarović et al. [Mesarović et al. 1970] prefer to define a system as being a "relation among attributes of objects". Davis and Olson [Davis & Olson 1985] refer to a system as a "set of elements which operate together to accomplish an objective". The definition used by Mesarović et al. can be seen as a more fundamental formulation than the definition used by Davis & Olson. Mesarović et al. uses their definition to develop a mathematical explanation of systems theory. Davis and Olson, on the other hand, concentrate on applying systems theory to (parts of) an organization such as the management information system. The definition presented by Davis and Olson is seen by Mesarović et al. as just one of the possible manifestations of a system. The system defined by Davis and Olson is referred to as a "goal-seeking system" by Mesarović et al.

The interpretation used by Davis and Olson is considered to be the most appropriate definition to use as the basis for the definition of a system in this study. A system here is defined as being a "set of related elements which operate together to
accomplish a specific objective or result".

In addition to the various definitions of a system, systems theory can also be used in a variety of different ways. Systems theory can be seen from many different perspectives, leading to a large number of possible applications [De Leeuw-1981]. The modelling approach proposed by De Leeuw, referred to as the axiomatic approach in his studies, will be used here.

The representation of a construction company as a system is presented in Figure 2.1.

![Figure 2.1: A Construction Company Represented as a System](image)

The diagram presented in Figure 2.1 indicates that a construction company can be seen as an "open" system in which the system exchanges data, materials or resource capacities with its environment. The interaction between the system and its environment is represented by the inputs and the outputs of the system. The model of the construction company depicted in Figure 2.1 assumes, for example, that the "procurement" of resource capacities (personnel and equipment) is an important aspect. Otherwise, if the quantities and types of these resource capacities are assumed to be fixed, then they would not be modelled as inputs and outputs.

The use of systems theory makes it possible to decompose a system into subsystems. The reason for wanting to distinguish subsystems is used as the criterion for determining exactly how the boundaries of the subsystems are to be defined. In the situation at hand, the various subsystems are defined based upon the inputs and outputs which have been identified. It should be apparent that a number of different alternatives are possible. The subsystems identified in Figure 2.2 can be seen as an alternative which is often used in connection with production control research [Van Aken-1978][Doumeingts et al.-1984]. This definition of subsystems makes use of the control paradigm in which a strict distinction is made between productive functions
and management control functions.

![Diagram of Control System and Controlled System]

Figure 2.2: Distinction Between a Control System and a Controlled System

The original (meta)system is divided into a control system and a controlled system to achieve this. Characteristic of this type of segmentation is the use of the feedback principle which is typical for a goal-seeking system [Mesarović et al.-1989]. Based upon the data from the controlled system, a decision is made within the control system which affects the future of the controlled system. Note that the division of functions presented in Figure 2.2 is somewhat different than the traditional division of functions found in systems theory literature in which a distinction is made between a controlled system and a controlling entity. The controlling entity subsequently consists of a control system and human resources. In the research presented here, however, the decision has been made to include the human resources as part of the model of the control system as indicated in Figure 2.2.

A further functional decomposition is desirable for carrying out an analysis of the function of the control system. A distinction is usually made between a decision system and a management information system for this purpose (see Figure 2.3) [Bertrand & Wortmann-1981] [Doumeingts et al.-1984].

The purpose of the decision system is to make correct decisions based upon the information provided by the information system in order to achieve the objective of the controlled system (production process). The purpose of the information system is to transform internal as well as external data into information which is relevant for the decision-maker.
Figure 2.3: Relationships Between a Controlled System, a Decision System and a Management Information System

Dividing an organization into subsystems as indicated in the diagram in Figure 2.3 is similar to the approach taken by Blumenthal (see [Blumenthal-1969]). Blumenthal uses other names for the various subsystems, however. Blumenthal identifies a control system rather than a decision system. A preference is given here to the use of the term "decision system" since it makes more sense to reserve the term "control system" to refer to the combination of decision and (management) information system (refer to the reference situation modelled in Figure 2.2). Another difference which can be found when comparing this model with that of Blumenthal is that a choice has been made here for a model of subsystems in which the interaction between the decision system and the controlled system always takes place via the information system. This is similar to the approach taken by Bertrand and Wortmann [Bertrand & Wortmann-1981]. In fact, the result of the decision process (i.e., a possible intervention in the processes of the controlled system) is also registered and stored as information. Information is, thus, always communicated via the information system in this way. Blumenthal, on the other hand, allows the result produced by the decision system to be used directly as an input to the controlled system.

The alternative chosen here leads to a situation in which the primary business process remains dominant. The way in which this process is controlled depends primarily upon the way in which the decision-maker reacts to the characteristic control problems associated with the primary business process. A simple problem generally requires simple decisions which are often less formal than the decisions needed to solve a complex problem. The information system supports the decision-maker by providing the proper decision information and communicating the results of the
decision to the production process.

The way in which a decision is made is represented by the choice of various decision functions (see further in Chapter 3). The number and types of decision functions to be used, as indicated above, are dictated by the complexity of the control problems associated with the primary business process.

The quality of a decision is determined by:

a. whether the appropriate decision functions have been selected, which, in turn, is dependent upon knowledge of the complexity of the control problems;

b. whether the decision function is performed correctly;

c. the uncertainty about the information used as the basis for making the decision.

Uncertainty is, as such, regarded as being a measure for determining the adequacy of the information system. The design of the information system is dictated by the design of the decision system and, thus, by the complexity of the control problem, on the one hand, and by the difficulty of providing reliable decision information based upon the available data, on the other hand.

The terminology used in Figure 2.3 is meant to be generic and applicable to any type of organization. For the purpose of this study of production control in construction, however, it is desirable to substitute the term "production process" for the term "controlled system" in order to indicate that we are concerned with the primary activities of an industrial company. The term "construction process" has purposefully not been used here in order to avoid any confusion due to the fact that this term often has a different meaning in the accepted literature. A construction process often denotes a whole collection of processes carried out by various participants (e.g., construction company, architect, subcontractors) for the common purpose of realizing a construction work. The production process, therefore, refers to a subset of the construction process, comprised of the primary business activities carried out by a construction company as an integral part of the total construction process (see also definition in section 2.2).

It should be clear that the decision system and the information system overlap to a large extent with respect to their positioning in the organization. Making a distinction between these two aspects of a controlling entity is only feasible in the form of a model. This distinction only makes sense within the context of fundamental research into the roles and functions of both systems. It would not be useful to make this distinction in a practical situation because then people would be confronted with unnecessarily constraints. Nielen [Nielen-1976] maintains that it is not possible to separate the human thought process into two independent processes whereby data is
processed and action is initiated. The literature which deals with management information systems typically discusses the decision process and the related information and information processing activities as an integrated whole [Davis & Olson-1985] [Murdick-1984]. All of the methodologies developed in the seventies and eighties to guide the development and implementation of information systems [Bemelmans-1987] incorporate this aspect of an integrated whole. This is evidenced, for example, by the role and use of process models in the development of information systems.

2.4.2 The controlled system: the production process

The primary objective of a construction company is to produce construction works under certain conditions. These construction works are produced via a production process (the processes included within the controlled system). The production process within a company is often referred to as the primary business process.

The production process (seen as a component of a meta-system called a "construction company") is illustrated again in Figure 2.4.

![Controlled System (Production Process)](image)

Figure 2.4: Controlled System (Production Process)

The necessary conditions are specified by the "control system." These conditions refer to requirements which have been established for the construction work to be produced as well as requirements with respect to the construction activities. Examples of such requirements could be the quality of the product and the period of time within which the product should be completed by the contractor. In addition, it is important for the product to be produced as cheaply as possible to help ensure the continuity of the construction company. This aspect is discussed in more detail in Chapters 3 and 4. The subject of this section is limited to the actual production
process. Similar to the approach used by Schomburg [Schomburg-1980], the following aspects of the production process can be identified with the help of a systems approach (see Figure 2.4):

- input characteristics: materials, resource capacities and information
- process characteristics: operations
- output characteristics: resource capacities and finished constructions

Each aspect has certain characteristics which may influence the nature of the production process and the control of this process. A number of the possible characteristics are described in the remainder of this sub-section to illustrate this.

Materials

The materials aspect covers everything which is consumed in the process of producing the product and can still be recognized as a physical part of the finished product [Van Rijn-1986]. An important characteristic of materials is, thus, that they are used only once. Once that certain materials have been used in the production process, they can no longer be used for an alternative production process (with the exception of recycling materials, a practice which became popular in the eighties). This characteristic has important implications for production control. When materials are not processed according to schedule and remain in stock longer than anticipated, a cost-price component representing the interest expense of financing the extra inventory may need to be taken into account.

Resource capacities

The aspect of "resource capacities" covers the resources or means which are utilized to produce the product. The key word here is utilize as opposed to "use" as in the case of materials. Capacities are not consumed or depleted. This means that they can be re-utilized in an identical way. Bertrand and others [Bertrand et al., 1990,a] have identified a number of different types of resource capacities: labor, equipment, space and tools.

Labor and equipment are clearly identifiable in the construction industry as aspects which are utilized and can be re-utilized in an identical way: the construction site is an area in which all sorts of labor (carpenters, bricklayers, foremen) and equipment (cement-mixers, cranes, earth-movers) are collected together.
Operations

Bertrand and others [Bertrand et al., 1990] describe the production process as a network of "manufacturing steps" (operations). These operations are viewed as the basic tasks which are performed by a resource capacity (labor or equipment). Examples of operations in the construction industry include: laying bricks, pouring concrete, dredging a canal, applying a protective layer in road construction.

Information

Information is essential for carrying out operations and, thus, necessary for utilizing resource capacities to transform materials into the finished construction. Information establishes the relationship between materials, resource capacities and operations. In practice, information is typically found in the form of instructions. The result of a decision function (e.g., a decision about the time when something should take place) is passed on in the form of information to the production process.

Finished constructions

The objective of the production process is to realize finished constructions. This is presented in the diagrams as an output of the production process. The final finished construction is, in fact, a combination of changed (transformed) materials.

Production data

Properties of the production process are recorded in the form of production data.
3 THE DECISION SYSTEM

3.1 Introduction

The model of the decision system is described in this chapter. A decision system is envisioned in this context as a combination of interrelated decision functions. The discussion of decision functions is based upon Simon’s theory with respect to how decision processes are carried out.

3.2 The Decision System: Definitions and Basic Assumptions

The position of the decision system within the scope of the total control system was described in Chapter 2. The decision system as a single entity is diagrammed below in Figure 3.1.

Figure 3.1: The Decision System

Decision processes take place within the decision system (a liberal interpretation of Simon [Simon-1960] and Van Rijn [Van Rijn-1986]). Decision information, provided by the management information system, is required as a basis for making decisions.

To start with, it is important to review the decision process. Several different definitions of "decision-making" can be found in the literature. Bemelmans [Bemelmans-1987] views "managing" as being a continuous decision process and, thus, uses the terms "managing" and "decision-making" as synonyms. Similarly, Simon [Simon-1960] makes no distinction between "decision-making" and the "management
process. All of the definitions of "decision-making" seem to have three things in common:

1. a choice must be made;
2. there are alternatives to be considered (otherwise, there would be no need to make a choice);
3. the choice is made based upon a subjective evaluation of whether a specific goal (which may or may not be extensively formalized) will be realized.

Based upon this, "decision-making" has been defined as follows for the purpose of this study:

**Decision-making is the act of making a (subjective) choice among alternatives, based upon information which is available, to pursue goal-oriented activities.**

Decision-making is, thus, by definition goal-oriented. A specific goal, regardless of whether it has been extensively formalized, must form the basis for any decision. Decision-making is subjective to some extent. Botter [Botter-1988] explains this in the following way: "The personal preferences of a human being play a decisive role in achieving a specific result through the decisions which are made. In making decisions, people try to satisfy a subjective utility function."

Van Rijn [Van Rijn-1986] discusses the subjective aspect of decision-making by stating that the decision-maker creates a mental model of the problem at hand. The decision-maker views this model as being relatively complex. This will be referred to here as the **complexity of the decision process** (similar to Van Rijn).

The subjective character of decision-making is, in principle, separate from the degree to which a decision is structured. Simon [Simon-1960] was the first to make a distinction between programmable and non-programmable decisions. Gorry and Scott Morton [Gorry & Scott Morton-1971] refer to structured, semi-structured and unstructured decisions. In both cases, a distinction is made between situations in which a known decision algorithm and a known optimization criterion are available to the decision-maker and situations in which these aspects are missing. Nevertheless, the interpretation of values is relative and, thus, a subjective activity even in the case of structured decisions.

The distinction between the subjective and the (un)structured aspects of decisions is illustrated further by the following example:

**Example:**

Even when a company issues a clear procedure concerning what to do in the case of
fire (turning this into a structured decision-making situation), it will still be possible for some people to decide that there is a serious "fire" before others are willing to draw the same conclusion and follow the prescribed procedure. Unnecessary panic may arise when this happens. The subjective aspect may turn the decision-making into an uncontrollable situation. If another company has trained its personnel in "how to cope with stress under all circumstances" but has not prepared an adequate fire emergency procedure, then the decision process will not be structured but it will, on the other hand, provide a more secure result!

Later in this chapter, attention will be focused on how the decision process can be made more "controllable". The subject of making a process more controllable is discussed intentionally here since it is certainly not always desirable to arrange everything ahead of time (i.e., structure the decisions). It is likely that a better result can be attained by focusing a significant amount of attention on the way in which a decision-maker anticipates problems (his subjective orientation).

The term decision function in the sense used by Van Rijn [Van Rijn-1986] is important within the context of this book. Our interpretation of Van Rijn's definition of a decision function is as follows:

A decision function is a group of related decision processes which are assigned, collectively, to a decision-maker or group of decision-makers.

Only the decision functions involved in the control of production processes are considered within the scope of this book. There are, of course, many other types of decision functions to be found within a typical organization.

3.3 Describing Decision Functions

It helps to investigate the different aspects of a decision process in order to find a suitable way of describing a decision function. Simon [Simon-1960] uses a phase model of the decision-making process. He distinguishes three phases in this model:

1. The Intelligence Phase
   The decision process activities in this phase are concerned with the recognition and identification of the problem.

2. The Design Phase
   The activities in this phase focus on analyzing the causes of the problem and designing alternative solutions to the problem.
3. The Choice Phase
   The activities here are oriented toward selecting one of the alternative solutions.

The Intelligence Phase

In the Intelligence Phase, the decision-maker attempts to analyze the decision problem in terms of:

A. What is the purpose of my decision? Is this decision really necessary?

B. What decision authority do I have? Which "buttons" can I push?

C. Which decisions are made by someone else? Are these decisions important with respect to my problem? Do I have sufficient information?

Actually, an attempt is made here to ascertain the complexity of the mental decision model. In addition, an analysis is made of the extent to which the mental decision model is complete, i.e., how much uncertainty is present. Using this framework, it is possible to describe a decision function in terms of the specific characteristics of each of the various steps in the decision process. This approach is similar to that used by Bemelmans [Bemelmans-1987].

Question A is answered by identifying a goal variable. Question B then results in defining control variables. Whenever variables are identified which cannot be influenced (Question C), these are referred to as independent variables.

The Design Phase

Alternatives for the decision process need to be identified during the Design Phase. Alternatives in the decision process lead to comparing a norm for a goal variable with the resulting value of that goal variable after a control activity has taken place. The way in which the control variables are used will typically vary from one situation to the next. The implications for the persons responsible for executing the decision are taken into account in identifying the alternatives. The other consequences of making a given decision are expressed in terms of neutral variables (similar to the approach used by Bemelmans [Bemelmans-1987]). Since we are interested only in the characteristics related to production control here, the neutral variables have been eliminated.

A description of the decision function is prepared to document the results of the
Design Phase.

The Choice Phase

One of the alternatives is selected in the Choice Phase based upon the translations into specific terms which were developed during the previous phases. An effort is made to optimize the goal variable. The results of the Choice Phase are also documented as part of the description of the decision function.

3.4 Decisions and Organizational Structures

Decision functions were discussed in the previous sections. Van Rijn [Van Rijn-1986] noted appropriately that:

"Decision-making situations which dealt with similar types of problems can be institutionalized within an organization by defining specific functions for this purpose. These are decision functions. Decision functions can be assigned to specific individuals and resources within the organization."

This will be translated into specific terms in a subsequent chapter by identifying the decision-makers within the framework of complete decision models.
4 INFORMATION SYSTEMS FOR PRODUCTION CONTROL

4.1 Introduction

Information systems for production control are described in more detail in this chapter. The information system is the part of the control system which is responsible for generating decision information and communicating decisions to the production process.

The design of the information system is dictated to some extent by the design of the decision system. In addition, the design of the information system is influenced by the amount of effort needed to provide reliable information based upon available data, eliminating as many of the uncertainties as possible.

4.2 Information Systems: Definitions and Basic Assumptions

The management information system in a production environment is illustrated in Figure 4.1.

![Figure 4.1: Model of the Management Information System](image)

The primary task of the management information system as a subsystem within this environment is to generate management information for the decision system so that decisions can be made. In addition to this primary task, a number of secondary tasks can be identified which belong to the information system. These secondary tasks
include providing information to the controlled system (the production process) about control measures to be taken or about the quality of the information system, itself.

Bemelmans [Bemelmans-1987] describes an information system as the total set of methods, resources and activities which an organization uses to satisfy its information requirements. He interprets methods as being procedures and work instructions related to collecting, processing and distributing data. Resources refers to human resources, facilities, materials and financial resources.

A different approach is taken by Davis and Olson [Davis & Olson-1985], however. They define a management information system as being "an integrated, user-machine system for providing information to support operations, management, and decision-making functions in an organization. The system utilizes computer hardware and software; manual procedures; models for analysis, planning, control and decision making; and a database". Using this definition, Davis and Olson assume that an information system is (partially) automated whereby the collection, processing and distribution of data is accomplished through the use of a computer. Misunderstandings often occur in the literature about whether a system should be interpreted as being an automated system or a manual system. Many authors note that an information system is not necessarily comprised of automated components, but then proceed to focus solely on the automated components of such a system. This results in an approach which lacks a sufficient theoretical framework for understanding how the total information system functions.

It should be emphasized, again, that an information system within the context of the research presented here is not necessarily automated.

To start with, the definition of a management information system as proposed by Bemelmans is preferred here: "a management information system is the total set of methods, resources and activities which an organization uses to satisfy its information requirements." A general definition of a system was provided in Sub-section 2.4.1. In connection with this definition, it was mentioned that a "goal-seeking system" involves the achievement of some goal. This is also a relevant aspect in connection with a management information system. For this reason, we propose expanding the definition used by Bemelmans as follows:

A management information system is the total set of methods, resources and activities which an organization uses to satisfy its information requirements with respect to supporting decision functions.

How the management information system works in the context of this study is described in more detail in the following section. The following questions are
answered: What is the difference between data and information? What is meant by decision information? Which requirements need to be satisfied by decision information? What implications do these requirements have for the information system?

Subsequently, it is investigated how the data is processed by the information system to produce information. Various data processing procedures are analyzed in this respect and it is shown how these can lead to the identification of different types of information systems.

In conclusion, an explanation is provided of how this analysis relates to the way in which information systems are described in the remainder of this book.

### 4.3 The Basic Aspects of the Management Information System

The incoming and outgoing flows associated with the information system were identified previously in Figure 4.1.

The incoming data flows are:

1. **I1** - production data (from the production process)
2. **I2** - external data (from the construction company environment)
3. **I3** - data concerning the results of the decision process

The outgoing information flows are:

1. **O1** - information to support the decision process
2. **O2** - information concerning orders for the production process

Once again, the identified incoming and outgoing flows suggest that the primary task of an information system is to transform data into information (see Figure 4.2).

![Figure 4.2: Transformation of Data into Information within the Information System](image-url)
Several of the aspects of this process will be described here in more detail, namely:

1. The difference between data and information (Sub-section 4.3.1);
2. Characteristics of decision information (Sub-section 4.3.2);
3. Transforming data into information (Sub-section 4.3.3).

4.3.1 The difference between data and information

A conscious choice has been made for the term "information for ..." rather than "data ..." since it is customary to make a distinction between data and information. These terms are normally defined together since they have interrelated meanings. Davis and Olson [Davis & Olson-1985] define data as being the "raw material for producing information" and information as "data that is meaningful or useful to the recipient and is of real or perceived value in current or prospective actions or decisions". Murdick defines the term "data" somewhat more precisely. The "raw material" seen by Davis and Olson is defined by [Murdick-1984] as being "a set of symbols or experience-stimuli". In conformance with the differentiation typically found in the English-language literature, the terms "data" and "information" are defined here as follows:

"Data is defined as being the objectively perceptible representation of facts or knowledge contained on a specific medium in such a way that the data can be transferred or exchanged."

"Information consists of interrelated data elements which can be interpreted in such a way that they have a special meaning for the receiver of the information."

These definitions, above, are similar to the definitions proposed by Bemelmans. The only difference is that the phrase "in such a way that they have a special meaning for the receiver of the information" has been added to the definition of information. The reason for this additional phrase is to leave the burden of proof with the receiver for determining whether a given collection of data elements can be considered to be information. In the context of Figure 4.1, the receivers of information can be considered to be a decision-maker or someone at the construction site. This suggests that there must be a communicative aspect to information. This is discussed in the following sub-section.

4.3.2 Characteristics of decision information

Several general requirements are associated with the incoming and outgoing flows of
information. These requirements suggest that a specific approach should be followed in designing the information system, itself. Bertrand and Wortmann [Bertrand & Wortmann-1981] have identified four different ways of looking at this:

- the empirical aspect;
- the syntactic aspect;
- the semantic aspect;
- the pragmatic aspect.

Bertrand and Wortmann [Bertrand & Wortmann-1981] refer to the empirical aspect as being the physical characteristics of a message which determine the way in which characters and symbols are physically transferred. The supporting theory in this respect is called "information theory". The empirical aspect, as such, will not be included within the scope of this study.

The other three aspects have been grouped together by Bertrand and Wortmann and placed under the heading "logical characteristics" of a message (information flow). These different aspects are described briefly in the following paragraphs.

The syntactic aspect

The syntactic aspect refers to the "language" which is used for communicating. The outgoing information needs to be interpreted by the receiver of the information, suggesting that he must be able to "decode" the message. The incoming information must also be formulated in the proper "code" before it is presented to be stored as data within the information system.

The semantic aspect

The semantic aspect of information deals with the meaning of the information flow. This refers to the relationship between the informational representation and the actual object [Sol-1987]. The receiver and the sender of the information both need to associate the same meaning to a specific term.

The pragmatic aspect

The pragmatic aspect is also the most relevant aspect in the context of the present study since it refers to the relationship between meaningful information and taking action [Sol-1987]. The pragmatic aspect deals with whether [Bertrand & Wortmann-1981]:

the information is a proper representation of the actual object (i.e., the quality of the message is sufficient with respect to accuracy, timeliness, etc.);
- the information can be used for the intended purpose (the message is useful).

The relationship with the decision process in the decision system is particularly relevant with respect to this point: Does the information support the decision process to the appropriate extent? Answers to the pragmatic questions can be given only when the nature of the decision process is considered. This is not the case when dealing with the other (syntactic and semantic) aspects.

The pragmatic aspect is discussed further, below. The question here is under what conditions the interrelated data elements (the decision information) can be interpreted in such a way that they are of value for the receiver of the information. For the purpose of this study, the receiver is a decision-maker (represented by decision functions) or an employee at the construction site who intends to take some action or issue instructions based upon the information he receives. The first-mentioned type of receiver, the decision-maker, will be discussed in more detail here, including the information needed by the decision-maker (the decision information). The data needs to be organized in such a way that the decision function receives the information that it requires.

A structured description of the decision function has already been presented in Section 3.3. Simon [Simon-1960] has defined the various phases which take place in the decision process:

1. the Intelligence Phase;
2. the Design Phase;
3. the Choice Phase.

Different researchers have made modifications to this decision model proposed by Simon in view of a number of shortcomings which have been discovered. Nevertheless, the phases defined by Simon appear to us to provide a sufficient differentiation for describing the role of the management information system throughout the whole process. The information system should be able to provide the proper level of support to the decision-maker during each phase of the decision process:

Phase 1: the Intelligence Phase

The information system provides information about the difference between the current situation and a desired situation. An example of this could be the difference between the estimated hours in a project budget and the actual hours spent at the
construction site. The information system identifies the fact that a variance has occurred and essentially provides a warning of a problem situation which may need to be resolved.

Phase 2: the Design Phase

The decision-maker identifies the decision alternatives during the design phase of the decision process. In connection with this, the information system should provide him with information concerning the implications of choosing each of these decision alternatives. To be able to do this, so-called decision models must be incorporated as part of the information system.

Phase 3: the Choice Phase

The information system should provide the decision-maker with information about the implications of the decision alternatives during the last phase of the decision process. The information system may even make decisions, independently, in certain cases.

Simon describes the steps taken by a decision-maker in analyzing a complex problem and decomposing a problem situation into several easier decisions. The information system can assist the decision-maker by reducing the complexity of his decision problem. The process of making a decision can be simplified by processing a large amount of data elements which, when viewed individually, may have little or no meaning. When this data can be reduced to a limited number of data elements, the presentation of this data will correspond more closely with the information requirements of the decision-maker.

Galbraith [Galbraith-1973] and Van Rijn [Van Rijn-1986] maintain that the decision-maker also has a second problem: the uncertainty of whether his decision information is correct. In addition to providing assistance with respect to reducing the complexity of the decision problem, the information system can also play an important role in reducing the uncertainty by providing reliable and timely information about the accuracy of the decision information.

In order to adequately describe the role of the information system in a specific situation, it is necessary to identify which information the system needs to provide in order for it to be able to support a complex decision-making situation. In addition, it is also necessary to identify any special system requirements which have been established in connection with reducing the uncertainty surrounding the decision information.
4.3.3 Transforming data into information

As previously mentioned, Figure 4.2 (Section 4.3) illustrates the basic aspects of the information system. This same diagram is referred to as the basic model of an information system by Davis and Olson [Davis & Olson-1985]. The information system receives data (internal as well as external data) and transforms this into information in accordance with predefined procedures. The model presented in Figure 4.2 represents the most simplified model of what an information system does. This model suggests that there is some sort of "Law of Conservation" regarding the volume of data since the data is transformed directly into information. This may not be true in many cases, however. For example, the transformation process may require data which has been collected previously or has been compiled by the information system at an earlier point in time. This means that, in addition to the transformation of data, a second important function may be found within the information system: the storage of data.

![Diagram]( Uncomment if needed)

*Figure 4.3: Representation of the Black Box Model (Davis & Olson)*

The model presented in Figure 4.3 can be used to represent a wide variety of different information systems. The primary purpose of the information system in the present study is to support the decision processes by providing information.

A further distinction normally found in the literature [Alter-1980] [Davis & Olson-1985] [Bertrand et al.,1990,a] is the functional separation of the "transaction processing" function from the "decision support" function within the information system. A new model is presented in Figure 4.4 which is based upon the premises of Figure 4.3 and additionally takes this functional distinction into account.

The intended purpose of the transaction processing system is to record the relevant changes in the state of the environment or the control situation and to store this data
in the data base. The decision support system can then generate information for supporting the decision-making processes based upon the data stored in this data base.

It is possible to split up the decision support system even further. A generally accepted segmentation of the decision support system has been used, for example, by Bemelmans [Bemelmans-1987]. Depending upon the type of decision supported by the system, a distinction can be made between a Structured Decision System and a Decision Support System. This differentiation was actually first introduced by Simon [Simon-1960] when he defined the difference between a "programmable" and a "non-programmable" decision. This type of distinction is useful primarily when specifying how the information system needs to provide information to the decision-maker during the aforementioned phases. In the case of a Structured Decision System, the result of the decision is evident as soon as the decision information is known. This is not true in the case of a Decision Support System.

In addition to defining different types of decision support systems, a distinction can also be made between different types of transaction processing systems. Bertrand and Wortmann [Bertrand et al.,-1990,a] make a differentiation between a "state-independent" and a "state-dependent" subsystem within a transaction processing system. In connection with this, a distinction is made between recording state-independent and state-dependent data. State-dependent data refers to a specific situation while state-independent data is recorded regardless of the specific situation and can always be accessed (for example, as norms).
4.4 Describing the Information System

The basic aspects of the information system were identified in the previous section along with an explanation of how they relate to each other. Using this as a basis, a further description of the information system is presented in this section. The following aspects are covered in the three sub-sections:

1. the physical components of an information system (in Sub-section 4.4.1);
2. a description of the information system as a whole (in Sub-section 4.4.2);
3. a description of the automated information system (in Sub-section 4.4.3).

4.4.1 The physical components of an information system

The practical aspects of the information system within a real organization are discussed in this sub-section. One of the most frequently used methods of describing the components of an information system is the ontological approach. An example of this approach is that used by Bemelmans [Bemelmans-1987] to distinguish the following components:

- a program or procedure library. This includes the set of computer programs and routines which are used to process the data;
- a data base. This includes the complete collection of data elements;
- a man-machine interface. This interface provides the means which enables a person to communicate with the information system;
- a system interface. This component provides the means for transferring data between systems.

Sol [Sol-1987] distinguishes a different set of components: data sets, equipment, computer programs, people and procedures. Davis and Olson [Davis & Olson-1985] use yet a different set of terms which includes "computer hardware and software, manual procedures, models for analysis, planning, control, and decision making and a database".

All of these definitions are strongly oriented toward assuming the use of computers to support the various functions of the information system. As previously indicated in the introduction to this chapter, this is not really a proper assumption. For this reason, it is more sensible to distinguish components which are more generic in nature and can be used to describe a non-automated situation as well as an
automated situation. The components used here are:

- methods;
- resources;
- activities.

The objective of an information system is, thus, realized by using resources to perform certain activities under the conditions and restrictions imposed by specific methods.

It is clear that there must be a certain amount of interaction between these elements or components. For example, different methods are needed when the resources are people instead of machines. A person may become tired while a computer performs at a consistent pace. The procedures which are developed must take this into account. It could even be stated that procedures, for the most part, can only be defined after the choice of resources has been made. This choice of resources is dependant on the activities to be carried out.

It is often necessary to refer to a series of resources rather than to just a single resource. An example of this could be when data is first recorded on a physical medium (e.g., a paper form) by a person, subsequently entered into a computer system via a user terminal, and finally transformed into information based upon a predefined, programmed procedure. This example indicates that it may not always be possible to make a strong distinction with respect to the resources which are used.

The use of computers is the most modern and easiest to visualize resource in this context. Early computers were only suitable for use by the transaction processing function within the information system. Subsequent technological developments made it possible to use computers additionally for the decision support function of the information system. This aspect of a modern information system needs to be described in more detail.

### 4.4.2 Description of the information system as a whole

An explanation was provided in Section 4.3 with respect to the basic requirements which decision information needs to satisfy and how transaction processing and decision support processes can be incorporated within an information system.

We can identify which information should be generated by the information system through an analysis of the data based upon the requirements of the decision system and the requirements of the information system in connection with reducing the
degree of uncertainty. It is also possible to indicate what measures need to be taken
to ensure the proper processing of data and an adequate level of decision support.
Requirements may be formulated with respect to, for example, procedures for coding
project data, checking invoices, etc.

4.4.3 Description of the automated information system

Davis and Olson [Davis & Olson-1985] use the following definition of an automated
management information system:

"an integrated, user-machine system for providing information to support
operations, management, and decision-making functions in an organization. The
system utilizes computer hardware and software; manual procedures; and a
database".

Two aspects of this definition are particularly interesting in connection with the
research here, namely, the software (computer programs) and the data base. Specific
attention is focused on these two aspects because they determine the practical value
of the automated information system.

Software

Bertrand, Wortmann and Wijngaard [Bertrand et al.-1990,a] provide a method for
describing the general architecture of computer software in a production control
environment. This approach is illustrated in Figure 4.5 in the form of four concentric
circles.

The innermost core of software, called "System Software", refers to the collection of
application-independent software which typically includes an operating system, a data
base management system (DBMS) and a query language facility. The other layers
refer to user programs. A distinction is made here between the transaction processing
software (second and third layers) and the decision support software. The
aforementioned distinction between state-independent and state-dependent data (see
Subsection 4.3.3) can, thus, be identified within the transaction processing software.
The basic data used to identify equipment, standard reference projects, norms and
supplier data are all examples of typical state-independent data elements. This type
of data is independent of the state of the production process at any particular point
in time, which is not the case for state-dependent data. Examples of state-dependent
data include purchase orders, the status of project activities, resource capacity loading
data, etc.
Figure 4.5: *General Architecture Visualized as Four Concentric Circles of Software*

**Data Base**

An important part of the information system is the storage of data in a specific form and format. The data recorded within the information system refers to various characteristics of aspects of the production process as described in Sub-section 2.4.2.

The volume of data recorded in this respect can be seen as a description and representation of the real situation within the process and may or may not be considered to be accurate. This is referred to as a model of the system in the terminology of systems theory. Van Rijn [Van Rijn-1986] refers to this as a state model.

A theoretical model of the controlled system can be defined using a data model. Included in such a data model are the significant objects of the controlled system and the relevant characteristics of these objects. The objects which are considered to be sufficiently relevant for inclusion in the model are called "entity types". The
characteristics of these entity types are referred to as "attributes".

The information requirements of the decision system dictate which entity types and attributes are relevant for the present research. Once these information requirements have been defined, it is then possible to determine which data elements need to be included in the state model of the information system. It should then be possible to compile the information needed for decision-making from these data elements. The interrelationships between these entities can be represented using a data model. An example of such a data model is presented in Figure 4.6.

Basic drawing conventions are used here to describe the entity types and their relationships in the data model. These drawing conventions (see [Bachman-1969]) are similar to those used by Van Rijn [Van Rijn-1986]. The relationships between entity types are represented by arrows. A single arrow signifies a 1:N relationship. This means that each of the occurrences of the first type of entity "owns" N occurrences of the second type of entity. In the example in Figure 4.6, each single construction order is comprised of N activities. From the point of view of an activity, each activity belongs to only one construction order. A two-way arrow represents a N:M relationship. This means that each occurrence of a Type X entity owns M occurrences of a Type Y entity and each occurrence of a Type Y entity owns N occurrences of a Type X entity.

When two single arrows are drawn between two entity types (from "A" to "B"), this signifies that two occurrences of "A" belong to each occurrence of "B". In the example presented in Figure 4.6, two occurrences of Activity belong to each of the occurrences of Activity Relationship.
Figure 4.6: Example of a Data Structure Diagram
PART 2: TYPOLOGY AND DESIGN RULES FOR DECISION SYSTEMS AND MANAGEMENT INFORMATION SYSTEMS FOR PRODUCTION CONTROL IN CONSTRUCTION
1 INTRODUCTION

A method for modelling the production control situation within a construction company is introduced in Part 1. This same approach has been used in the past for modelling production control situations in manufacturing companies. Modelling production situations in this way has shown that it is possible to identify a number of standard types.

This part of the book discusses the use of a typology for analyzing the construction orders in construction companies from the point of view of decision-making and the associated information requirements. An ideal typical approach to production control in construction is used here, based upon the scientific approach typically used in the field of industrial engineering related to manufacturing companies.

The intention of the proposed typology is to provide insights into the (theoretical) characteristic differences which are important in connection with controlling construction orders. Design rules can then be defined for developing the required functions of the decision system and information system for each of the different types of construction orders.

Chapter 2 discusses the theory behind the definition and use of typologies. The various possible points of view, objectives and the choice of domain are covered here.

In Chapter 3, an evaluation is made of the extent to which the typologies developed for manufacturing companies are applicable to the construction industry. The major conclusion in this respect is that only the structure (but not the content) of these existing typologies can be used since they have been developed for production situations which are significantly different from most construction orders in the construction industry. Subsequently, a new typology designed specifically for construction orders is developed in Chapters 4 and 5.

Design rules for developing the decision and information systems for the types of construction orders thus defined are presented in Chapter 6.
2 USING A TYPOLGY TO DESIGN DECISION SYSTEMS AND MANAGEMENT INFORMATION SYSTEMS FOR PRODUCTION CONTROL

2.1 Introduction

This section expands on the concept of a typology. A typology is typically used in the literature on industrial engineering for manufacturing companies (for example, [Van Rijn-1986]) to distinguish between the types of companies or production situations for which the production control functions need to be structured differently.

*Intermezzo*

regarding the definition of "production control", "production control system", "decision system" and "management information system"

Within this context, *production control* can be divided into two components referred to as the decision aspect and the information aspect. Decisions must be made as an integral part of the control process. In order to make the right decisions, the correct information must be made available. The production control system is therefore analogous to Bertrand and Wortmann [Bertrand & Wortmann-1981], for example divided into the *decision system* and the *management information system*. These terms are discussed in more detail in Part 1.

*End intermezzo*

A similar approach is followed within the framework of this study; a typology is used to make a distinction between the various types of construction orders. After defining this typology for construction orders, design rules for developing the required decision system and the management information system can then be formulated for each of the identified types. Design rules are formulated for the purpose of achieving a (theoretically) optimal form of control.

An explanation of what is meant by a typology is presented in this chapter. The minimum requirements which a suitable typology for construction orders needs to
satisfy will also be specified.

2.2 What is a Typology?

A typology is actually a method for dividing objects into groups.

In the dictionary, [Webster-1986] a typology is described as follows:

typology: study of or study based on types; classification based on comparative study of types

A typology is used to gain insight into the relationships between objects and their characteristics [Botter-1988]. It is not sufficient that a certain object merely be classified as being of a certain type. It must also be possible to explain or even improve the operation or usage of the object by means of the typology. A typology, therefore, must have a clear objective which implies that a certain amount of synthesis is required. Van Rijn [Van Rijn-1986], for example, uses the following objective for his typology:

"to create a diagnosis tool which can be used in business situations to quickly find a satisfactory and fitting combination of a decision system and management information system for production control."

2.3 Methodology for Developing a Typology

After reading the work of Grosse-Oetringhaus [Grosse-Oetringhaus-1974], Van Rijn [Van Rijn-1986] discovered that the following must be taken into consideration when developing a typology:

a. the point (or points) of view;
b. the objective;
c. the domain.

Regarding a. (the point of view)

Models are developed from a certain point of view. This point of view is essentially an indication of where the developer of the model has focused his attention.
Regarding b. (the objective)

The objective of a typology is used as the basis for determining the most important distinguishing characteristic within the typology. This objective suggests how the object of the typology needs to be classified in order to arrive at a satisfactory explanation or improvement. The objective also determines the nature of the typology. For example, an ideal-typical typology can be used to distinguish between theoretically ideal situations.

Regarding c. (the domain)

In reference to the domain of a typology, Van Rijn poses the following questions:

1. Which objects are to be distinguished?
2. On the basis of which characteristics and the relative importance of these characteristics will subsets be defined as "types" within the total set of objects? In other words: which characteristics will be used to distinguish between the types?

The answers to both of these questions depend to some extent upon the objective of the typology.

2.4 Typology for Construction Orders

2.4.1 Introduction

Numerous typologies have been developed for the purpose of improving the operations within a company. The objectives, points of view and objects of these typologies may vary considerably. Before formally discussing the basic assumptions, it is appropriate to establish the reasons for wanting to use a typology within the context of this book.

The construction industry is often presented as a homogenous group of activities for the purpose of production control. This is apparent from the literature on industrial engineering (see, for example, [Botter-1988]) as well as the literature on construction management (see, for example, [Twijnstra-1969]).

Nevertheless, considerable differences can be identified in the production control methods currently used in the construction industry [Melles & Wamelink-1990,a]. The origin of some of these differences can be seen as being cultural or historical. Most of these differences, however, stem from the differences in production control problems which typically occur in the various production processes.
With this assumption, it is logical to assume that a distinction can be made between various decision and information systems based upon the various types of construction orders in the construction industry. When cultural and historical factors are not taken into consideration, ideal decision and information systems can be defined and developed. An ideal-typical typology can, thus, be developed.

The requirements to be satisfied by such a typology of control systems for construction orders in the construction industry can be derived from the aforementioned considerations. These are discussed in the following sub-sections.

2.4.2 The point of view for a typology for construction orders

The basic assumptions formulated above imply that this typology should focus primarily on distinguishing between various types of production control systems. *It can thus be concluded that the typology for construction orders will need to be developed from a point of view which pays specific attention to the decision and information aspects.*

2.4.3 The objective of a typology for construction orders

The typology should provide an overview of the theoretically ideal methods for making decisions and providing information which can be identified within the construction industry. The typology should also indicate which characteristics are associated with each type of construction order and the implications these have for the decision and information systems in each case.

2.4.4 The domain of a typology for construction orders

As previously stated in Section 2.3, the following questions can be asked in reference to the domain of this typology:
1. Which objects are to be distinguished?
2. On the basis of which characteristics and the relative importance of these characteristics will subsets be defined as "types" within the total set of objects?

Regarding 1. Criteria for defining the objects within a typology for construction orders

Based upon the objective as stated above, the typology should focus on the construction orders in the construction phase, either individually or as an interrelated
group, within the construction company. These construction orders can, thus, be seen as the objects of the typology.

In connection with this definition of the object, three terms need to be defined more explicitly: the "construction order", the "construction company" and the "construction phase".

A construction order is the obligation to complete specific work which a construction company enters into with a client. A construction order normally comprises the completion of all phases of a construction work at one site, but it may also cover only a part of the total construction work.

A construction company is a commercial organization whose objective is to complete construction orders. Construction companies may be specialized in a wide variety of different kinds of construction orders. A distinction is often made between construction companies specializing in residential construction and commercial buildings, on the one hand (including buildings, homes and renovations), and road construction and civil works, on the other hand (including infrastructure projects dealing with highways, laying cabling and pipelines, dredging and concrete construction such as tunnels).

This definition implies that orders from suppliers such as the suppliers of prefab concrete products, building supply companies, etc. will not be considered as objects within this typology.

The construction phase is understood to mean the phase consisting of all of the activities associated with the actual completion of a construction work. This phase also includes work preparation which may be carried out before the actual construction is started, provided that the construction order has already been approved.

Regarding 2. Criteria for defining the distinguishing characteristics

The intended use of the typology here is to make a distinction between the different ways of controlling construction orders. This means that a change in the state or importance of certain characteristics may lead to a change in the method of production control. In this context, production control refers to the decision system and the management information system. In this view, the design of the management information system should be determined primarily by the design of the decision system. The distinguishing characteristics, therefore, will be chosen primarily based upon their effect on the decision system.
3 THE APPLICABILITY OF EXISTING TYPOLOGIES FROM INDUSTRIAL ENGINEERING FOR MANUFACTURING COMPANIES

3.1 Introduction

In this chapter, a number of existing typologies from industrial engineering will be reviewed with respect to the requirements for a typology for the construction industry as outlined in Chapter 2. The applicability of these typologies will also be evaluated.

The remainder of this chapter presents an analysis to identify which elements from the reviewed typologies can be used to develop a typology for construction orders. The typologies proposed by Woodward, Harvey, Botter, Wild, New, Schomburg and Van Rijn are reviewed here.

3.2 Synopsis of Seven Typologies from Industrial Engineering for Manufacturing Companies

A number of typologies from industrial engineering for manufacturing companies are reviewed briefly in this section. A more detailed discussion based on the methodology presented in the previous chapter is included in the Appendix to Part 2.

The typologies proposed by Woodward, Harvey and Botter were developed for the purpose of identifying different types of companies. The distinguishing characteristic used by Woodward is the "technical complexity" (the extent to which a production process can be technically controlled); Harvey uses the "technical specificity" (the extent to which a company manufactures a consistent range of products) while Botter uses "the position in the supply chain" (whether the company supplies finished products, sub-assemblies or both) and "the composition of the range of products" (the number of different products manufactured by the company). These three typologies cover the organizational characteristics for each of the types without discussing the details of the operational control. These typologies were developed primarily to assist companies in making strategic decisions.

The typologies proposed by Wild, New, Schomburg and Van Rijn are all applicable to the control of production situations. Implied in their approaches is that more than
one type of production situation may be found within a single company. The typologies used by Wild and New were developed primarily for use in making strategic decisions related to production situations at a relative high, abstract level. Wild distinguishes different types using a model of the production process (based upon the approximate number of inventory locations, manufacturing processes and flows of materials which can be identified). New’s typology uses three characteristics to distinguish between types: the organization of the production process (how the production environment is physically organized, e.g. a production line), the product structure (how many components are in the finished product) and the type of client order (how much influence the client has in specifying the finished product). Wild and New both explain how the production control is organized for each type of production situation, but do not provide any detailed analyses.

Schomburg and Van Rijn both provide detailed descriptions of their approaches to operational production control, including the decision and information aspects. Schomburg identifies nineteen types of production situations based upon eight distinguishing characteristics. Van Rijn uses seven characteristics and distinguishes between five basic types of production situations. The characteristics used by Schomburg and Van Rijn are based upon the relationship which exists between the state of the characteristics and the complexity of the control problem. In addition, Van Rijn uses another characteristic: uncertainty. This characteristic refers to the uncertainty which exists in a production situation in connection with making decisions.

### 3.3 Applicability of the Reviewed Typologies

The typologies proposed by Woodward, Harvey and Botter were developed to identify different types of companies. The points of view and objectives incorporated in these typologies do not satisfy the requirements of this study. In addition, the descriptions of the differences in control within these typologies are too abstract to be of any practical use for the present study. These typologies are useful primarily in situations where strategic decisions need to be made.

With respect to the level of abstraction, Wild, New, Schomburg and Van Rijn all provide a more suitable typology in terms of the requirements stated in the previous chapter. They recognize that it is necessary to focus on smaller units corresponding to specific production situations in order to establish an adequate production control function at the operational level. More than one type of production situation may exist within a single company.

In terms of their objectives, the typologies of both Wild and New are oriented
primarily toward controlling the production situation ("operating strategies") without being concerned with the decision and information aspects which are necessary in a typology for construction orders. Both typologies devote particular attention to the structure of the production situation. This involves aspects such as:

- the inventory locations;
- the organization of the production units (e.g., a flow shop in which a product is manufactured at a series of work stations);
- whether the products are made to stock or made to order according to the client's specifications.

Wild and New clearly illustrate that it is important to determine how the production situation should be controlled for each specific (sub-assembled) product. More than one product may be manufactured by a company, and each product may require a different approach in terms of production control. Wild and New do not address the information aspect, nor do they cover the organization and interrelationships of the decision functions.

For Woodward, Harvey, Botter, and Wild as well as New, the added value of the typology can be found primarily in the general assessment of production control problems. They address the issues of how production control generally should be viewed within a given company, or (with Wild and New) how production control generally should be viewed in manufacturing a certain product. This general nature makes the typology shallow and superficial, as well. In studying the typology, the choice of the distinguishing characteristic(s) appears to be logical. Nevertheless, there is no explanation provided to indicate why these specific characteristics have been selected above others. It is virtually impossible to argue that one typology is better than the other.

Schomburg and Van Rijn both use an objective and a point of view in their respective typologies which are similar to the objective for a typology for construction orders. Both typologies include details of the decision and information aspects of operational production control.

It is easier to understand how the distinguishing characteristics have been derived in the case of these two typologies. The distinguishing characteristics are those related to the factors which directly influence the production control and collectively describe the complexity and (in Van Rijn's typology) the uncertainty of the control of the production process.

The typologies of both Van Rijn and Schomburg use distinguishing characteristics which are based upon the effects of a number of factors which describe the complexity of a production situation. These effects are all related to production
control as defined in the industrial engineering theories for manufacturing companies. Both of these typologies implicitly accept the theories on production control in the field of industrial engineering as being valid and sufficiently applicable. Arguments are presented in both instances to explain why the identified characteristics are sufficient for determining the most appropriate type of production control, even though it remains unclear to which extent the influence of the various characteristics may overlap and interfere with each other or whether other characteristics may also be significant.

Van Rijn introduces the characteristic of uncertainty as an additional factor. The relevancy of this characteristic is related particularly to the approach which he uses to describe the relationship between the decision system and the information system. As previously discussed in Section 2.4.4, the function of the information system as defined here is to support the decision system. The complexity of the control problem dictates how the decision-maker needs to make decisions. A relatively simple problem requires a smaller number of formal decisions than a more complicated problem. This is due to the fact that the decision-maker may not be able to recognize, immediately, all of the implications of a decision in a complicated problem situation.

The way in which a decision is made is represented by the choice of various decision functions. The number and types of decision functions to be used, as indicated above, are dictated by the complexity of the control problems associated with the primary business process.

The quality of a decision is determined by:

a. whether the appropriate decision functions have been selected, which, in turn, is dependent upon knowledge of the complexity of the control problems;
b. whether the decision function is performed correctly;
c. the uncertainty about the information used as the basis for making the decision.

If the complexity factors are based on an accepted, applicable and theoretically correct framework for production control, then it can be implicitly assumed that the choice of the decision functions has been carried out properly. The design of the information system should be based upon these decision functions. The functions to be included in the information system are dictated primarily by the requirements of the decision system. This means that the complexity factors indirectly influence the design of the information system through their influence on the definitions of the various types of decision situations.

In addition, the support to be provided by the information system is influenced by the importance of making the best possible decision (i.e., the highest quality decision).
This means that the information system plays an important role in controlling the degree of uncertainty. To illustrate this point, assume that an information system is needed in two different construction order situations to support the same set of decision functions. The support provided by the respective information systems may need to be different in order to make allowances for differences in the uncertainty. The uncertainty factor, thus, may lead to the definition of different types of information systems even when there is only one type of decision system. Following the example of Schomburg, it has been decided not to include the uncertainty factor within the framework of the typology for construction orders for the purpose of the research here. The terminology used in Schomburg's typology, on the other hand, is oriented particularly to production situations as found in mechanical engineering companies (a fact that Schomburg has also noted). It is difficult to translate this terminology to a construction industry situation. This is easier with Van Rijn's terminology.

Van Rijn's typology has been used by the authors in a number of production situations in the construction industry; some differences in production control have already been identified [Melles & Wameling-1990,a]. The use of Van Rijn's typology leads to the conclusion that there may be only two basic types of production situations in the construction industry: one-of-a-kind construction orders (typically small-scale orders in various sectors of the construction industry) and project-oriented construction orders (typically large-scale construction projects). Recognized differences in the production control found in different large-scale construction orders cannot be explained using Van Rijn's typology.

Despite the fact that Schomburg and Van Rijn's typologies seem to meet the basic requirements previously formulated for a suitable typology for construction orders in terms of objective, point of view and function, an attempt to use either of these typologies for defining different types construction orders does not provide satisfactory results. The reason for this can be found in the fact that the objects of these typologies (production situations in manufacturing companies) are fundamentally different from the types of construction orders which need to be distinguished here. To understand this fully, a brief explanation of the theory of production control as interpreted within the field of industrial engineering is provided here.
Intermezzo

Production control as interpreted within the field of industrial engineering

Bertrand et al. [Bertrand et al.-1990,a] identify three levels of control in their review of production control:

- Control at the company level
- Control at the factory level
- Control at the production unit level

Certain parameters are determined at the company level which define the specific environment within which a factory - as part of the company - must function. These are seen as being production-related parameters such as normative service levels, normative utilization and allowable throughput times, yield, etc.

Within the limits specified by these parameters, a factory is free to determine the structure of its own control processes. The factory’s decisions in this respect can be found at two levels: the aggregate decision level and the detailed control decision level. The aggregate decisions deal with the long-term availability of resource capacities and the types of products to be made with the resource capacities. The detailed production control decisions are oriented more towards the actual control of production orders and the associated flows of materials (and/or resource capacities) within the factory.

Aggregate production control is used to govern how many different products will be made in the factory. Detailed production control, on the other hand, is used to determine what quantities (or which batch sizes) of the various products will be produced. Aggregate control, for example, provides a sales department with information about how many products can be sold in a certain period. However, delivery dates can only be promised based upon the detailed production control information.

Detailed production control at the factory level concerns the release of work orders to production units. Thus, the release of work orders is regulated, because there is work order acceptance by production units (when a conscious decision is made to do so). Completion of the work orders is the responsibility of the production unit.
However, the determination of which work orders are to be made available for release is performed at the factory level. A production unit can, thus, be defined as a collection of production resources for which some control over the workload is required.

The choice of production units can be made in a variety of ways. The production units could be set up based upon the kind of technology (for example, when all of the milling machines are grouped together) or, alternatively, based upon an assembly line or flow shop (for example, when all of the machines required to make a product are set up in series). A single, functional production unit may be used in the production of a variety of products. In order to make a complete product, more than one production unit may need to be utilized. In this case, multiple work orders will need to be released as part of the detailed production control process at the factory level. A flow shop can be controlled much more simply at the factory level. Only one work order is required for all the activities. However, the production unit in this case would be oriented towards manufacturing a single product and is, therefore, not very flexible. For this reason, production units (referred to as cells) are often set up in practice which are capable of manufacturing a variety of similar products. The definition and creation of groups of products with this in mind is referred to as Group Technology.

Exactly how a production unit should be set up is determined primarily by the type and variety of products being produced. Van Rijn [Van Rijn-1986] makes a distinction between five basic situations:

a. mass production, where the production unit manufactures large quantities of similar products. The production sequence is always the same;

b. batch (serial) production, where the production unit manufactures batches of products. The machinery is reset for each batch.

c. one-of-a-kind production, where only one specific product is produced at a time;

d. final assembly production, where finish products are constructed based upon known designs and completed sub-assemblies (sometimes in batches);

e. project-oriented production, where a product is constructed which has been specifically designed for a certain situation.

Detailed production control at the factory level is often called material coordination or materials management. For the coordination and scheduling of work orders, the material coordination function may make use of various types of scheduling techniques. Different scheduling techniques typically use different approaches for controlling production. With the network technique, focus is placed on coordinating the activities which are interrelated in the project while attempting to minimize the throughput time required to complete the entire project.
MRP (Material Requirements Planning) focuses primarily on optimizing the flow of materials (minimizing inventory levels). The OPT approach (Optimized Production Technology) emphasizes monitoring the loading of the bottleneck capacities to ensure that they do not become overloaded.

End intermezzo

To begin with, it is important to determine to what extent the levels of company, factory and production unit can be distinguished in the construction industry. The production process must be analyzed in order to identify the characteristics of these levels. In industrial engineering, the production unit is a recognized concept. A production unit can be identified as being a location (within a factory) where a group of production resources complete a certain quantity of work (a work order), independently.

With construction orders, the work order is typically given to a group of people referred to as a work crew. These work crews may be composed of either fixed or variable number of construction workers. After a work order is issued to a given work crew, the work crew then carries out the work more-or-less independently.

The work orders may vary significantly in terms of their duration. Depending upon the conditions and restrictions under which the work instructions are to be carried out (e.g., maximum throughput time, available workmen, available materials, technical specifications), the work crew may be given a large amount of independence with respect to performing the actual work. Work crews may be comprised of the company's own employees or may otherwise be provided by subcontractors. Usually, a whole work crew is called up at one time to carry out a specific assignment at the construction site. In other instances, however, the work crew may be formed from other groups of workmen who are already busy at the construction site.

Two different situations can be identified with respect to distinguishing between the factory level and the company level within a construction company:

1. The first type of situation occurs when dealing with (extremely) small-scale construction orders. These are typically small orders in the residential and commercial construction sectors (e.g., the constructing dormer windows and garages, hanging doors, replacing window frames, etc.). Alternatively, these could be small-scale paving orders, the construction of small culverts, etc. in the civil works construction sector. This situation is similar to that found in manufacturing companies. The company employs a number of production units
Typology and design rules

(e.g., a work crew consisting of several workmen with a truck and tools), which are formed to carry out the orders as instructed at the factory level (i.e., by the production manager). These production units are also responsible for reporting when the work is completed. The company, the factory and the production units are of a static nature. When compared with other construction orders, these construction orders can be distinguished by the fact that they are carried out completely based upon a single work order. In principle, there is no inherent reason to define a sequential relationship between the construction orders (and, thus, between the various work orders).

2. A second type of situation can be identified with respect to large-scale construction orders (often referred to as projects) found in all sectors of the construction industry. For these orders, the construction company generally establishes a temporary, new "factory" (the project organization) for the completion of a single product (referred to as the "unique nature" which is characteristic of large-scale construction projects). The factory in this situation is unique not only because of its temporary nature, but also because it typically consists of a mixture of production units which are active throughout the entire duration of the project as well as (extremely) short-lived production units (referred to as the "dynamic nature" which is characteristic of large-scale construction projects). The employees may even work in more than one production unit during the course of such a project. Production units from third parties may also work in this factory. These may be work crews from subcontractors (hired by the company) or, more likely, production units from consortium partners (companies which collectively carry out a construction order). This is referred to as the "consortium aspect" which is characteristic of large-scale construction projects. It is also possible that multiple contractors are involved in the completion of a large-scale construction project without the establishment of a consortium. External consultants may also be involved. As a result, different partners may be responsible for design decisions and the production activities, referred to as the "segmented nature" of large-scale construction projects. In addition to the establishment of a temporary factory, it is often necessary to build this factory at the construction site where a number of additional environmental aspects need to be taken into consideration. The characteristics of the construction industry described here are covered in more detail in the literature (see, for example, [Twijnstra-1969]).

The typologies proposed by Schomberg and Van Rijn were not developed to describe these kinds of extremely dynamic production units within equally dynamic factories. As a result, the differences between the various large-scale construction orders which need to be distinguished for the purpose of production control (see [Melles & Wamelink-1990,a]) cannot be identified sufficiently based upon the typologies.
proposed by Schomburg and Van Rijn. This suggests that a new typology needs to be
developed for construction orders. In addition to the distinction between large-scale
and small-scale construction orders as already explained (with the distinguishing
characteristic of the number of work orders per construction order), a major objective
of the new typology will be to identify differences in the production control
requirements of different types of large-scale construction orders.

3.4 Conclusions and Suggestions for Developing a Typology for
Construction Orders

The typologies in industrial engineering are not suitable for distinguishing different
types of large-scale construction orders based upon differences in the production
control requirements. Nevertheless, these typologies can still be used to define
different types of construction orders based upon the identifiable differences in
production control between large-scale and small-scale construction orders.

The structure of the typology proposed by Van Rijn appears to be the most suitable
structure to use as a basis. The structure of Van Rijn's typology will therefore be
used here as a starting point.

In order to determine the distinguishing characteristics, it is important to identify the
factors which influence the way in which the production of construction orders is
controlled. Since Van Rijn's typology is based on the principles of production control
according to industrial engineering, the extent to which these principles can be
applied to large-scale construction orders, in particular, should be investigated first.
The theoretical principles for production control according to Bertrand, Wortmann
and Wijngaard ([Bertrand et al.,1990,a] and [Bertrand et al.,1990,b]) are used here as
a reference framework.

The aspect of uncertainty, as proposed by Van Rijn, will not be included in the
typology here. Following the example of Schomburg, it is assumed that this factor
may be significant for developing the specifications of the information system, but is
not important in connection with specifying the decision system.
4 BASIC FRAMEWORK OF A TYPOLOGY FOR CONSTRUCTION ORDERS: DEALING WITH TECHNICAL UNCERTAINTY

4.1 Introduction

This chapter briefly describes the objective, the point of view and the objects for the new typology for construction orders.

The objects to be included in the typology are construction orders, but not just any construction orders. Construction orders will be included in the typology only to the extent that they occur within the context of the activities of a construction company (contractor). The object is, therefore, defined as a construction order which has passed the phase of technical work preparation, whereby (as will be discussed in detail later) the technical uncertainty has been eliminated.

4.2 Objective, Point of View, Objects and Distinguishing Characteristics of the Typology

The objective, point of view, objects and distinguishing characteristics are defined here in accordance with the requirements presented in Chapters 2 and 3.

Objective:

The typology should provide a framework in which the different types of construction orders can be identified based upon the (theoretical) differences in the ways in which decisions are made and information is communicated. In addition to the basic classifications provided by existing typologies, this new typology should devote particular attention to explaining the differences in production control among the various types of large-scale construction orders.

Objects:

The objects of the typology are construction orders within the context of a construction company.
Point of view:

The point of view of the typology should focus on the decision and information aspects related to the production control of construction orders.

Distinguishing characteristics:

The distinguishing characteristics will be derived from an analysis of the theoretical differences in the control approaches needed to ensure the completion of a variety of different types of construction orders. A major distinguishing characteristic in this respect has already been discussed in Chapter 3: large-scale versus small-scale construction orders (distinguishing characteristic: a single work order versus multiple work orders per construction order). Still to be identified are the distinguishing characteristics which explain the different methods of production control used for different types of construction orders.

4.3 A Closer Look at the Construction Order as the Object of the Typology

Analogous to Van Rijn, the production control method is determined primarily by the production process (the primary process). The production process is generally unrelated to the product.

Example:

Consider the example of a car manufacturing company which considers its manufacturing strategy. The cars could be manufactured in batches, but it is also conceivable to manufacture each car using a one-of-a-kind production process or as a project. In each of these cases, the final product (a car) will be exactly the same. The method of production control, however, will obviously need to be different for batch production than for project-oriented production. A typology needs to be developed which distinguishes between different types of production control situations (with respect to producing certain products) rather than the different types of products produced.

A similar example can be identified in connection with the completion of construction orders.

Example:

Consider a situation in which the structure of a building is to be constructed using
concrete poured at the construction site. In this case, a significant amount of work must be carried out at the construction site. Formwork must be brought in, various work crews (with varying skills) must be called in, and the concrete must be supplied (multiple truckloads). The crane capacity is dependent on the weight of the formwork and whether concrete pumps are used. The control process must deal with a large number of different activities and identify the interrelationships in order to keep the throughput time to a minimum. Materials, equipment and work crews are called in based upon the resulting activity plan.

The same structure could be made, alternatively, using prefab elements. In that case, the manufacturing process in its entirety can be performed off-site at a factory; the prefab elements are only assembled at the construction site. The crane capacity and the schedule for the delivery of the prefab elements (sequence in which and speed at which they are brought in, crane capacity, type of crane, etc.) become the determinants for the control method in this situation. The control process focuses on the flow of materials in this situation.

It is not appropriate to consider all possible types and definitions of construction orders as the objects of the required typology. Therefore, the typology will be limited to the characterization of construction orders in the context of a construction company.

In practice, there are a number of factors which influence the choice of the production method for construction orders. The following general factors can be identified in this respect (see also [Birrell-1988]):

a. Traditional construction methods and specific company experience

An example of the influence of this factor can be found with respect to the assembly of window frames in the residential construction industry. In Germany, the walls of a house are traditionally constructed, first. Then, openings are cut for the window frames. As a result, the openings are made to fit the dimensions of the frames and the sizes of window frames have become standardized to a great extent. In the Netherlands, on the other hand, window frames are positioned, first, before the surrounding brick wall is constructed. The shapes and dimensions of the window frames are determined largely by the general architecture of the house. Only a limited amount of standardization is found in this situation (even in cases where it would be extremely logical).

Another example can be found in the road construction sector. In the region of The Hague in the Netherlands, a new road surface is generally constructed by first preparing a flat roadbed of sand before laying any of the bricks. The bricks are not
hammered in this instance. In the vicinity of Gouda, however, a different technique is typically used whereby the roadbed is flattened as the bricks are laid. Each brick is hammered in separately. Different methods of laying the bricks to pave the streets can also be seen: standing or kneeling. The preference for one method over the other is apparently dependent upon which method is taught by the trade schools in a particular region. The preferences shown by a given trade school depend largely upon the preferences of the more experienced road workers in the region.

b. Available capacity

In many developing countries, a conscious choice is made for non-mechanized solutions. When cheap labor is available, mechanization is often an expensive option. Japan's enormous lead with respect to the industrialized nations in Western Europe and elsewhere in the application of robot technology in the construction industry was the direct result of a serious shortage of workers in the Japanese construction industry [Atkin et al.-1990] [Cusack-1990].

A contractor who has invested in (expensive) tunnel formwork equipment will quickly decide to make use of this tunnel formwork equipment whenever possible, while another contractor may opt for an entirely different production method.

c. Market factors

Different types of batch production methods have been used for the construction of rows of town houses in the Netherlands for many years. In the surrounding countries, however, such batch construction methods are virtually unknown, since town houses are built on a much smaller scale.

d. Company culture and tradition

The type of management as well as a company's history have proven to have a significant effect on the construction methods used. It is important to determine whether the company is willing to risk making changes or if the attitudes are more conservative and how much freedom is given to people with new ideas (see e.g. [Kleijn-1989]).

In actual practice, one example was found where a concrete engineer decided to replace the supports for the formwork (which normally consist of scaffolding combined with steel beams) with a pile of sand. Naturally, this type of construction cannot be used in every situation (due to soil conditions, the possibilities for temporarily closing down roads, etc.) and this approach can also be considered to
be rather unconventional. In this case, however, this solution proved to cost only about half as much as the traditional approach!

It is for this reason that the typology cannot be simply applied to any construction order. More than one suitable production method is often available. In order to apply the typology, the production method should already be known. This is called the elimination of technical uncertainty. The activities which need to be carried out to eliminate the technical uncertainty are referred to as technical work preparation activities.

In summary, consideration of the aforementioned factors suggests that the objects for the typology to be developed can be defined as the construction orders which have already passed the technical work preparation phase. This means that the production methods normally used by a given company will limit the range of possibilities for the typology.

In the case studies discussed in Part 3 of this thesis, the choices made in the development of the technical work preparation plan are reviewed. Nevertheless, the final choices reflected in the technical work preparation plan are considered to be fixed for the purpose of this research.

The design rules for defining decision and information systems are also intended to support the production control, rather than the technical work preparation, for these types of construction orders.
5 DISTINGUISHING BETWEEN THE DIFFERENT TYPES OF CONSTRUCTION ORDERS

5.1 Introduction

In this chapter, a typology is derived for construction orders. Construction orders, here, are explicitly understood to be construction orders which have passed the technical work preparation phase.

The reason for distinguishing various types of construction orders is to provide a basis for developing a theoretically appropriate control method for each type of construction order which has passed the technical work preparation phase. This typology is to be based upon the generally accepted theories concerning production planning applied in industrial engineering for manufacturing companies. In particular, the theories developed by Bertrand et al. (see, [Bertrand, Wortmann and Wijngaard-1990,b]) and Van Rijn (see, for example, [Van Rijn-1986]) provide a suitable foundation. The typology to be developed for construction orders can, thus, be viewed as an ideal-typical typology.

First, a summary of the terminology used here is presented in Section 5.2. Then, in Section 5.3, the production control theories used in the field of industrial engineering are discussed. These theories serve as the basis for the design of a general control model for the construction industry which is subsequently developed in Section 5.4. This model is then discussed in more detail in Section 5.5, including a number of possible variants. At the same time, the distinguishing characteristics are described which can be used to determine which variant is relevant to which situation. Based upon this, the different types of construction orders identified within the typology are presented in Section 5.6.

5.2 Summary of the Terminology Used

In this chapter, terminology is used which originated in industrial engineering as well as the terminology found in actual practice in the construction industry. First, in order to bridge the gap between these two worlds, a number of terms have to be discussed.
Construction company

A construction company is a commercial organization whose primary business activity is the completion of construction orders. A wide variety of specialized construction companies exist, corresponding to a wide variety of different kinds of construction orders. The sectors commonly recognized in the construction industry are the residential construction and commercial building sectors, on the one hand (this includes buildings, homes and renovations), and the civil works sector (this includes infrastructure projects such as roads, cables and pipelines, dredging and concrete construction such as tunnels), on the other hand.

Construction order

A construction order is a contractual obligation to complete a construction work, agreed between a construction company and a client. A construction order usually comprises the completion of all phases of a construction work on one site, but may be limited to only a part of the total construction effort.

Construction orders can be divided into projects and small-scale orders. A construction order is a large-scale construction order if it consists of a large number of different operations which are carried out by different work crews. A client work order is a small-scale construction order consisting of a number of operations which are carried out by a single work crew.

Production unit
(referred to as a work crew in the construction industry)

A production unit (referred to as a work crew in the construction industry) is a group of workers, sometimes including equipment, which carries out a number of agreed operations. An agreed set of operations is referred to as a work order. Based upon a work order, the work crew operates independently.

Work order
(referred to as a work crew assignment in the construction industry)

A work order is a complete set of operations which is given to a work crew for completion. Within a work order, a work crew may divide the assignment into different operations.
Work orders within a large-scale construction order
(work crew assignments within a project)

Within a large-scale construction order (also known as a project), a large number of related work orders (clustered together into activities) can be identified.

Work orders within small-scale construction orders

In small-scale construction orders, all of the operations to be carried out are included in a single work order. The construction order is, thus, the same as the work order in this case.

Activities within a project

An activity is a number of related work crew assignments (work orders). An activity is used to monitor the progress of functionally-related work crew assignments.

Example:

Activity A: construct floor
Work crew assignment A1: install formwork using own Work Crew #1
Work crew assignment A2: install reinforcement using work crew from "Good Work, Inc."
Work crew assignment A3: oil formwork using own Work Crew #1
Work crew assignment A4: pour concrete using work crew from "Good Work, Inc."

Activity B: build wall
Work crew assignment B1: prepare forms, join reinforcement rods and pour concreted using work crew from "Good Work, Inc."

The work crew assignments A1 through A4 are clearly related (they are all needed to construct the floor). Each work crew assignment includes clear instructions for completing a total "package" of work for a work crew.

Procurement plan
(referred to as purchase orders in the construction industry)

On the basis of a procurement plan, manufacturing plants make agreements about the materials and services to be delivered by supply companies. Quantities and price agreements are established.
In construction companies, there are two types of procurement plans:

- **blanket orders**
  Within these orders, quantity discount schedules are agreed with suppliers for all construction orders placed within a certain period of time.

- **project purchase orders**
  Within the project purchase orders, agreements are made about quantities, approximate delivery lead times and project-related specifications.

**Purchase order**
(referred to as call orders in the construction industry)

The purpose of a purchase order is to arrange for the physical delivery of materials and services provided by suppliers to the construction site. The quantities of materials to be delivered are normally less than or equal to the quantity specified in the blanket order or project purchase order.

**Operation**

An operation is a detailed task carried out by an individual member of a work crew as part of a work order.

### 5.3 Approach to Production Control from the Viewpoint of Industrial Engineering

In the remainder of this chapter, a number of distinguishing characteristics are identified which can be seen as the key factors used to explain differences in production control methods for construction orders. Thus, a relationship must exist between the relative importance of a given distinguishing characteristic and the influence that a change in the state or importance of this characteristic will have on the production control. In order to define this relationship more precisely, a number of aspects of production control are discussed first. Production control in this context refers to the generally accepted principles of production control theory in industrial engineering for manufacturing companies.

In this respect, the following characteristics are of importance:

I: Thinking in terms of hierarchical decision levels

Basically speaking, a distinction is made between three different levels.

a. Control at the company level
b. Control at the factory level
c. Control at the production unit level

Control at the factory level pertains to decisions concerning all production units, such as the allocation of resource capacities and releasing work orders to production units. Control at the production unit level pertains to decisions made within the production unit. At the company level, production-related parameters (service level norms, delivery norms, etc.) are determined.

An important element is the way in which the communication between levels is organized. Between the company and factory levels, communication takes place through the exchange of the assumed and achieved values for production-related parameters. Between the factory and production unit levels, communication takes place when orders for production units (the work orders) are released or notification of completion is given.

Organizing and structuring production control starts with determining where the hierarchical levels of a company lie (where is the factory level, how are production units to be defined, etc.) and how work orders are to be grouped.

II: Thinking in terms of decision functions within the hierarchical levels

Within the various levels, a distinction can be made between the various decision functions which can be recognized in production situations involving the control of a company's own production activities. Within this structure, it is useful to refer to the framework proposed by Bertrand, Wortmann and Wijngaard (Figure 5.1).

The various basic decision functions are explained, briefly, below:

Aggregate production planning

Aggregate production planning is the highest decision level within the framework as shown in Figure 5.1. Based upon a number of production-related parameters (for example the desired service level norm, throughput times and capacity loading
Figure 5.1: Framework for Production Control (from: [Bertrand et al.-1990,a])

percentages) a high-level plan is developed to schedule the utilization of the production resource capacities for the medium to long term (for example, a year or longer). The choice of production-related parameters is dependent upon the company’s business strategy and is, thus, not part of the operational control of the company.

Externally (i.e., interfacing with the market), this decision function often results in
producing a sales plan (which and how many products) and a procurement plan for critical materials.

Internally, aggregate production planning results in a plan of the production volumes for the medium to long term, on the one hand, and a plan of the availability and use of resource capacities (resource capacity plan), on the other. It is important to note that at this level, specific client orders (i.e., a client's order for the supply of a product) are not normally taken into account. In other words, assumptions are made concerning the desired production volume based on the expected market demand (market potential). The production volume and the resource capacity plan are related to production units within the factory.

Material coordination

The material coordination function involves making decisions concerning the flow of materials throughout the entire factory. More must be taken into account than just the basic flow of production materials normally used in the construction industry. An important difference between manufacturing and the construction industry is the fact that in manufacturing, the results of the activities of one production unit (welding bicycle frames, for example) are then used by a different production unit (bicycle assembly, for instance). In the mean time, an "intermediate inventory of sub-assemblies" is created which must also be controlled by the basic function "material coordination".

The final production schedule should serve as the basis for this function. In other words, the decisions should have already been made regarding what quantities of which products are to be produced within a certain time period. Of course, the production schedule may still be altered in the future as new information becomes available.

It is not necessary for all of the client orders to be placed before decisions are made. In many cases, a manufacturing company will make final assumptions based on forecasts.

The material coordination decision function is authorized to make delivery agreements with clients (order acceptance). The planned production volume from the aggregate production planning is specified in work orders based upon the products to be made, the points in time and the quantities required. Based upon the assigned due dates, the material coordination function can then determine the proper sequence for processing the work orders.

The material coordination decision function can be carried out in a number of ways.
Relevant in this respect are the types of production units involved. If the production method, the specifications (type, description and number of materials) and the routing through the resource capacities are all known, then the factory can be controlled by controlling the flow of materials and the level of inventories. This approach is normally followed in mass production and batch production situations as well as in final-assembly production situations. In situations where the procedures and routings are known but the final specifications are determined by the client (for example, all of the possible "bells and whistles" on a car are known but the client selects his or her own package of options), the primary problem lies in scheduling the resource capacities. This is typical of one-of-a-kind production situations. In situations where the procedures, specifications and routings are not known, control focuses on controlling the order throughput time. This is typical of project-oriented production situations. The decision of whether to base the control on the flow of materials, resource capacity loading or throughput time is referred to as choosing the focus of control.

**Workload control**

Workload control is actually an approach whereby the planned production activities are quantified in terms of the loading of the major resource capacities at the production unit level. This is based upon the resource capacity plan (prepared as part of the aggregate production planning function). In a number of cases, this may also place limitations on the production possibilities. In other words, workload control specifies the degrees of freedom and the restrictions which need to be taken into account by the material coordination function.

This decision function ensures that the expected capacity loading percentage for the available resource capacities does not exceed the levels determined by the production unit's production-related parameters.

Workload control and material coordination are also collectively referred to as detailed production control at the factory level.

**Work order release**

The sequence of work orders determined by the material coordination function need not be the most desirable sequence from the perspective of production unit control. New information may become available, on the basis of which a different sequence may be desired. This is the case, for example, in situations when materials are not available or when resource capacities cannot be supplied for some reason (see the "workload acceptance" decision function). The decision function "work order release" will determine which work orders can be produced, in principle, when new
information about the availability of materials or resource capacities is provided.

**Workload acceptance**

The release of orders by the "work order release" decision function cannot take place without an assessment of the current resource capacity availability. This availability is determined by the "workload acceptance" decision function. This decision function takes into account the currently available resource capacity, as well as any current work backlog or work started ahead of schedule in the production units. If work orders are subcontracted to third parties, the same procedure can be followed to assess the resource capacity which is available from these third parties. The result of this decision function may impose certain restrictions on the work order release function.

**Detailed work order planning**

Within the production unit, based on considerations such as "minimum set-up times" and other production unit dependent conditions and restrictions, the detailed work order planning decision function determines when the work order will be produced.

**Resource capacity allocation**

Within a production unit, a certain resource capacity (a person or unit of equipment) may be available for more than one assignment (multi-skilled resource capacities). In this case, a decision function is required to control the allocation of such multi-skilled resource capacities. In the framework here, this function is referred to as "resource capacity allocation".

**Material and work distribution**

If a queue of pending operations is waiting at a work station (resource capacity) on the shop floor, a choice must be made. This is an extremely short-term decision. This decision function provides for all of the necessary materials, tools and instructions at the same time.

**III: Identifying and using different types of production units**

Various types of production units can be identified in the manufacturing industry. Distinctions can be made based upon the type of production process. The following types can be identified (see also: [Van Rijn-1986]):

- **Mass production units**: These production units make the same products in
large quantities over an extended period of time according to standard specifications and procedures.

- **batch production units**: These production units make a batch of a specific product which belongs to a range of products. The product specifications and the production procedures are known in advance.

- **one-of-a-kind production units**: These production units make a product based upon a specific client order. The general product specifications and production procedures are known in advance.

- **project-oriented production units**: These production units make a customized product based upon non-standard specifications and procedures.

- **final-assembly production units**: These production units make one or more (batches of) finished products from a large number of available sub-assemblies. The procedures are known in this case, however, the specifications may vary.

In general, the production units for mass production, batch production, one-of-a-kind production and final assembly are situated at a specific location and are stable in terms of size. Temporary assignments are given to project-oriented production units or project-oriented production units are set up specially for a given project, with its own location and own work crew.

The type of production unit to be used is generally determined after the completion of the technical work preparation phase. A basic characteristic of the approach to production control generally followed in the field of industrial engineering is to identify the different types of production units in this way so that the most appropriate method of production control can then be determined.

### 5.4 Applicability in the Construction Industry of Theories on Production Control from Industrial Engineering

As previously discussed in Section 3.3, a construction project which is initiated to carry out a large-scale construction order can be compared to a factory situation. The production unit is equivalent to a work crew in the construction industry.

The basic elements of the framework for decision functions used by Bertrand, Wortmann and Wijngaard can also be used in the construction industry. Nevertheless, there are a number of differences to be noted which are specifically oriented to the construction industry. Most of these differences are due to the fact that some functions cannot be individually identified, but instead form an integral part of a group of decisions. A general translation of the framework for production control proposed by Bertrand, Wortmann and Wijngaard to the construction industry is
presented below. This translation is done in two phases. First, for each decision function from the framework proposed by Bertrand, Wortmann and Wijngaard, the equivalent decision function in a construction industry situation is identified. Then, in Section 5.5, an analysis is presented to identify which variants of each decision function in the construction industry which are theoretically relevant. This analysis is based upon the assumption that the control method to be used for each decision function is also dependent on the type of production process.

*Aggregate production planning*

For the decision function "aggregate production planning", there is no obvious, equivalent concept in the construction industry. This is due to the fact that this kind of decision function does not occur in today's construction industry. Resource capacity plans covering periods of a year or more into the future are rare in the construction industry. A specification of the desired production volume (in terms of revenue, etc.) can be found in the business plans, but primarily for the purpose of calculating the expected coverage of overhead expenses. The calculated overhead cost percentage is then added to the direct expenses when project cost estimates are made. This type of annual planning for covering the overhead expenses is often referred to as the strategic business plan. A recognizable term for this decision function in the construction industry could thus be "business planning". The other component of aggregate production planning is considered to be a separate decision function here: *resource capacity planning*.

The business planning function takes place together with the resource capacity planning function for the (extremely scarce) production resources which cannot be increased on short notice. In practice, these are referred to as the durable production resources (i.e., exceptionally expensive production resources such as formwork equipment, asphalt plants, asphalt paving equipment, cranes, etc.) and technical and administrative staff.

The data files associated with the business planning function include the business plan as well as the resource capacity plan for those production resources which cannot be increased on short notice [i.e., the resource capacity plan for the (extremely) scarce company resource capacities]. A complete procurement plan will normally not be found since only blanket order purchasing orders generally exist in this respect at this level.

*Workload control*

The "workload control" function optimizes the use of the company's resource
capacities. The concept of workload control is equivalent to the concept of "multi-project planning" as used in the construction industry. The relevant data pertains to the operational resource capacity requirements for construction orders (in the form of internal orders) and the resource capacity plan.

In a construction company, acceptance of a construction order generally means that a new "factory" will need to be established. This can only be done if, for example, the required staff members and durable production resources are available. This means that client order acceptance, in contrast with the model used by Bertrand and Wortmann, does not take place as part of the material coordination function but is seen, instead, as a separate decision function: the "construction order acceptance" function.

The data related to this function includes the order acceptance notification, the multi-project plan and the construction company's order portfolio. Input data for this function consists of order details and forecasts as well as feedback information from the project coordination function. The multi-project planning and construction order acceptance notifications are related to one another via internal orders.

Material coordination

The "material coordination" function is concerned with relating the work orders (known in the construction industry as work crew assignments) to one another. This involves more than just coordinating the flow of materials. The term "material coordination" is, thus, really not suitable. Material coordination in the construction industry is comprised of separate activities which involve monitoring the costs and the progress of the construction project, scheduling activities to be carried out and mobilizing the required resources.

Monitoring progress takes place based upon functional groups of operations referred to as activities. Each activity represents a part of a specific construction order and is generally dependent upon interrelationships with other activities. This can be represented by a network structure. It would be logical to use the term "project coordination" here.

The finalization of resource requirements also takes place within the project coordination function. On the one hand, this results in the generation of purchase orders for subcontractors, materials and the company resource capacities. The decision "make or buy" is also made at this point.

The data files related to the project coordination function include detailed client information, feedback information from mobilization planning and progress reports
on the completion of the construction order (incoming information), the procurement plan (comprising the project-oriented purchasing orders), the high-level activity plan, the project staffing and equipment plan and the detailed project agreements.

**Detailed work order scheduling, work order release and workload acceptance**

*Work order release* in the construction industry does not take place explicitly as suggested in the framework proposed by Bertrand, Wortmann and Wijngaard. This is due to the fact that detailed planning and work order release can take place simultaneously since the person responsible for these functions, usually the (chief) foreman, can reschedule work orders based upon the availability of materials. This combination of the detailed planning function, the work order release function and a part of the material coordination function is referred to as "mobilization planning" in the remainder of this book. Mobilization planning is actually the detailed scheduling of (parts of) activities for which the resource capacities (either internal or external) and the materials could be available at the time scheduled for performing the activities (often presented in six-week schedules). The availability is guaranteed by calling materials, subcontractors, equipment and internal work crews to the construction site. Mobilization planning uses work crew assignments (referred to as work orders in manufacturing). A work crew assignment is a group of operations which is allocated to a production unit.

Bertrand, Wortmann and Wijngaard also recognize the workload acceptance function at the same level as the work order release function. The workload acceptance function may exist within a subcontractor's organization, however, this falls outside of the span of control of the construction company (main contractor). The internal form of this function has already been identified as the *multi-project planning* function. This decision function is explicitly not carried out at the production unit level.

The data related to the mobilization planning function includes the six-week schedule (including work crew assignment priorities), external call orders, internal call orders, due date delays and feedback on allocation planning.

**Resource capacity allocation and material and work distribution**

The "resource capacity allocation" and "material and work distribution" functions are combined in a single function in the construction industry: *allocation planning*. Allocation planning takes place based upon the operations allocated to individual construction workers.
The data which is relevant to this function includes the work assignment schedule, the bill of materials associated with the assignment, progress delays with respect to subcontractor production and feedback on the completion of the activities.

Special attention should be focused on the feedback information. Bertrand, Wortmann and Wijngaard have identified only two instances of decision information which can be seen as feedback from the production activities. These two instances are associated with the workload acceptance function and the aggregate production planning function. In the model presented here for the construction industry, feedback is - in principle - always provided to the higher-level decision functions. The reason for this is that each project is viewed as an individual factory and feedback needs to be communicated to company management from the factory level. Within the factory (the project), all of the activities can be decomposed into sub-activities. In a factory within the context of industrial engineering, some work orders are interrelated, but most work orders are not. As a result, production units (work crews) in the construction industry are more closely related to each other than the typical production units in a manufacturing company. Direct feedback from the work crews to higher management levels would become impractical.

This general framework for production control in the construction industry is illustrated again in Figure 5.2.

5.5 Differences in Production Control in Construction

As indicated in the caption to Figure 5.2, the control model described here is a general model which provides a possible framework for controlling construction orders in practical situations. This implies that it is necessary to consider whether this model is applicable to all practical situations without further modification.

A number of analyses [Melles and Wamelink-1990,a] have shown that modifications to this model are, indeed, required in a number of situations. One example of such a modification was presented in Chapter 3. For small-scale construction orders, the construction order is used as the basis for multi-project planning for all of the company resource capacities as well as for project coordination, mobilization planning and allocation planning. This does not conform with the example in the previous section where the construction order is used as the basis for multi-project planning and the activity, work order and operation, respectively, are used as the bases for the other decision functions.

In this section, the theoretical relevance and the design of production control will be
discussed in more detail, based upon the definition of the decision functions as presented in Figure 5.2.

First, a general description is provided for each decision function. The characteristics of the decision functions are then discussed along the same lines as in Section 3.3 of Part 1.

Next, the extent to which differences can be seen in practice (the variants) are discussed. For each variant, the distinguishing characteristic is described which was used to define the variant of the object of the typology (construction order).
5.5.1 Business planning

General description

As indicated earlier, it should always be possible to identify the "business planning" function within the decision system of a construction company. An important prerequisite for this decision function is decided at a higher decision level, namely, the formulation of a company vision and strategy with respect to how "strong" it is and wants to be in specific business areas. In other words, the construction company needs to identify its strengths and how it intends to use these strengths with respect to its future business strategy. The company's business strategy may also be influenced by developments in the market, e.g., an expected increase or reduction in the volume of construction work in a certain sector. The results of decisions at the strategic level can be seen as independent variables which influence the "business planning" decision function. The same is true for information concerning the company's order position and its positioning in the market.

The objective of the "business planning" decision function can thus be formulated in terms of this independent variable and a specific target value. This could, for example, be a statement regarding the sales volume to be achieved, the distribution of revenue over the various sectors of the industry and the size and composition of the company's resource capacities which will be used to achieve the strategic business objectives (e.g., increased return on investment, better leveraging of market strengths).

The company can monitor and control its performance using indicators such as the forecasted sales revenues per market sector. In addition, the results generated by the "resource capacity planning" decision function with respect to the most scarce company resource capacities will play an important role.

The following variables are related to the "business planning" decision function:

Goal variables

- return on investment
- distribution of revenue over various market segments

Control variables

- planned sales revenue per market sector
- type and amount of resource capacity in each period
Independent variables

- strategic objectives
- information concerning order position and positioning in the market
- feedback from construction order acceptance
- feedback from project coordination

Variants

No variants are discussed here in view of the fact that the "business planning" decision function is closely associated with corporate strategy decisions as well as operational control decision.

5.5.2 Resource capacity planning

General description

The objective of the "resource capacity planning" decision function is to ensure that adequate resource capacities are available for use by the production process in the medium to long term. This decision function determines whether the company should divest or invest in certain assets and resources, depending on the production (construction orders) expected for the coming planning period.

The goal variable in this case is always formulated in terms of maintaining an "optimal amount of resource capacity at minimum cost".

The amounts and types of resource capacities can be seen as control variables for this function. The specifications associated with the resource capacities (in other words, the assignments for which a resource capacity can be used) are viewed as independent variables for this function. The resource capacity requirement is also an independent variable derived from the business planning decision function.

The following variables are related to the "resource capacity planning" decision function:

Goal variables

- optimal amount of resource capacity at minimal cost
Control variables

- amount and types of resource capacities per period

Independent variables

- specifications associated with the resource capacities
- data from the business plan

Variants

In practice, a number of different kinds of resource capacity plans can be found. The decision horizon may vary from plan to plan since some resource capacities are more scarce than others. A significant effort is normally required in terms of time and/or money in order to change the amount of scarce resources by investing or divesting).

This means that the "resource capacity planning" function is useful only for controlling the resource capacities which cannot be rented or purchased within the time horizon of a construction order (or in situations in which it is not wise to do so). This is the case for (scarce) resource capacities which must be manufactured, for example, or which may be difficult to finance.

This is summarized in the table below:

<table>
<thead>
<tr>
<th>State of the distinguishing characteristic</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Almost) no scarce resource capacities exist within the construction company</td>
<td>No &quot;resource capacity planning&quot; decision function required</td>
</tr>
<tr>
<td>Scarce company resource capacities exist</td>
<td>&quot;Resource capacity planning&quot; decision function is required</td>
</tr>
</tbody>
</table>

Table 5.1: Distinguishing Characteristics for Resource Capacity Planning

5.5.3 Construction order acceptance

General description

The "construction order acceptance" decision function determines whether construction orders will be accepted. Conformance with the business strategy as
formulated in the strategic business plan is used as one of the evaluation criteria in connection with the construction order acceptance decision.

Control is exercised in the form of focused marketing and sales efforts, on the one hand, and clear criteria for the acceptance and refusal of orders on the other. "Pricing" is used as a primary control variable.

The relevant independent variables include the data from the business plan, feedback from project coordination, and detailed information concerning (potential) orders.

The following variables are related to the "construction order acceptance" decision function:

**Goal variables**

- achieving all of the revenue targets as formulated in the business plan

**Control variables**

- pricing
- acceptance or refusal of the construction order

**Independent variables**

- data from the business plan
- feedback from project coordination (relevant construction order experience)
- detailed information concerning (potential) orders

**Variants**

In principle, construction order acceptance, as described here, must be performed in a consistent manner in every instance.

### 5.5.4 Multi-project planning

**General description**

The "multi-project planning" decision function translates the planned production into a resource capacity loading plan for the company's most important resource capacities. In other words, it is decided when the available resource capacities will be used to complete all or parts of the various construction orders. An effort will be
made to ensure an optimal loading of the company resource capacities when allocating these resource capacities to the various construction orders for completion in the coming period (e.g., several months).

Optimal loading is achieved when the resource capacities are used in such a way that operating costs are minimized, taking the specific requirements of the work in progress and future construction orders into consideration.

In practice, minimizing the operating costs means that the capacity loading percentage must be as high as possible and the set-up times as short as possible, since a lower capacity loading percentage and longer set-up times both lead to increased costs. This is, of course, dependent upon the type of resource capacity concerned.

Examples of factors which increase set-up times include the relocation of equipment from one construction site to another and setting up a resource capacity for a new order at a new construction site.

In order to achieve the stated goal, the decision-maker can choose among various resource capacity employment/deployment alternatives. In other words, he will try to control the use of resource capacities in terms of duration, point in time and location for the various construction orders in such a way that the highest possible capacity loading percentage and the shortest possible set-up times can be realized.

The internal orders, thus, become the primary control variable. Certain orders may also need to be subcontracted.

The following variables are related to the "multi-project planning" decision function:

**Goal variables**

- capacity loading percentage
- set-up time

**Control variables**

- duration, point in time and location of resource capacities to be employed/deployed (for internal orders)
Independent variables

- resource capacity employment/deployment requirement of the construction order (external or internal)
- business plan

Variants

Multi-project planning can be found in a number of different forms in practice. There is often a relationship between this decision function and the total period of employment/deployment of the resource capacity. When a resource capacity needs to be used for a long period of time in comparison with the total duration of the construction order, the resource capacity normally needs to be reserved for use by the construction order at the earliest possible point in time. This is generally when the order confirmation is received. The "multi-project planning" function therefore has a relationship with the "construction order acceptance" decision function.

If a resource capacity is only needed for a short period of time in comparison with the total duration of the construction order, the "multi-project planning" function may be closely related to the "mobilization planning" decision function (coordination of the work crew assignments).

This discussion applies to resource capacities which are scarce (as defined in connection with the "resource capacity planning" decision function). If the resource capacities are not scarce, then the only concern is to ensure that they are sufficiently available. There is no need to be concerned with optimizing the usage of such non-critical resource capacities across the various projects. Nevertheless, it is important to ensure that sufficient resource capacity will be available, based upon the information provided by the "mobilization planning" decision function. This essentially involves controlling the availability of each of these resource capacities.
This is summarized in Table 5.2.

<table>
<thead>
<tr>
<th>State of the distinguishing characteristic</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long employment/deployment of scarce company resource capacities</td>
<td>&quot;Multi-project planning&quot; in conjunction with construction order acceptance</td>
</tr>
<tr>
<td>Short employment/deployment of scarce company resource capacities</td>
<td>&quot;Multi-project planning&quot; in conjunction with mobilization planning</td>
</tr>
<tr>
<td>No scarce company resource capacities</td>
<td>&quot;Multi-project planning&quot; in the form of stock control</td>
</tr>
</tbody>
</table>

Table 5.2: Distinguishing Characteristics for the "Multi-project Planning" Decision Function

5.5.5 Project coordination

General description

The "project coordination" decision function deals with optimization within the construction order. Unlike the previously discussed "business planning" and "multi-project planning" functions, the decisions here are made based upon the requirements of the construction order rather than the business requirements and goals.

It is important to note that all of the decision functions identified in the framework pertain to making decisions concerning operational activities and logistics. Decisions related to the technical work preparation activities for a construction order (e.g., choosing the size of a work crew, determining cycle times, choosing whether to use prefab elements and determining the technical relationships between the activities within a construction order) are treated as independent variables here.

The "project coordination" decision function pertains to the highest decision level within the construction order. In principle, this function deals with the entire duration of the construction order. One of the basic goals of this decision function is to ensure that the entire construction order is completed on schedule, minimizing the total duration of the construction order and minimizing the set-up times within the construction order when appropriate. This leads, in turn, to minimizing the costs.

Within this context, the decision-maker can control the sequence of activities and the throughput times of the activities within the construction order. This is directly
related to the loading of resource capacities (a shorter throughput time can only be achieved by employing/deploying additional resource capacities). One or more diagrams can be prepared as part of the project coordination function to indicate when the various resource capacities will be required (e.g., a procurement plan, a project staffing plan and a project equipment plan).

The following variables are related to the "project coordination" decision function:

**Goal variables**

- duration of the construction order
- set-up time
- minimal costs

**Control variables**

- activity sequence
- duration of an activity
- activity initiation and completion times

**Independent variables**

- results of the technical work preparation activity (e.g., specification of work crew size, cycle time, production method, the technical relationships between activities)
- data from construction order acceptance function
  (order portfolio of the construction company)
- data from the multi-project planning function for scarce resource capacities
- detailed client information
- feedback from the mobilization planning function (relevant experience)

**Variants**

The "project coordination" decision function is responsible for coordinating the activities within a construction order. This decision function has only two significant variants, which are dependent upon the number of work crew assignments. When there is only one work crew assignment for a given construction order, the project coordination function is carried out at the construction order level. When there are multiple work crew assignments, the project coordination is carried out at the activity level whereby each activity represents a group of related work crew assignments.
This is summarized in Table 5.3:

<table>
<thead>
<tr>
<th>State of the distinguishing characteristic</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of work crew assignments = 1</td>
<td>&quot;Project coordination&quot; is carried out at the construction order level</td>
</tr>
<tr>
<td>Number of work crew assignments &gt; 1</td>
<td>&quot;Project coordination&quot; is carried at the activity level</td>
</tr>
</tbody>
</table>

Table 5.3: Distinguishing Characteristics for the "Project Coordination" Decision Function

5.5.6 Mobilization planning

General description

The "mobilization planning" decision function is similar to "project coordination", but then at a more detailed level and with a limited planning horizon. The basis for this function is a specification of the activities associated with the construction order which are to be completed in the near future; work crew assignments are then prepared.

Based upon the release of these activities, the decision function "mobilization planning" must ensure that optimum use is made of resource capacities (minimizing idle time) and materials (minimum inventory, optimum delivery quantities and minimum transport costs). This optimization also contributes to minimizing the overall costs of the construction order.

The decision-maker can achieve the desired objective by making decisions concerning points in time at which work crew assignments commence and are completed, their sequence, the size and time of deliveries (of both resource capacities and materials).

The following variables are related to the "mobilization planning" decision function:

**Goal variables**

- Materials:
  - minimal stock levels (cost)
  - minimal transport costs
Resource capacities:
- minimal employment/deployment costs
- minimal transport and relocation costs

Control variables
- sequence of the work crew assignments
- location, initiation time and completion time of the work crew assignments
- size and time of deliveries

Independent variables
- conditions and restrictions imposed by project coordination
- work crew size
- available space at the construction site
- delivery delays
- feedback from allocation planning (work crew assignment experience)

Variants

The way in which "mobilization planning" is carried out depends upon the complexity of the problem of controlling the resources which are needed to complete the construction order. This is due to the fact that the purpose of mobilization planning is to further optimize the use of materials and the employment/deployment of resource capacities within the construction order. The complexity of this problem can be evaluated based upon the number and diversity of the materials and resource capacities to be used. In situations where there is only a single work crew assignment, coordination is relatively simple and the "mobilization planning" can be carried out for the entire construction order at one time. If the situation is somewhat more complex, e.g., multiple work crew assignments with a limited number and limited diversity of materials and resource capacities, the mobilization planning will generally be carried out separately for each activity representing a group of related work crew assignments. If the situation is extremely complex, then mobilization planning will normally be carried out separately for each individual work crew assignment.
This is summarized in Table 5.4.

<table>
<thead>
<tr>
<th>State of the distinguishing characteristic</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of work crew assignments = 1</td>
<td>Mobilization planning is performed for the whole construction order</td>
</tr>
<tr>
<td>Number of work crew assignments &gt; 1 and many different materials and resource capacities within the construction order</td>
<td>Mobilization planning is performed separately for each individual work crew assignments</td>
</tr>
<tr>
<td>Number of work crew assignments &gt; 1 and a limited number of different materials and resource capacities within the construction order</td>
<td>Mobilization planning is performed separately for each activity (group of work crew assignments)</td>
</tr>
</tbody>
</table>

*Table 5.4: Distinguishing Characteristics for the "Mobilization Planning" Decision Function*

5.5.7 Allocation planning

General description

The "allocation planning" decision function deals with the employment/deployment of resource capacities and the use of materials at the construction site. Proper instruction must be provided to ensure an optimal employment/deployment of resource capacities and an optimal use of materials. The level of instruction required is dependent upon the particular type of work crew. An efficient use of resource capacities implies that the under-utilization of these capacities will be minimized.

Minimizing the under-utilization of capacities can be achieved by controlling the location, time and sequence of the work crew assignments which need to use these resource capacities. Factors such as the type of work crew, the specifications provided to the assigned work crew, production delays and previous experience in carrying out the required operations should also be taken into account.

The following variables are related to the "allocation planning" decision function:
Goal variables

- under-utilized capacity within the work crew

Control variables

- location, time of initiation, time of completion and sequence of operations
- work crew member performing an operation

Independent variables

- type of work crew
- specifications provided to the work crews
- delays in production (of company work crews as well as subcontractors)
- feedback from the construction activities (operational experience)

Variants

The manner in which allocation takes place at the construction site is dependent upon the complexity of the work crew assignments. The complexity of the work crew assignments can be evaluated based upon the distinguishing characteristic previously discussed in connection with the "mobilization planning" decision function (i.e., the number and diversity of materials and resource capacities). An important part of this evaluation is also to consider whether the work crew (or a part of the work crew) needs specific, assignment-related information in order to be able to carry out the required operations. This effectively leads to the specification of an increasing amount of detail.
<table>
<thead>
<tr>
<th>State of the distinguishing characteristic</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>No assignment-related information and only a limited number of different materials and resource capacities are used within the construction order</td>
<td>&quot;Allocation planning&quot; is combined with &quot;mobilization planning&quot; and &quot;project coordination&quot; (since specific work crew assignments and operations have not been identified)</td>
</tr>
<tr>
<td>No assignment-related information, but many different materials and resource capacities are used within the construction order</td>
<td>&quot;Allocation planning&quot; is combined with &quot;mobilization planning&quot; (since specific operations have not been identified)</td>
</tr>
<tr>
<td>Assignment-related information is required to carry out the required operations</td>
<td>&quot;Allocation planning&quot; is carried out separately for each operation</td>
</tr>
</tbody>
</table>

Table 5.5: Distinguishing Characteristics for the "Allocation Planning" Decision Function

The type of work crew dictates whether a work crew needs assignment-related information. It is clear that various types of production units can be identified in the manufacturing industries (see Section 5.3). A similar type of distinction can be made between various types of production units (work crews) in the construction industry. The following types of work crews can be identified:

* **mass production work crews**

These are work crews with established working methods based upon the same equipment each time to make a single type of product, albeit at different locations. Examples of this type of work crew include paving crews, dredging crews and bricklayers. These are permanent work crews, however, the composition of work crew members may be adjusted periodically, irrespective of the construction orders to which they are allocated.

* **batch (series) production work crews**

These are work crews which make batches of similar products using established working methods, whereby the product must meet certain specifications as stated in the construction order. Examples include tunnel form crews in residential construction and finishing crews for renovation work. Batch
production work crews usually have a standard crew size which is independent of the construction orders and can be increased or decreased as necessary to accommodate a specific rate of construction as may be required for the construction order.

* one-of-a-kind production work crews

These are work crews which use established working methods to carry out a wide range of activities. They require construction order-related information for each order. Examples of this type of work crew include the general repair crew and certain carpentry crews. These work crews have a standard size, irrespective of the construction orders.

* final assembly work crews

These are work crews which construct products solely from completed subassemblies. The working methods are established. Specifications related to a particular construction order must be provided as instructions to this type of work crew. An example of this type of work crew would be an assembly crew provided by the supplier of a steel structure.

This type of work crew usually has a standard size, irrespective of the specific construction order. The size of this type of work crew can often be increased or decreased as necessary depending upon the rate at which the construction work needs to be completed.

* unique production work crews

These are non-standard work crews which are called together and instructed as necessary for the purpose of carrying out specific activities. A unique production work crew is often stationed at a construction site for a major portion of the project duration. Various activities are then allocated to this work crew each week. This type of work crew typically carries out a variety of odd jobs in a variety of sectors such as in the commercial building sector, the residential construction sector and the (dry) civil works sector. This type of work crew is also often used for the construction of structures.

Based upon these descriptions of the various types of work crews, it is apparent that "unique production" and "one-of-a-kind production" work crews both need assignment-related information. This implies that the "allocation planning" decision function should be carried out separately for each of the operations within the construction order in these cases.
The different variables (goal, control and independent variables) which are relevant for the various decision functions described in this section are summarized in Table 5.6.

<table>
<thead>
<tr>
<th>Decision function</th>
<th>Goal variables</th>
<th>Control variables</th>
<th>Independent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business planning</td>
<td>- return on investment</td>
<td>- planned sales revenue per market sector</td>
<td>- strategic objectives</td>
</tr>
<tr>
<td></td>
<td>- distribution of revenue</td>
<td>- type and amount of resource capacity in each period</td>
<td>- information concerning order position and positioning in the market</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- feedback from construction order acceptance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- feedback from project coordination</td>
</tr>
<tr>
<td>Resource capacity planning</td>
<td>- optimal amount of resource capacity at minimal cost</td>
<td>- amount and types of resource capacities per period</td>
<td>- data from the business plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- specifications associated with the resource capacities</td>
</tr>
<tr>
<td>Construction order acceptance</td>
<td>- achieving all of the revenue targets as formulated in the business plan</td>
<td>- pricing</td>
<td>- data from the business plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- acceptance or refusal of the construction order</td>
<td>- feedback from project coordination (relevant construction order experience)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- detailed information concerning (potential) orders</td>
</tr>
<tr>
<td>Multi-project planning</td>
<td>- capacity loading percentage</td>
<td>- duration, point in time and location of resource capacities to be employed/deployed (for internal orders)</td>
<td>- resource capacity employment/deployment requirement of the construction order (external or internal)</td>
</tr>
<tr>
<td></td>
<td>- set-up time</td>
<td></td>
<td>- business plan</td>
</tr>
<tr>
<td>Project coordination</td>
<td>- duration of the construction order</td>
<td>- activity sequence</td>
<td>- results of technical work preparation (work crew size, cycle time, construction method, technical relationships between activities, etc.)</td>
</tr>
<tr>
<td></td>
<td>- set-up time</td>
<td>- duration of an activity</td>
<td>- data from construction order acceptance (construction company's order portfolio)</td>
</tr>
<tr>
<td></td>
<td>- minimal costs</td>
<td>- activity initiation and completion times</td>
<td>- data from multi-project planning for the scarce resource capacities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- detailed client information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- feedback from mobilization planning (relevant experience)</td>
</tr>
<tr>
<td>Mobilization planning</td>
<td>Materials:</td>
<td>- sequence of the work crew assignments</td>
<td>- conditions and restrictions imposed by project coordination</td>
</tr>
<tr>
<td></td>
<td>- minimal stock levels (costs)</td>
<td>- location, initiation time and completion time of the work crew assignments</td>
<td>- work crew size</td>
</tr>
<tr>
<td></td>
<td>- minimal transport costs</td>
<td>- size and time of deliveries</td>
<td>- available space at the construction site</td>
</tr>
<tr>
<td></td>
<td>Resource capacities:</td>
<td></td>
<td>- delivery delays</td>
</tr>
<tr>
<td></td>
<td>- minimal employment/deployment costs</td>
<td></td>
<td>- feedback from allocation planning (work crew assignment experience)</td>
</tr>
<tr>
<td></td>
<td>- minimal transport and relocation costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allocation planning</td>
<td>- under-utilized capacity within the work crew</td>
<td>- location, time of initiation, time of completion and sequence of operations</td>
<td>- type of work crew</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- work crew member performing an operation</td>
<td>- specifications provided to the work crew</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- delays in production delays (of company work crews and subcontractors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- feedback from the construction activities (operational experience)</td>
</tr>
</tbody>
</table>

Table 5.6: Goal, Control and Independent Variables for the Various Decision Functions
5.6 Deriving the Different Types of Construction Orders

The identification of variants with respect to the different decision functions described in the previous section provides a basis for drawing the conclusion that the following distinguishing characteristics can be used to determine how the decision functions need to be defined. The range of "values" for determining the state of each of these distinguishing characteristics is indicated in parentheses:

1. scarcity of company resource capacities (scarce [+], not scarce [-])
2. employment/deployment period for company resource capacities (long [+], short [-])
3. number of work crew assignments (one [1], more than one [>1])
4. number and diversity of materials and resource capacities (many [+], few [-])
5. assignment-related information (yes [+], no [-])

It is possible that both "values" of distinguishing characteristic may occur within a single construction order (e.g. both scarce and readily available resource capacities are used in a construction order). In this case, both variants of the decision function will be found.

Based upon these distinguishing characteristics, the situations typically encountered in today’s construction industry can be analyzed. This analysis is based upon the recognized market sectors in the construction industry (the abbreviations to be used are shown in parentheses):

Commercial building (C)
Residential construction (Re)
Renovations (R)
Concrete construction (Cn)
Road construction (Ro)
Dredging (Dr)

A review of each of these sectors was carried out to determine the combinations of distinguishing characteristics typically found in each of these sectors. The results of this review are shown in Table 5.7.
<table>
<thead>
<tr>
<th></th>
<th>Commercial building</th>
<th>Residential construction</th>
<th>Renovations</th>
<th>Concrete construction</th>
<th>Road construction</th>
<th>Dredging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
<td>Re 1</td>
<td>Re 2</td>
<td>Re 3</td>
</tr>
<tr>
<td>Scarcity of company resource capacities</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Employment/deployment period of company resource capacities</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Number of work crew assignments</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Number and diversity of materials and resource capacities</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Assignment-related information</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.7

Explanation of Table 5.7

Each of the aforementioned sectors was analyzed to determine which combinations of distinguishing characteristics are typically found. For example, in the commercial building sector, three different combinations of distinguishing characteristics were discovered. The first variant (listed as C1) is represented by the following combination of distinguishing characteristics:

- regarding the company resource capacities, both scarce and non-scarce resource capacities are found. This means that both variants of the decision function "resource capacity planning" occur (see Sub-section 5.5.2);
- within the construction order, resource capacities may be employed/deployed for either a short or a long period of time; This means that both variants of the decision function are found here (see Sub-section 5.5.4).
- the number of work crew assignments is clearly more than one;
- a large number and wide diversity of materials and resource capacities are found within the construction orders;
- in order to carry out the operations within a work crew assignment, specific information is required.
This combination of values of distinguishing characteristics is subsequently referred to as Type A *(Unique Project)*. Two other combinations were found to exist in the commercial building sector, referred to here as Type B *(Subcontracting Project)* and Type C *(Standard Construction Project)*.

An analysis of the residential construction sector shows that four variants can be identified. The first three variants correspond to the three types of construction orders found in the commercial building sector. The fourth type is a new type which does not occur in the commercial building sector. This type is subsequently referred to as Type D: *Work Order Production*.

The various combinations of the values of the distinguishing characteristics as shown in Table 5.7 render the following five types of construction orders:

<table>
<thead>
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<td>Subcontracting Project</td>
<td>Standard Construction Project</td>
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An important observation and conclusion is that within the traditional division of sectors (residential construction, commercial building, etc.), various approaches to production control can be found. Furthermore, a majority of these different approaches to production control are used in more than one of the traditional sectors!

The required decision structure and management information system for each of these different approaches to production control will be discussed in the following chapter.
6 DESIGN RULES FOR DECISION SYSTEMS AND MANAGEMENT INFORMATION SYSTEMS FOR VARIOUS TYPES OF CONSTRUCTION ORDERS

6.1 Introduction

In Chapter 5, five basic types of construction orders were identified based upon the different production control approaches used.

This chapter discusses the design rules needed to develop the required decision systems and management information systems for the different types of construction orders. A design rule is defined here as being a specific instruction which prescribes how a decision function and the management information system should be developed with respect to the (ideal) types of construction orders identified in the typology.

The design rules are discussed in a specific sequence, which makes it easier to understand the properties of the different types of construction orders. The following sequence has been chosen:

- Work Order Production (section 6.3)
- Mass Production Project (section 6.4)
- Standard Construction Project (section 6.5)
- Unique Project (section 6.6)
- Subcontracting Project (section 6.7)

6.2 Describing the Design Rules for Decision and Information Systems for the Various Types of Construction Orders

6.2.1 Describing the design rules for the decision system

The control situations found within construction orders were identified in Chapter 5. An essential assumption with respect to this typology is that decision functions always exist. It is possible that certain decision functions will be combined with other decision functions.
For each type of construction order, an indication is given of how the decision system can be modelled. If decision functions are shown together, this means that the decision functions are typically combined in practice in such a way that they are not explicitly discernable. The starting point for this discussion is the model presented in Figure 5.2. The variants of the decision functions which are based upon the different states of the distinguishing characteristics are reflected in the modifications to this basic model. An indication is also provided regarding where the responsibility for making the decision is likely to be found in a construction company's organization.

6.2.2 Describing the design rules for the information system

In reference to the design rules for the information system, two aspects are discussed here in more detail: the analysis of data and the automated parts of the information system.

• Data analysis

The aspects of an information system which are relevant for supporting a decision system were discussed in Part 1. The information system may have a dual role in this respect:

1. support in reducing complexity;
2. support in reducing uncertainty.

In order to understand these two roles, the data which is entered into, or generated by, the information system is analysed here for each type of construction order. This analysis focuses on the complexity and uncertainty involved in processing the data. With respect to the aspect of uncertainty, a distinction is made between requirement uncertainty, delivery uncertainty and process uncertainty:

- Requirement uncertainty is defined as the uncertainty with respect to the specification of what is to be constructed;
- Delivery uncertainty is defined as the uncertainty with respect to deliveries to the construction site (time of delivery, quantity, etc.);
- Process uncertainty is defined as the uncertainty of the forecasts regarding the construction work or the uncertainty surrounding status reports regarding the progress of the work.

Based upon this analysis, conclusions are drawn with respect to possible requirements for the (potentially automated) information system.

• Discussion of the automated information system

The decision of whether to automate (parts of) the information system depends upon
a variety of company-related factors such as the number of construction orders in progress, the number of resource capacities and the skill levels of the administrative staff. It is, thus, not appropriate to draw any conclusions in this respect within the framework of an ideal-typical typology. It is assumed here that all of the company-related prerequisites for the successful implementation of an automated system have been satisfied. With this in mind, the envisioned automated systems to be implemented for the respective types of construction orders are described in the following sections.

The automated information systems are described using the methods presented in Chapter 4 of Part 1. For each type of construction order, the general architecture will be reviewed and the various types of applications (transaction processing systems and decision support systems) and their interrelationships will be described. A data model is also presented for each type of construction order.

6.3 Discussion of Design Rules for the "Work Order Production" Type of Construction Order

6.3.1 Where is "Work Order Production" found?

"Work Order Production" is typically found in construction companies which carry out small-scale, simple, well-defined construction orders. Examples include small-scale repair work, small-scale road construction (roadwork, ground work) and small-scale concrete construction (pile-driving, digging culverts). In all of these cases, the work crews normally carry out construction orders independently, without further support.

6.3.2 The decision system for a "Work Order Production" type of construction order

With production based upon work orders, the company's own personnel and equipment is used. This implies that it is difficult to increase or decrease resource capacities on short notice. A properly developed Business Plan is necessary under these circumstances, including the related Resource Capacity Plan.

Control is exercised through the scheduling of construction orders to be completed in the near term based upon available resource capacities. The relevant decision function here is multi-project planning for scarce resource capacities with a short employment/deployment period. All of the construction orders are relatively small and are carried out by one-of-a-kind production work crews which are extremely versatile within their particular field of expertise. The task assignments within these
work crews are more-or-less permanent. The construction order includes sufficient information to allow the construction workers to complete the work without further instructions. This means that the construction order acceptance, project coordination, mobilization planning and allocation planning decision functions can be performed together, at the same time. The construction orders are limited in scope and can, therefore, be communicated in their entirety to the work crews. Since the duration of the construction order is extremely short, it would not be sensible to identify specific activities, work crew assignments and/or operations. This decision structure is shown in Figure 6.1.

---

![Diagram](image)

**Figure 6.1: Decision Structure for the "Work Order Production" Type of Construction order**

The **Managing Director** (occasionally assisted by a **Production Manager**) will be the normal person to make decisions with respect to this type of construction order, particularly in small companies where the decision-maker will normally be the **Owner/Manager**. The department dealing with such small-scale construction works within a large construction company will normally be run by a **Production Manager**.

### 6.3.3 Analysis of the data requirements in a "Work Order Production" situation

**General**

An important basic assumption in a "Work Order Production" situation is the
combination of the four decision functions within the construction order as indicated in the previous sub-section. This means that all of the data to be entered into the information system will be related to the construction order. Within the construction order, no further distinction is made with respect to activities, work crew assignments or operations. Instructions for the construction workers are also provided at the construction order level.

The data which is relevant for this type of construction order includes a specification of the resource capacity/capacities which will carry out the construction order, the (planned and actual) usage of materials, initiation and completion times and the work instructions.

In addition to this data which is to be collected as part of the construction order, other data must be collected at the company level to support the business planning, resource capacity planning and multi-project planning decision functions. The data concerning resource capacities is of particular importance. It can be assumed in this situation that all of the resource capacities are scarce. Furthermore, they will normally be employed/deployed to carry out the entire construction order. In practical terms, this means that there is a link between personnel and equipment; this combination can then be controlled as a single resource capacity (e.g., pile-driving equipment together with the pile-driving work crew, a repair truck with an all-around repairman, a ground work crew). The specifications, charge-out rates, employment/deployment data, reservations, etc. for these resource capacities must also be maintained.

Complexity of the composition of decision information

- Business planning

The information which is required to adequately support the business planning decision function includes the cost and revenue figures for each construction order category. When this basic data is available, the revenues and profit margins can be calculated for each order category. Each company will normally want to define its own classification of the order categories. One approach for this classification is based upon the type of client (private clients, local governments, regional governments, non-profit institutions, etc.).

Based upon the revenues and profit margins for each order category, it is possible to evaluate whether the business targets for the previous planning period have been achieved. This evaluation then serves as a basis for formulating new targets in the
business plan for the coming period.

- Resource capacity planning

The information system must be able to report the key ratios and performance indicators concerning capacity loading percentages in the past. In doing so, a relationship should be established between the order category and the type of resource capacity. When this link exists, the decision-maker can then make effective use of the Business Plan (in which the planned revenue per order category is stated) to decide whether the company should invest in certain new resource capacities and dispose of other resource capacities.

Since the duration of this type of construction order is often extremely short, the management information system must be set up to be able to generate reports frequently during the course of a year. A great deal of flexibility with respect to the frequency of reporting is needed due to the changeable nature of the market for work order production. This also implies that there is a need for a timely warning about changes in the market situation so that the resource capacities within the construction company can be adjusted quickly as may be required.

The resource capacity plan and a business plan are rarely found in practice in companies which are specialized in carrying out a "Work Order Production" type of construction order [Kleijn-1989].

- Multi-project planning for the scarce resource capacities with a short employment/deployment period

For the previous decision functions, the information system's primary function is to process historical data. The generation of a reliable prognosis for the revenue and profit margin per order category, for example, (a goal variable for the "business planning" function) is often impossible due to a variety of external factors.

This situation is different in the case of the multi-project planning decision function for resource capacities with a short employment/deployment period, however. This decision function can be characterized as having considerably less uncertainty with respect to the external factors (independent variables). When it is assumed that certain conditions will remain unchanged (e.g., the resource capacity requirements of the construction orders over a given period of time), the influence of changes in the employment/deployment of resources (such as the duration, time and location) can be calculated. The result of these calculations can be expressed in terms of a new value for the goal variable (capacity loading percentage). This is a good example of an important function of the information system in the second phase of Simon's
decision model (see Part 1, Section 4.3.2).

In cases where there are few resource capacities, the calculation of new values for the goal variables (i.e., the use of simulation studies) is easier to perform than in situations where many resource capacities need to be taken into account. However, even when a company decides not to use a computer to carry out the simulation calculations, certain procedures should still be established and followed in making these calculations. If the decision-maker does not follow established procedures, then he may be influenced by emotional, irrational arguments. Various secondary requirements associated with the construction orders should, of course, also be taken into consideration (such as the desired date for initiating the construction activities).

Due to the short employment/deployment period of the resource capacities resulting from the short duration of this type of construction order, the information system must respond quickly to any changes. The current employment/deployment data must be available, centrally, without delay. This implies that real-time transaction processing may be required in this situation.

- Work order coordination (construction order coordination)

Especially in cases where many construction orders are carried out, work order coordination can be highly complex with respect to data processing. Because of the short project planning and production periods, materials must be available at the required times, for example. A large number of materials may be involved. It would be sensible for a construction company to make provisions to ensure that the materials which are almost always used in connection with each of the resource capacities, are always available. There are also construction order-related materials for which special purchase orders must be issued. The information system should provide for easy access to this information. This can be done by selecting suppliers based upon satisfactory performance in the past with respect to supplying the required products (based upon reliable delivery lead-times). Quotations can normally be obtained and processed quickly in these cases.

Again, because of the short duration of the construction order, it is important for the information system to provide sufficient support in estimating throughput times. Historical data concerning similar construction orders (reference construction orders) should therefore be available for use as performance norms.

**Uncertainty in the decision information**

In general, there is a significant degree of requirement uncertainty with this type of
order. To begin with, these orders are often received from private individuals or municipal government departments who have not documented their requirements in the form of detailed construction specifications. Secondly, the client typically introduces new ideas and changes as the order is being carried out ("do this, too, while you are at it").

The delivery uncertainty for this type of order is usually limited to a number of major purchases of materials (window frames, steel structures, etc.). Many of the materials used are standard and/or bulk materials which are available from the supplier's stock. A problem often seen in this respect is that it is uncertain exactly where the required materials are kept in stock.

In residential work (building dormer windows, hanging doors, etc.), unexpected disruptions and weather conditions will have only a limited adverse effect with this type of construction order. The sequence of outdoor activities and indoor activities can often be changed; a large portion of the activities must be carried out indoors, anyway. For small-scale orders in the civil works sector, however, equipment malfunctions and weather conditions can be extremely disruptive. When the work is not clearly defined, it is often difficult to apply satisfactory standards. Thus, the work often takes longer than expected, and scheduled deadlines may not be met.

When an automated information system is used, this reduces the delivery uncertainty for both residential work and small-scale orders in the civil works sector. For example, a large part of the delivery uncertainty can be eliminated by having on-line access to supplier data bases in which information about the available stock of materials is maintained.

Within the non-automated part of the information system, construction order assessment instructions could be maintained and used to gain improved insights into client requirements (reducing requirement uncertainty). The reliability of quoted delivery dates can also be improved by establishing clearer agreements with suppliers and including a certain amount of slack in the production schedules.

6.3.4 The automated information system for the "Work Order Production" type of construction order

General architecture

The general architecture for the automated information system and the relevant data model for the "Work Order Production" type of construction order are shown in Figure 6.2 and Figure 6.3, respectively. The outer circle of arrows shows the
relationship between the various applications and the decision functions in the "Work Order Production" type of situation. For the theoretical background on the general architecture, see Part 1.

![Diagram](image)

**Figure 6.2: General Architecture for the "Work Order Production" Type of Construction Order**

**State-independent data**

Data must be recorded concerning the scarce resource capacities which the construction company manages. In order to compile a resource capacity plan, it must be known which type of resource capacity the scarce resource capacity is. In
this respect, it is important to consider which data may be required at a later point in time to be able to determine for which construction order category the resource capacity can be used. For this purpose, the data model includes a relationship with the construction order category entity. In order to subsequently guarantee certain
standards of quality for the construction work, it is sensible to maintain standard
instructions and normative construction times for repetitive construction orders.
These instructions are related to the *reference construction order* entity. This last
entity can also be related to construction norms. It is not possible to relate
instructions and standards to the *construction order category* entity. This entity
pertains to a classification of the order categories which is used as the basis for
calculating key ratios and performance indicators needed by the business planning
function. In general, this will be a different classification of orders than the
classification used for deciding when (standard) instructions should be available for
certain construction orders. Another difference is that each *construction order* used
for the "business planning" function is always related to a single *construction order
category*, while in some cases there may be more than one standard instruction
related to a given *construction order*.

Next, data must be recorded which pertains to *suppliers* and *products from
suppliers*; these data could be periodically updated from the external data bases as
previously indicated.

**State-dependent data**

Data must be recorded concerning the *construction orders*. Important in this respect
is the facility for clearly recording the client's wishes (e.g., the date the client
would like the construction to start). This appears in the data model as the
*resource capacity utilization* entity. Both the desired and the actual (scheduled)
construction start date can be included as attributes. For each construction order,
the *material usage* is recorded. Here, too, both the planned or estimated usage and
the actual material usage should be defined as attributes for the *material usage*
entity.

Next, it should be possible to record the *purchase orders* as a possible combination
of the aforementioned *material usage*. The specific point in time at which the order
is called in for delivery (often coinciding with the initiation of the construction
order) is also linked to the purchase order. Finally, work instructions must be
prepared upon the client's requirements in addition to the possible existence of
standard work instructions (*reference construction order*). Naturally, it is also
important that data concerning the construction process be recorded. However,
this data is not maintained for the purpose of operational control. The duration of
the *construction orders* may be so short that adjusting the process based upon
production data would be impossible. This data is used, instead, for invoicing, for
setting improved norms in the future (based upon *reference construction orders*) and
as a basis for a future analyses to be carried out by the business planning function.
(revenue and profit margins).

In order to meet the extremely important minimum throughput time requirement as discussed previously, small hand-held computers could be used at the construction site, for example, to carry out multi-project planning. Periodically (each day, for example, or upon completion of the construction order), data could be transmitted to a central computer system.

Decision support

The data analysis discussed in Section 6.3.3 indicates that the automated information system should support the decision-maker in: selecting suppliers, evaluating the loading percentages for the scarce resource capacities and optimizing the utilization of scarce resource capacities.

- selecting suppliers

A decision support application for selecting suppliers may expedite the selection process considerably. By maintaining data about supplier delivery performance and the supplier products, the system can indicate which suppliers might be preferred over others based upon a number of selection criteria. This means that the frequent and reliable exchange of product data should take place with the various data bases of the suppliers or groups of suppliers. Making agreements with suppliers about the use of Electronic Data Interchange (EDI) could be an attractive option in this respect.

- evaluation of resource capacity loading

The decision function "resource capacity planning" produces a resource capacity plan which schedules investments and divestments in such a way that the company will have access to sufficient quantities of the required production resources for the coming period. The information system records operational data, on the basis of which key performance indicators can be calculated to support the "resource capacity planning" decision function. The data referred to in this respect is the capacity utilization data on the basis of which loading percentages can be calculated for the scarce resource capacities. These capacity loading percentages provide an important basis for decision-making.

- optimization of the loading of scarce resource capacities

An automated information system can play an important role in supporting the "multi-project planning for scarce resource capacities" decision function. The
purpose of this type of application is to optimize the allocation of scarce resource capacities to construction orders while satisfying the conditions and restrictions imposed by the construction orders (e.g., resource capacity requirements within a certain period of time).

Techniques have been developed in the field of operational research to solve this type of optimization problem. Linear programming is one of the best-known and widely-used methods. Elements of this technique could be included in the application envisioned here.

6.4 Discussion of Design Rules for the "Mass Production Project" Type of Construction Order

6.4.1 Description of the "Mass Production Project" type of situation

This type of production is seen in the dredging sector. All of the construction orders of this type consist of the same activities. Heavy, extremely expensive equipment is used.

6.4.2 The decision system in the "Mass Production Project" type

In terms of control, emphasis is placed on good business planning and workload control. Not only does the acquisition of this type of construction order take a considerable amount of time, but the location of the equipment must be considered carefully since the effort required to relocate the right equipment to the right place is a significant factor in the cost price. (Multi-project) planning of the resource capacities therefore takes place at the construction order level. In principle, since mass production units are used, instructions for carrying out the production could be conveyed in the form of a construction order (the distribution of individual work assignments is standardized). Due to the long duration of this type of order, however, it is sensible to define specific activities with shorter throughput times and separate instructions.

Project coordination, mobilization planning and allocation planning are combined in this case.

The decision structure is shown in Figure 6.4.
The typical decision-makers in this type of situation are the Managing Director (for the business planning, the resource capacity planning and construction order acceptance functions), the Project Manager who monitors the progress of activities at the construction site (which is often far from the company offices) and the Projects Coordinator at the office who calls in materials, subcontractors and any other resource capacities as required.

6.4.3 Analysis of the data requirements for a "Mass Production Project" construction order

General

Comparing the decision structure for the "Mass Production Project" type of construction order with that for the "Work Order Production" situation as discussed in the previous section shows only one important difference: control decisions are
made at more levels within the construction orders here. The implications for the data model are that the construction order is conceptually split up into various activities. This means that the material usage, for example, are no longer related to the construction order, but are instead related to the individual activities within the construction order.

However, the number of different materials required for each activity is extremely limited in the "Mass Production Project" type of situation.

As with "Work Order Production", the utilization of scarce company resource capacities is related to the construction order. As a result, the throughput time for the construction order is determined primarily by the resource capacities employed. Sometimes, auxiliary equipment is needed for certain construction orders. Employment of these resource capacities is therefore related to the activities.

*Complexity of the composition of the decision information*

- business planning, resource capacity planning and multi-project planning

The data required for decision-making in this case is basically the same as the data in the "Work Order Production" type of construction order. A difference in this situation, however, is that resource capacities with an extremely long employment/deployment period (of months or even years) are used. The information system need not react as quickly as in a "Work Order Production" situation.

- construction order acceptance

Construction order acceptance (deciding whether the work should be accepted and, if so, at what costs and when) is also relatively simple. The project can be divided into simple activities, for which standards (costs and time) are defined. An additional consideration is the availability of the required scarce resource capacities within a given period of time.

- project coordination, mobilization planning, allocation planning

The project schedule and project budget which was prepared on the basis of the various activities defined as part of the construction order acceptance function, can be finalized at this stage. The materials and resource capacity requirements can also be determined. In comparison with the "Work Order Production" situation, this is relatively simple. The required materials are usually not specific, making it easy to prepare the purchase order. This also implies that it is not necessary to have on-line
access to extensive amounts of (historical) data concerning the suppliers and their products. In addition, due to the long duration of this type of construction order, there is sufficient time for ordering (extra) resource capacities and the related administrative processing.

Uncertainty in the decision information

There is virtually no requirement uncertainty in this situation. The activities are normally defined precisely as part of the construction specifications. Delivery uncertainty is primarily caused by the fact that there may be a considerable distance between stock locations. Whenever equipment becomes defective or new work is initiated, this typically has far-reaching consequences for the availability of equipment. Process uncertainty with this type of order is basically due to the risk of equipment malfunction. Standards are based primarily upon the type of soil, geological situation, etc.

6.4.4 The automated information system in the "Mass Production Project" type of construction order

*General architecture*

The general architecture and the data model for the "Mass Production Project" type of situation are shown in Figure 6.5 and Figure 6.6, respectively.
State-independent data

The "Mass Production Project" type of situation is similar to the "Work Order Production" situation as previously discussed with respect to the state-independent data requirements and types of data entities related to the control of the scarce resource capacities (type of resource capacity, scarce resource capacities).
Due to the nature of this type of work in which different activities can be clearly distinguished, no data related to past experience is maintained at the construction order level. In the case of a "Mass Production Project", this data can be recorded as a reference activity. In general, in a master project plan, the activities will be divided in such a way that experience data is available for the various activities. This will normally be sufficient for calculating the expected duration of construction order, for example.

Reference data concerning suppliers need not be maintained. Materials are readily
available in each (different) local situation.

**State-dependent data**

At the *activity* level, data should be maintained with respect to the estimates incorporated in the work plan and the actual work progress in terms of both costs and time. Because supplier data (and experience) is not recorded as such, the name of the supplier (and when materials and resources are called in) is directly related to the *material usage* and *resource capacity requirement* entities. An even simpler structure could be defined by combining the *material usage* and *resource capacity requirement* entities to create, for example, a new "resource requirement" entity. The manner in which data is used is basically the same for both types of resources. In fact, the duration of all of the activities is defined by attributes associated with the *scarce resource capacities* entity.

The employment of the company's *scarce resource capacities* is recorded by means of the *resource capacity utilization* entity. In general, this will occur at the construction order level. In a number of cases (for example, when auxiliary equipment is required), there will be a relationship with a lower level entity: an *activity*.

**Decision support**

The data analysis presented in Section 6.4.3 indicates that the automated information system should provide support for evaluating the loading percentages for scarce resource capacities, optimizing the utilization of scarce resource capacities and scheduling activities.

In principle, evaluating loading percentages and optimizing the utilization of scarce resource capacities can both be implemented in the same way as in a "Work Order Production" situation. An important difference, however, is the fact that resource capacities in the case of a "Mass Production Project" are employed/deployed for extremely long periods of time. This implies that an information system for this type of construction order will not have the same stringent response time requirements. Simple procedures (not necessarily automated procedures) can be used to keep track of the status of the data processing.

In reference to scheduling activities, the system should be able to calculate the effect of various resource employment/deployment alternatives on the order throughput time. However, it should be noted that due to the simplicity of this
type of construction order, an automated system could be experienced as more of a hinderance than an asset in some situations.

6.5 Discussion of the Design Rules for the "Standard Construction Project" Type of Construction Order

6.5.1 Where is a "Standard Construction Project" found?

This type of production situation is found, for example, in residential construction, commercial building construction, renovation work and road construction orders. This type of construction order typically makes use of experienced and efficient mass production or batch production work crews. The work crews are generally employed only for a limited part of the construction order. In residential construction, for example, separate work crews are employed for the structure, the prefab inside wall sections, roof construction, installation of sanitary facilities, etc. Road construction projects typically utilize ground work crews, asphalt paving crews and equipment operators.

6.5.2 The decision system in the "Standard Construction Project" type of construction order

A primary characteristic of this type of construction order is that activities are defined which are of a repetitive nature. Based upon the business planning function, a resource capacity plan is produced. The actual resource capacity requirement for scarce resource capacities within this type of project is known only a short period of time before the resource capacity is needed. The period of employment/deployment of the scarce resource capacities is extremely short in comparison to the total throughput time of the related activities. If the company does not have the required resource capacity, it is subcontracted. In addition to multi-project planning at the construction order level, this planning function is also found at the mobilization planning level.

An important difference between this type of construction order and the "Work Order Production" and "Mass Production" situations can be seen in the form of a higher degree of complexity within the construction order. There are more and different types of activities and, similarly, more and different types of work crews and materials involved. As a result, this complex situation implies that more attention should be devoted to mobilizing workers, equipment and materials. This leads to a clear distinction between the decision functions "project coordination" and
"mobilization planning" in the decision structure.

The decision diagram is shown in Figure 6.7.

![Decision Structure Diagram](image)

**Figure 6.7: Decision Structure for the "Standard Construction Project" Type of Construction Order**

6.5.3 Analysis of the data requirements for a "Standard Construction Project" construction order

**General**

In comparison with the two previous types of construction orders, the data recorded in the information system differs with respect to two important aspects.

In the first place, the information system must be able to distinguish between different categories of resource capacities. A classification which distinguishes
between scarce resource capacities and non-scarce resource capacities is required. A second distinction must also be made within the category of "scarce resource capacities" between (scarce) resource capacities with a long employment/deployment period and those with a short employment/deployment period.

The second difference in comparing a "Standard Construction Project" with the two previous types of construction orders is the definition of multiple decision levels within a construction order. Because of this distinction, data must be related to three entity types: the construction order, activities and work crew assignments.

*Complexity of the composition of the decision information*

- Business planning, resource capacity planning for scarce resource capacities and construction order acceptance

With respect to these decision functions, the information system should provide the same support as for the types of construction orders discussed previously.

- Multi-project planning for scarce resource capacities with a long employment/deployment period

In the case of a "Standard Construction Project", the scarce resource capacities with a long employment/deployment period pertain primarily to personnel. Examples include project managers, construction workers and project planners. The relevant data is not particularly complex; it can be recorded using a simple procedure. Based upon this data, various employment/deployment alternatives can be evaluated. In general, there will be little or no scarce equipment with a long period of deployment in this type of construction order.

- Multi-project planning for scarce resource capacities with a short employment/deployment period

The data structure for the multi-project planning function for scarce resource capacities with a short employment/deployment period is much more complicated than in the case of this same function applied to the scarce resource capacities with a long employment period. This is caused primarily by the high frequency at which changes take place, similar to the "Work Order Production" type of construction order. Moreover, the high degree of uncertainty with respect to the conditions and restrictions stipulated by the projects (refer to the discussion of uncertainty) complicates matters even more.
- Multi-project planning for readily available resource capacities

The complexity of this planning function is dependent primarily upon the number of changes. Actually, this function cannot really be considered as true multi-project planning since no attempt is made to optimize the employment/deployment of readily available resource capacities across multiple construction orders. The information system should provide data regarding the availability of resource capacities (which generally refers to equipment capacities). If the resource capacities required for a certain project are not available, they must be subcontracted. The information system can provide support here which is similar to the support provided for inventory control for materials. One difference, however, is that the information system should keep track of when certain equipment should return from a project in this case.

- Project coordination

A large amount of data is required for the "project coordination" decision function for the "Standard Construction Project" type of construction order. This data should be related to activities. The scope of the projects and the diversity of the utilized resource capacities and used materials imply that a large number of different disciplines will generally be involved in the projects. The exchange of information must be based upon adequate procedures, for example, when recording the progress of the project, project costs and project man-hours spent. In practice, this data is often supplied by a number of different departments, adding to the complexity of the data management problem.

Due to the standard nature of this type of construction order, the company normally will have built up a large data base of relevant knowledge and experience. The information system should be capable of recording and maintaining this data. In addition, the information system should have provisions for storing detailed data regarding experience acquired within a construction order. Within this type of project, a batch of repetitive activities often can be identified. There will normally be a provision in the system for entering key data (e.g., batch cycle times, man-hours) upon the completion of each cycle of a project step (e.g., completion of one floor of a building or a section of road). Subsequently, the system should be able to provide indications of how the production statistics compare with the established norms for this type of construction order.

It is useful to monitor the progress and performance of the construction orders in this way in view of the fact that the throughput time of the construction order is generally quite long. In this way, adjustments can normally be made during the course of the project (as opposed to a "Work Order Production" type of construction order). A
useful comparison of actual versus budgeted costs can also be made with this type of project due to the high degree of standardization and uniformity in the production process.

Entering and maintaining data concerning the material and resource capacity requirements can also be relatively complicated. Here, too, the company will have acquired experience with certain suppliers or subcontractors. The information system should provide easy access to this data so that suppliers and subcontractors can be evaluated and selected efficiently.

- Mobilization planning / Allocation planning

The information system must also process a large amount of data in connection with these functions. This is due primarily to the large number of call orders, work crew assignments and work crews. The information system should play an important role in indicating the restrictions and conditions in developing project schedules and work crew assignments (the availability of work crews and their composition, etc.).

**Uncertainty in decision information**

There is virtually no requirement uncertainty in this case. In general, the work is precisely defined in the construction specifications. Product data will not change significantly during the course of the project. The results of the technical work preparation function are normally clear and unambiguous.

The uncertainty of the availability of the company's own equipment and assembly crews plays an important role. This is primarily due to the fact that delays may occur in other projects as a result of, for example, weather conditions or transport problems. The effect of these kinds of interruptions is often significant since the resource capacity is often only used for a few hours or a few days at a time (the ratio of delay time to employment period is extremely high). The information system should help in reducing this uncertainty. This can be achieved by improving the manner and speed of reporting disturbances (regardless of whether an automated system is used).

Process uncertainty with this type of order is primarily caused by adverse weather conditions. Another contributing factor in the road construction industry is equipment malfunction (due to the heavy reliance on equipment in this type of work).

The multi-project planning for scarce resource capacities with a short employment/deployment period is directly affected by the process uncertainty in the
construction orders. In other words, it is not known precisely when a construction order will need a specific resource capacity. Scheduling is carried out with a limited planning horizon, taking the most recent information pertaining to the construction orders into consideration.

It is doubtful whether an automated system will always be effective in this type of situation since it is sometimes better to prepare work schedules, manually, while consulting with the project managers responsible for the various construction orders. This makes it possible to use the most recent information and to include estimates at the same time. An automated system in this situation would provide support only with respect to recording the data.

6.5.4 The automated information system for a "Standard Construction Project" type of construction order

*General architecture*

The general architecture and the related data model for the "Standard Construction Project" type of construction order are shown in Figure 6.8 and Figure 6.9, respectively.

In comparison with the "Work Order Production" and "Mass Production Project" types of construction orders, a number of aspects have been added or changed in the general architecture and the related data model. These modifications are discussed in the following paragraphs.

*State-independent data*

The collection of state-independent data at the company level pertains to recording the basic data concerning the company's resource capacities. In a "Standard Construction Project" situation, a distinction must be made between *scarce resource capacities* and *readily available resource capacities*, and also between *scarce resource capacities with a short employment/deployment period* and *scarce resource capacities with a long employment/deployment period*. This distinction is important since different data elements must be recorded for each of these entity types. These resource capacities must also be recognizable in the total group of company resource capacities because they are used by different decision support applications. Since only the scarce resource capacities are included in a *resource capacity plan*, there is no relationship between the *type of resource capacity* entity and *readily available resource capacities*. 
Figure 6.8: General Architecture for the "Standard Construction Project" Type of Construction Order

In addition to the basic data concerning resource capacities, a further characteristic of the "Standard Construction Project" type is the large amount of state-independent data which is normally maintained pertaining to experience from projects carried out in the past. This data base of knowledge and experience (including norms) can be maintained at various levels. As a result, the data model distinguishes between reference construction orders, reference activities and reference work crew assignments. If a model for cost calculations is combined with these reference standards, then it is possible to plan and budget for this type of construction order with a high degree of accuracy. Another important aspect is that a reference work crew assignment can be linked to standard work crew instructions.
Figure 6.9: Data Structure Diagram for the "Standard Construction Project" Type of Construction Order
State-independent data can subsequently be recorded concerning various construction site workers who are allocated to a work crew by the "mobilization planning" decision function.

Finally, state-independent data should be recorded concerning suppliers (including subcontractors) and their products. As before, this is useful due to the repetitive nature of the construction order. Supplier performance and reference information is maintained in order to be able to evaluate the experience with supplier or subcontractor in the past, whether deliveries were made on schedule, whether the quality was up to standard, etc.

In summary, it can be concluded that a relatively large amount of state-independent data can be recorded in the "Standard Construction Project" type of situation. As a result, the construction order and its component parts can be planned and controlled with a relatively large degree of certainty.

State-dependent data

The registration of state-dependent data at the company level pertains to the status of the company's various resource capacities. Control here implies having information about where equipment is located, whether certain units of equipment are currently undergoing maintenance, are reserved or are available, etc. Reservations are especially useful in situations where scarce resource capacities with a short employment period are utilized since the actual point in time when these capacities will be needed is known only at the last minute.

Historical loading statistics should be recorded for each of the various resource capacities. State-dependent data is also recorded at the company level for construction orders which are in progress or are planned.

Within a construction order, state-dependent data should be recorded concerning activities, activity relationship, material usage, resource capacity requirements and purchase orders (resource capacity purchase orders and material purchase orders). It is also important that the system be capable of recording data regarding the past experience in carrying out activities (refer to the data analysis discussion). Due to the repetitive nature of the activities, the experience gained in performing the activity for the first time (bricklaying in block 1, for example) can be used as the basis for planning the same type of activity in the remainder of the project. In the data model, this is referred to as the standard order activity entity.
The fact that the *purchase orders* (unlike the situation with a "Mass Production Project") are registered separately (and not as an attribute of the *material usage* entity) is a result of the fact that it must be possible to record various material usages (possibly even for various activities) in a single purchase order (per supplier).

Because it is not always sensible to deliver all of the materials ordered (or the ordered quantity of a resource capacity) to the construction site at once, the information system must recognize the *material call order* and *resource capacity call order* entities as the relationship between the *work crew assignment* and the *purchase order*.

Data should also be recorded concerning the *work crews*.

**Decision support**

In reference to decision support, a variety of applications can be envisioned within the "Standard Construction Project" type of construction order: evaluating loading percentages, optimizing the usage of scarce resource capacities, inventory control for readily available resource capacities, time and cost scheduling and determining and scheduling work crew assignments and call orders.

To the extent that they differ from the previous types of construction orders, these applications are described below.

1. *Optimizing the usage of scarce resource capacities*

This kind of automated decision support was already discussed in connection with the "Work Order Production" type of situation. The difference in the "Standard Construction Project" type of situation here is that a distinction is made between scarce resource capacities with a long employment/deployment period and scarce resource capacities with a short employment/deployment period. The requirements placed on the applications will, therefore, also differ. With the short employment period, the system must take factors into account which include reservations. The optimization algorithm will be the same. The information system should also respond more quickly in order to be effective. In practice, this means that an automated system will often be used to support the control of resource capacities with a short employment/deployment period.
2. Inventory control for readily available resource capacities

This application ensures that sufficient resource capacity is available on short notice based upon the usage data for readily available capacities and the expected resource capacity requirements for activities within a construction order. This means that if the amount of available resource capacity threatens to drop to zero, this type of resource capacity will automatically be purchased or hired in. If the "stock levels" of the resource capacity are much too high, it is also possible that excess resource capacity will be divested.

The basis for this kind of application is similar to the rules traditionally used for inventory control. Techniques from industrial engineering used in this field can also be applied to the construction industry (see, for example, [Bertrand et al., 1990,b] or [Damen-1989]).

3. Time and cost scheduling

In the "data analysis" section, it was explained that there is little uncertainty concerning the object to be constructed and the construction process to be used. Mass production work crews were used since the production method is well-defined and reliable production norms are known (in the form of reference activities and reference work crew assignments). As a result, in this type of project (for road construction or batch residential construction, and also for high-rise building construction projects) an attempt is made to simulate a batch production situation. An optimization technique which the project coordination can use for this purpose is the "line-of-balance" method [Pilcher-1992]. The basis for this technique is the completion schedule (the number of homes, number of floors or number of meters to be finished each week). Based upon this schedule and the definition of a network plan for constructing a single component (one home, one floor, one section of road), the algorithm can be used to develop an optimal schedule. The "line-of-balance" method is similar to the "time-result diagram" (in Dutch: tijd-weg diagram) used in the Dutch road construction industry.

3. Determining and scheduling work crew assignments (combined with call orders for the work crews)

This refers to a decision support system which helps to determine which activities should be split up into multiple work crew assignments on the basis of the activity plan and the related capacity requirements. The system must take the designated due dates into consideration and arrive at a proposed call-up schedule for the required materials and a work crew assignment schedule. With the work crew assignment schedule, the system should be able to propose a solution which
6.6 Discussion of the "Unique Project" Type of Construction Order

6.6.1 Where is a "Unique Project" found?

This type of construction order is found primarily in large scale commercial building projects, residential construction projects and concrete construction projects (see Table 5.7).

Personnel employed by the company as well as subcontracted workers are used in these projects. The production process is comprised of a large number of different activities, sometimes exhibiting slight repetitive nature. The company supplies the management for organizing the production activities. Considering the scope of the projects, the management resources must be highly experienced and are, thus, scarce. In addition, readily available capacity resources are used (such as work crews and equipment which can be quickly hired in).

6.6.2 The decision system in the "Unique Project" type of construction order

With respect to a "Unique Project" type of situation, all of the decision functions discussed in Sub-section 6.5.2 are also seen here in one form or another.

Because all of the different types of capacity resources are used (scarce, readily available, short period, long period), the multi-project planning function for resource capacities occurs in several different forms, similar to the "Standard Construction Project" type of situation.

The primary difference with the "Standard Construction Project" type of construction order is the unique character of the projects here. As a result, the orders are complex and typically have a long period. This implies that it is important to have adequate project coordination in which the relationships between the activities, their progress, the consequences of malfunctions (in terms of both time and costs), etc. are accurately monitored. It is virtually impossible to coordinate activities without using network techniques (refer to the discussion of traditional project management methods).

Due to the large number of activities with many different work crews (including the frequent use of subcontractors) and the many different materials which are used,
considerable attention must be devoted to mobilizing people, equipment and materials. In this type of situation, a large number of the work crew assignments are released (i.e., the mobilization planning function releases the materials, equipment and work crews for activities) before the detailed activity assignments have been made with respect to the individual construction workers in the work crews. In addition to this, instructions must still be issued concerning the specific operations to be carried out (allocation planning is, therefore, related to the operations).

The decision system is shown in Figure 6.10.

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**Figure 6.10: Decision System for the "Unique Project" Type of Construction Order**

A large number of decision-makers are involved in a "Unique Project" situation. Business planning, construction order acceptance, resource capacity planning for
scarce resource capacities and multi-project planning are the responsibility of Management. If the scarce resource capacities involve equipment, the "multi-project planning" decision function is carried out by the Maintenance & Storage Yard. Decisions concerning project coordination are made by the Project Manager (assisted by a Production Planner). Decisions concerning mobilization are made by the Chief Foreman, while allocation decisions are made by the Foreman.

6.6.3 Analysis of the data requirements for a "Unique Project" construction order

General

The kind of data which must be collected for a "Unique Project" construction order is basically the same as for the "Standard Construction Project" type of situation. The primary difference is that a distinction is made between operations within a work crew assignment (due to the presence of the "allocation planning" decision function).

Complexity of the composition of decision information

The composition of the decision information needed in connection with the "business planning", "resource capacity planning for scarce resource capacities", "multi-project planning for scarce resource capacities" and "construction order acceptance" functions is the same as the information needed in the "Standard Construction Project" type of situation.

However, the situation within this type of construction order is highly complex due to the fact that a large amount of the information is unique. Various disciplines are involved in collecting and processing this information; proper information exchange procedures are therefore required. Because multiple construction companies are often involved in projects of this type, the situation is often highly complex. The various data processing activities may be carried out by personnel from the different consortium partners (at various locations).

In the most extreme situation, a separate company (e.g., partnership) may be created which functions as an independent company. In the area of automated data processing, a completely independent system (including a variety of application modules) is often implemented.

Uncertainty in the decision information

Uncertainty with respect to the decision information is an extremely important factor
in the "Unique Project" type of situation. An extensive discussion of this uncertainty is therefore warranted.

Requirement uncertainty

For commercial building projects and civil works as well as residential construction projects, the requirement uncertainty is often extensive in this case. In projects in the commercial building sector, requirement uncertainty is seen during the construction of the structures as well as during the finishing stage. This uncertainty is usually caused by the fact that the client changes the specification of his requirements numerous times, sometimes in reference to specific requests and demands from tenants, which are not known until after construction activities have started. This uncertainty is often seen in the form of various changes to the construction specifications, which often lead to problems and mistakes in carrying out the construction activities. The best approach to follow is to ensure that construction plans are kept up-to-date and are always feasible, making it possible to clearly show the client the results of any last minute changes and decisions.

With large-scale civil works, the cause of the requirement uncertainty is often due to technical problems and inconsistencies. The technical design is often unfinished when construction starts due to a lack of technical knowledge and experience. Requirement uncertainty is seen in all construction phases and is typically reflected in numerous changes to the construction drawings. Requirement uncertainty in concrete construction due to technical problems can be reduced by taking more time to complete the engineering activities. These activities should also be properly scheduled and monitored; sufficient slack should be included depending on the technical complexity.

Requirement uncertainty in large-scale residential construction is primarily seen during the finishing stage. This requirement uncertainty is prevalent when home buyers are allowed to choose between a large number of finishing options. Often only general information is available. In order to reduce the requirement uncertainty in residential construction, a solution can be sought in both the automated and non-automated parts of the information system. The timeliness of information can be improved by clearly indicating the point in time (in the production schedule) when changes can no longer be accepted for each of the options (from the production point of view). In the interest of client service, this should be indicated for each possible option. In current construction practice, often only a single final decision date is given. When the decision time is not the same for all of the possible options, "flexibility after the fact" is often seen ("we'll take care of that"). However, promises are sometimes also made for options for which the true final decision date has already passed. Additional demands are then placed on the automated information
system to improve the reliability of the recorded information.

**Delivery uncertainty**

Delivery uncertainty is seen in commercial building and residential construction projects. In both cases, large quantities of various materials are used which are order-specific, even though they are based upon standard products. If the supplier delivers too little or too late, considerable delays may be incurred. In addition to delivery uncertainty for materials, delivery uncertainty involving subcontractors plays an important role. Because subcontractors are employed to a large extent for both large-scale commercial building projects and large-scale residential construction projects, and there is always a risk that such subcontractors will fail to fulfill their obligations, this uncertainty is an important factor. Solutions can be sought in increased slack in scheduling, which will in turn increase the reliability of the delivery dates.

**Process uncertainty**

Process uncertainty is sometimes seen in the structure construction phase of commercial or residential construction projects (in particular due to cold weather conditions). This uncertainty is much more common in concrete construction, first of all, because concrete construction always takes place out-of-doors. Secondly, access to the construction sites may often be poor.

Another kind of process uncertainty is caused by the fact that a number of expensive, critical resource capacities are used (such as large tower cranes or elevators) which are not easily replaceable. It is difficult to find a quick solution for a malfunctioning crane.

It is almost impossible to resolve the problem of unreliable norms in the commercial building sector by referring to previously completed projects since the construction orders in this sector vary significantly. However, some results can be achieved in this respect by devoting more time to preliminary studies and the preparation of accurate work schedules for the critical activities. In residential construction, unlike commercial building construction, norms can be improved in a number of situations if the information system functions properly. When the activities for various construction orders are similar (placing a roof, installing a kitchen, etc.), the collection of accurate data and proper cost calculations can result in significant improvements. This is also applicable to construction orders in the concrete construction sector.
6.6.4 The automated information system for a "Unique Project" type of construction order

General architecture

The general architecture and the relevant data model in a "Unique Project" type of situation are shown in Figures 6.11 and 6.12, respectively.

Figure 6.11: General Architecture for a "Unique Project" Type of Construction Order
Figure 6.12: Data Structure Diagram for a "Unique Project" Type of Construction Order
State-independent data

A major portion of the state-independent data to be collected in this case is the same as for the "Standard Construction Project" type of situation. A major difference, however, lies in the fact that only a few reference norms are available (due to the unique character of this type of construction project). As a result, within the state-independent part of the data model, the reference construction order, reference activity and reference work crew assignment entities are not used.

However, the reference operation entity does appear in this model. An operation is an action carried out by an individual work crew member for which an instruction is normally prepared. Useful information can only be obtained and recorded at this extremely detailed level. Even then, a norm may be partially dependent upon a particular situation. This is the reason for defining the operation category entity in this model. This makes it possible to determine various norms for a certain operation (installing a kitchen, for example). This essentially defines an particular area in order to restrict the applicability of this type of norm.

For each reference operation, a standard instruction can also be recorded. This is another difference in comparison with the "Standard Construction Project" type of situation which arises due to the fact that instructions are not given to the entire work crew. Within a unique project, the information is task-related; instructing the entire work crew would not be appropriate. The information system must be able to maintain work instructions for each operation.

State-dependent data

Here, too, the same basis is seen as for the "Standard Construction Project" situation, with the additional data being collected at the operation level. Thus, the operation and operation relationship entities appear in this data model. A relationship is also defined between a work crew member and an operation.

Another difference in comparison with the "Standard Construction Project" type of situation is that there is no standard order activity entity. It is not possible to effectively use experience within the construction order at this level.

Decision support

In reference to decision support, a variety of applications can be envisioned to support a "Unique Project" type of construction order. These applications are the same as those for standard construction projects with the exception of three components:
1. Time and Costs Scheduling

Applications which serve to support the decision function "project coordination" have been discussed in detail in previous studies. In the case of the "Unique Project" type of situation, where a wide variety of different activities with a large number of interrelationships need to be scheduled, the network technique can be used (unlike situations of the "Standard Construction Project" type). In the past, two basic groups of methods for network planning have been developed:

1. Activity-on-the-arrow

With this group of methods, activities are represented by arrows which are connected at the nodes. Well-known examples of methods from this group are CPM (Critical Path Method) and PERT (Program Evaluation Review Technique).

2. Activity-on-the-node

Activities are represented by nodes; the arrows are used to determine the sequence of the activities.

In view of the fact that more than thirty years have passed since these techniques were initially developed, numerous studies have been carried out concerning their applicability. These studies brought the advantages and disadvantages of network techniques, in general, to light. The advantages of using each of the individual techniques have been highlighted, in particular. Generally speaking, the second group appears to provide a number of additional advantages [Pilcher-1992, Houten-1970]. The primary advantages pertain to the fact that the case of Activity-on-the-node, no dummies are needed for scheduling slack. Since slack is important in the case of the "Unique Project" type of situation as discussed above, applications which support the Activity-is-node method would be the most logical choice. After recording the duration of an activity, the relationships between the date of commencement and date of completion and the desired slack, a detailed activity plan can be generated.

2. Levelling resource capacities

The required resource capacities (equipment and personnel) can be linked to the activities. As a result, an overview of the planned loading and duration can be obtained for each resource capacity. This can also be reasoned the other way around: within a certain period of time, certain quantities of equipment and personnel are available. The application of resource allocation algorithms enables the system to find an optimal relationship between activities and resource
capacities (load scheduling). This was originally lacking in the network technique methods, but the addition of such resource allocation algorithms resolved this shortcoming to a significant degree [Moder et al., 1983].

3. Allocation of operations and sequencing

In order to allocate work crew members to operations, it is theoretically possible to use the same techniques as previously indicated for multi-project planning (linear programming). Once the operations to be carried out by each individual work crew member are known, theoretical and technical methods can be used to determine the sequence of the operations, i.e., the sequencing. Considerable experience has been acquired with these methods in other sectors of industry [Bertrand et al., 1990b]. This technique is not totally unknown in the construction industry [Pilcher, 1992], but in our view, these methods are too rigid to be of practical use in a construction situation. A good foreman will be much more capable of determining both the allocation and the sequence of operations, taking a variety of social factors into consideration, as well.

6.7 Discussion of the Design Rules for a "Subcontracting Project" Type of Construction Order

6.7.1 Where is a "Subcontracting Project" found?

Construction orders of this type are seen primarily in commercial building projects and residential construction projects. The scope and complexity of the projects are such that almost all of the required personnel (both staff and construction workers) as well as the necessary equipment must be hired in. This means that the projects are either smaller and less difficult, with a limited throughput time, or extremely large with such a long throughput time to the extent that a new company (often a consortium formed by existing companies) is needed for the sole purpose of realizing the construction order.

In the case of smaller construction orders with a shorter throughput time, the projects are typically carried out by companies striving to be highly flexible. They expand their production capacity or curtail it, according to the economic situation.
6.7.2 The decision system for a "Subcontracting Project" type of construction order

The primary difference between this type of construction order and the "Unique Project" type as discussed previously, is that there is no company level with regard to resource capacity allocation. Absolutely no consideration is given to other projects (construction orders). Otherwise, construction orders of this type would not differ significantly from those of the "Unique Project" type.

The decision structure is shown in Figure 6.13.

![Diagram showing the decision structure for a "Subcontracting Project" type of construction order]

*Figure 6.13: Decision Structure for a "Subcontracting Project" Type of Construction Order*

The typical decision-makers in this situation are the Management for construction order acceptance, the Project Manager for project coordination, resource capacity
planning and multi-project planning, the Chief Foreman for mobilization planning and the Foreman for allocation planning.

6.7.3 Analysis of the data requirements for a "Subcontracting Project" construction order

The primary difference between a "Unique Project" type of construction order and a "Subcontracting Project" type of situation is the fact that there are no company-related decision functions with respect to resource capacity allocation in the latter case. The various multi-project plans are not needed here. Within the construction order, the situation is similar to projects of the "Unique Project" type, while some "Subcontracting Project" instances also show a number of characteristics of the "Standard Construction Project" type of situation, such as the use of norms at the activity level and work crew assignment level. The latter is a result of the fact that similar, repetitive activities can often be identified across a number of projects.

6.7.4 The automated information system for a "Subcontracting Project" type of construction order

General architecture

The general architecture and data model for a "Subcontracting Project" type of construction order are shown in Figures 6.14 and 6.15, respectively.
Figure 6.15: Data Structure Diagram for a "Subcontracting Project" Type of Construction Order

In comparison with the general architecture for a "Unique Project" type of
construction order, the applications on the company level are not included here. The remainder of the applications are the same as for the "Unique Project" and "Standard Construction Project" situations.

However, the following should be noted:
- depending on the batch characteristics within the construction order, either the technique used in a "Standard Construction Project" type of situation (line-of-balance) or that for a "Unique Project" type of situation (network technique) can be used;
- in a number of cases, experience or reference norms from projects completed in the past can be used. Thus, the reference activity and reference work crew assignment entities have been included in the data model.

6.8 Comparison with Currently Available applications

Based upon this analysis of the various types of construction orders and the relevant (automated) information systems, it is interesting to compare these conclusions with the data processing applications which are currently available for control in the construction industry.

Generally speaking, the following kinds of applications can be found:
1. project management software
2. software developed specifically for the construction industry (in the Netherlands, in this case)
3. packages for small-scale construction works (in the Netherlands)
4. research prototypes

These software packages are marketed by a variety of suppliers. Most of the packages have common features which can be described as follows:

1. project management software

In the early Eighties, various project management software packages were developed to support of the "project coordination" decision function, in particular (Primavera, Artemis). The majority of these packages were not developed in the Netherlands.

Figure 6.16 indicates which parts of the general architecture used to describe the various types of production control can be supported by project management software currently available on the market. It can be concluded that there is no support for the decision functions which are carried out at the company level. Moreover, the coverage of the functions indicated in the lower part of the application circle
(allocation planning) is incomplete.

The relative flexibility for the user is an advantage offered by project management software, certainly in reference to the applications in the second group (see [Melles & Wamelink -1990,a]).

Figure 6.16: General Architecture Coverage provided by Project Management Software

The "Subcontracting Project" type of construction order defined in the typology is the type which can be most easily be supported by this kind of software package. The general architecture coverage is fairly complete. It is, thus, surprising that this type of software is rarely if ever used in practice for this type of construction order. The "Standard Construction Project" and "Unique Project" types of situations can also be
supported with the traditional project management software. In both of these cases, however, the lack of functional coverage at the company level is a serious drawback. In a "Standard Construction Project" type of construction order, the fact that it is difficult to use experience from previous projects (on various levels) is another disadvantage. Moreover, it is virtually impossible to use any technique other than network planning (e.g., line-of-balance) in combination with this kind of package, which limits the usefulness of the packages considerably (as a result, it is difficult to deal with a series of activities as a single batch).

In the case of a "Unique Project" type of situation, there is no support at the allocation level. However, it remains to be seen whether this is a serious shortcoming (refer to the considerations presented in Sub-section 6.6.4).

2. Software developed specifically for the construction industry (in the Netherlands)

Figure 6.17 shows the general architecture for the second kind of standard software. This pertains to applications which are marketed by Dutch software houses. Generally speaking, this type of software is divided into packages or modules which support the various company functions (estimating, procurement, project administration, equipment administration, etc.). For the sake of clarity, it must be noted that Figure 6.17 reflects the largest common denominator of the packages currently available on the market.
Figure 6.17: Software Developed Specifically for the Construction Industry in the Netherlands

As can be clearly seen, these applications are basically limited to the inner circles (transaction processing systems) of the general architecture as described for the various types of construction orders. In addition, registration of work crew data, work crew assignments and operations are not recognizable in the available packages. In fact, the decision support system as indicated for the various applications is available to only an extremely limited degree.

One advantage which this group offers, unlike the packages in the first group, is the integration with an accounting sub-system. With integrated applications in this way, it
should be possible to enter data only once for various company functions.

Another striking aspect is the segmentation of this type of package according to the traditional sectors of the construction industry. For all of the function-oriented packages (such as project administration, procurement, estimating) different variants can be found (depending upon the software house) for the residential and commercial sectors and the civil works sector. A segmentation according to control types as suggested in the previous sections is not seen.

3. Packages for small-scale construction works (in the Netherlands)

Figure 6.18 illustrates the parts which are currently included in the packages for the "Work Order Production" types of situations (small-scale projects, etc.). The nature of the packages is primarily designed for data entry and validation. Decision support for optimizing the loading of resource capacities and for selecting suppliers is not available. In addition, a part of the transaction processing system is missing: registration of purchase orders and call orders.
4. Research prototypes

In addition to the commercially available software packages discussed above, the applications for production control in construction which are being developed by research institutions should also be mentioned.

In recent years (in other countries), various expert systems have been developed which include decision support systems for the various types of construction orders as discussed here. These are often prototype systems which cover only a small, isolated aspect of the general applications architecture. In general, the construction industry
has shown little interest in these research applications. These applications have not been distributed commercially despite the fact that the ideas on which they are based are sound. The primary reason for this is probably the fact that these applications limit their focus to a specific detail of the total problem. A significant amount of effort is typically required to enter the basic data (e.g., the state-independent data as described for each of the types of construction orders). In addition, this data would have to be entered into more than one system, either automated or otherwise, at the same time.

INTERMEZZO: APPLICABILITY OF INDUSTRIAL APPROACHES TO PRODUCTION CONTROL IN CONSTRUCTION

In this chapter, four production control concepts from industrial engineering will be assessed based upon their applicability within the construction industry. This topic has been discussed in detail in many articles published within the framework of this research project ([Melles et al.-1990], [Melles & Wamelink-1991], [Melles & Wamelink-1991], [Melles & Wamelink-1992]). A collective review of published literature was also carried out in collaboration with a research group at Stanford University [Koskela, Melles and Wamelink-1992] and a discussion paper was written within the framework of a meeting of Working Commission 65 of the International Council for Building Research, Studies and Documentation (CIB) [Melles & Wamelink-1992].

The review presented below follows the line of the reviews by Bertrand, Wortmann and Wijngaard concerning the possibilities and impossibilities of the various production control concepts in industrial manufacturing companies [Bertrand et al.-1990,a].

* The applicability of the network technique (CPM)

The network technique is a method for scheduling project activities based upon calculations which take a number of known activity attributes (interrelationships, date of initiation and date of completion) into account.

A number of versions of this network technique have been developed, of which the Critical Path Method (CPM) is the best known. CPM is used as the basis for many of the popular project management software packages. In packages of this kind, CPM is often supplemented by a resource levelling option. To start with, however, the resource capacity and materials requirements are determined primarily by the results of the network calculation.

The CPM method was originally developed for use in planning and monitoring industrial projects. Later, this method was also used to some extent in the construction industry [Twijnstra-1969], but has never gained wide acceptance.

In our opinion, this is due to the fact that CPM is used too often as just a planning
and monitoring technique for isolated projects. The general requirements of a construction company (i.e., the multi-project planning problems) are typically not addressed. The typology presented here can be used to explain why this network technique is much more valuable in large-scale commercial building construction projects (the "Unique Project" and "Subcontracting Project" types of construction orders) than in road construction projects (the "Work Order Production" and "Standard Construction Project" types of construction orders). In "Work Order Production" and "Standard Construction Project" situations, an emphasis is placed on control in the sense of monitoring the (multi-project) loading of resource capacities rather than controlling and monitoring the (extremely limited number of) activities. As might be expect from the typology, the best results from using CPM to date have been achieved in connection with "Subcontracted Project" types of construction orders (see section 6.8). This is particularly true in the situations where the construction order can be seen more-or-less as an independent business in which monitoring the usage of resource capacities is less important than monitoring the duration of (a large number of) activities.

* The applicability of Material Resources Planning (MRP-II)

The MRP-II concept (Material Resources Planning) can be seen as a set of conventions which have been established based upon the MRP-I (Material Requirements Planning) algorithm. On the basis of the requirement for finished products as determined in a Master Production Schedule, the MRP-I algorithm calculates when subassemblies need to be produced and when materials and components should be ordered. In order to carry out this reverse calculation from finished products to material and component requirements, a reliable Bill of Materials is needed in addition to accurate information regarding the work-in-progress and inventory levels and carefully controlled throughput times. This approach is based, to a large extent, on the control of materials. In order to arrive at a realistic Master Production Schedule, the MPS in MRP-II is reviewed against a first-cut resource capacity schedule. In addition, the MPS must fit within the boundaries of into the longer term production plan in which the availability of resource capacities and critical materials is set out over a longer period of time. Following the MRP-I calculations, a detailed resource capacity schedule is produced within MRP-II. The MRP-I results are then adjusted as necessary. Attention is also paid to controlling the release of materials and work orders on the premise that the entire factory functions as a single production unit.

A weak point of the MRP-II concept is its lack of support in resolving resource capacity utilization problems. A strong point in favor of MRP-II is that it controls production based upon the availability of materials and monitors inventory levels.
The throughput times for related activities are not monitored at all since no network relationships are recognized if such a relationship is not defined via the Bill of Materials for the construction object. Furthermore, calculations are always based upon inventory levels rather than on throughput times. It has often been difficult to prepare satisfactory Bills of Materials for construction objects [Bürmann-1990].

It is, therefore, logical to conclude that the complete MRP-II concept is not really applicable in the construction industry. Parts of MRP-II can be used if and when situations are created in which clear Bills of Materials can be prepared for the construction objects and the control is related to the supply of materials. This kind of situation would only appear to exist in the case of a "Standard Construction Project" where the importance of controlling resource capacities is limited because readily available resource capacities are used. This type of situation is conceivable in the finishing phase of residential construction projects where standard materials are used for kitchen units, tiles, bathroom fixtures, etc.. However, three conditions would have to be met:
1. The primary interests of the construction project would have to be suppressed.
2. Any problems in controlling the utilization of resource capacities would need to be resolved.
3. The control problem must be solvable using the principles of inventory control.

This could be found in a situation in which homes are not finished via a construction project based at a construction site and using specialized work crews (such as kitchen installers, electricians, plumbers), but rather from a central finishing yard using all-around work crews. The project-oriented aspect can be eliminated in this way (the homes can be finished in a completely random order), the date for starting the finishing activities can be determined based upon the principles of inventory control (when all of the finishing materials for the home are available), and the resource capacity utilization problem has been eliminated (a complete container with the necessary finishing materials can be given to the first available all-around work crew which can then complete the work on any unfinished housing unit in any construction project).

* The applicability of the Just-In-Time philosophy (JIT)

The basic idea behind the Just-In-Time approach is the establishment of a simple production scheme with simple control procedures. In other words: let the persons involved in the production process, when possible, make control decisions such as finalizing the sequence of operations. This means that detailed scheduling (e.g., in a "push" approach in which each operation is included in highly detailed planning schedules) is not carried far in advance. Instead, primarily short-term decisions are
made based upon the current demand for products. The Kanban system used in the Toyota factories is an excellent example of this approach. New subassemblies are made only immediately before they are actually needed. The ultimate result is that only extremely small subassembly inventories are needed (the goal of having no intermediate stock has often proved to be unrealistic in practice when the production is batch-oriented). With this approach, the production of new subassemblies is initiated based upon the demand for finished products which use the subassemblies (the "pull" approach).

The Kanban system was developed for the batch production of relatively simple, standardized products. This type of situation does not occur in the construction industry. The basic philosophy, however, is still relevant.

Two basic aspect (also related to construction) are:

1. Consider how the production process should be controlled and coordinated.

The way in which the production process is controlled and coordinated (on the basis of operations, work crew assignments, activities or even complete construction orders) inherently determines the degree to which production personnel are free to make their own decisions. The type of work crew being employed directly affects the extent of control and coordination.

2. Depending on the chosen approach to supervising and coordinating the production process, consciously create more control levels for implementing workload control.

Activities are divided into specific work crew assignments. Work crew assignments can be allocated, for example, at the same time that the availability of the work crews is reported.

The basic JIT philosophy can therefore be considered to be applicable in all areas of the construction industry.

* The applicability of Optimized Production Technology (OPT)

OPT is a scheduling method which optimizes the use of bottleneck resource capacities. The OPT approach models the production process in terms of bottlenecks with the relevant buffers (in order to ensure that bottleneck resource capacities are optimally utilized). Each bottleneck is modelled as a separate production unit, while the buffer ensures that the production unit can be analyzed separately ("uncoupled") from the other resource capacities in terms of its loading. An ingenious algorithm is
then used to generate a production schedule for each bottleneck such that the set-up times are minimized. The production schedule for the bottlenecks can subsequently be used as the basis for producing production schedules for the non-critical resource capacities.

Optimized Production Technology focuses only on solving resource capacity problems pertaining to bottlenecks. In view of the importance of throughput time control for many types of construction orders, OPT could be used as a resource levelling method for "Unique Project" and "Subcontracting Project" types of construction orders.

In "Standard Construction Project" and "Mass Production Project" situations, a project interest exists which must be taken into consideration, but control primarily takes place through the mobilization planning and the multi-project planning functions. In this type of situation, it should be possible to calculate an optimal sequence for scheduling work crew assignments on the basis of the multi-project planning for the (scarce) bottleneck resource capacities (such as paving equipment in road construction or dredging vessels in the dredging sector) using OPT algorithms. This schedule can then be adjusted if necessary to fit within the constraints of an (independently developed) high-level project plan. Changeover times can be defined in terms of transport times and set-up times in projects involving road construction or dredging equipment.

In the "Work Order Production" type of situation, control focuses solely on the utilization of resource capacities. However, there are no clearly distinguishable bottleneck resource capacities. All of the resource capacities are equally critical, making it difficult to calculate the priority of work orders based upon an optimal utilization of the bottleneck resource capacities.
APPENDIX: REVIEW OF SEVEN TYPOLOGIES FROM INDUSTRIAL ENGINEERING FOR MANUFACTURING COMPANIES

THE TYPOLOGY PROPOSED BY WOODWARD

A brief description of the typology proposed by Woodward

Woodward's typology can be used to distinguish between types of companies. The typology proposed by Woodward [Woodward-1959] was one of the first and is also the least extensive typology. Woodward uses the characteristic called "technical complexity". She understands this to be the extent in which a production process can be technically controlled (thus its predictability). She distinguishes between three classes of companies, namely:

* unit production companies (special orders, small batches, large projects)
* mass production companies (large batches, manufacture of moulded products)
* process production companies (chemicals)

Process production companies are considered to have the greatest amount of "technical complexity". This characteristic indicates the extent to which manufacturing processes can be made (technically) controllable and predictable.

Based upon the various types production situations, Woodward sees a shift in the formalization of leadership (more in accordance with formal rules). She recognizes a number of distinguishing (non-classifying) characteristics which change in proportion to the classifying characteristic ("span of control", relationship between leaders/workers, number of hierarchical levels).

Assessment of the typology proposed by Woodward

A. Point of view

The typology proposed by Woodward is primarily oriented towards organization structures, not towards decision and information aspects.
B. Objective

The objective of the typology proposed by Woodward is to explain the relationship between the organizational structure and the type of production. This is not the same as the objective for this typology.

C. Objects

Woodward divides complete companies into types. Differences within companies are not mentioned.

D. Distinguishing characteristics

Woodward classifies the types of production situations based upon a single characteristic: the technical complexity. In her discussion of the types of production situations, she lists a number of additional characteristics which pertain to the organizational structure. These are only marginally related to the decision system and totally unrelated to the information system.

E. Conclusion

The typology proposed by Woodward completely fails to meet the objective and point of view for the typology desired within the framework of this study; the typology gives no directions concerning the design of the decision and information systems. In addition, Woodward's typology cannot be used to make a distinction between different types of (construction) companies.

A study of the typology proposed by Woodward shows that distinguishing types on the basis of a single characteristic brings the majority of the objects into the "grey areas" between the classes as determined. The choice of classifying characteristic appears to be rather random.
THE TYPOLOGY PROPOSED BY HARVEY

A brief description of the typology proposed by Harvey

Harvey's typology was also compiled for the purpose of distinguishing between types of industrial companies. Harvey [Harvey-1968] applies the primary characteristic of "technical specificity" for his typology. He is referring to the stability of the supply of products. This is actually a measure of the innovative orientation of companies. The control aspects to which the typology proposed by Harvey refers are, again, organizational measures taken by companies.

Assessment of the typology proposed by Harvey

A. Point of view

The typology proposed by Harvey is primarily oriented towards organizational structures, not on decision and information aspects.

B. Objective

The objective of the typology proposed by Harvey is to explain the relationship between the organizational structure and the type of production. This is not the same as the objective of our typology.

C. Objects

Harvey distinguishes between types of companies. As a result, differences in production control within companies cannot be determined.

D. Distinguishing characteristics

The distinguishing characteristic Harvey uses is the technical specificity. In his view, all construction projects probably qualify as being "technically specific". No distinction is made within the construction projects themselves.

For each type of production situation, Harvey discusses a number of additional characteristics (number of hierarchical levels, number of specialized groups, relationship between leaders/workers, degree to which procedures are structured) which (like with Woodward) are primarily related to the organizational structure and only to a lesser extent to the decision and information systems.
E. Conclusion

In principle, the typology proposed by Harvey has the same problems as the typology proposed by Woodward. The difference between these two typologies is basically related to the choice of distinguishing characteristic. It is for this reason that Harvey's typology cannot be used within the framework of this study. Striking is the fact that like Woodward, Harvey uses only a single distinguishing characteristic, the choice of which appears to be random.
THE TYPOLOGY PROPOSED BY BOTTER

A brief description of the typology proposed by Botter

Botter's typology was also developed in order to distinguish between types of industrial companies. Botter [Botter-1988] recognizes that it is really rather limited to apply only a single distinguishing characteristic as Harvey and Woodward had done. A review of published literature shows that most typologies use one or more of a group of nine characteristics. These nine characteristics (which are not independent) are as follows:

1. production control method  
2. batch size  
3. product standardization  
4. type of technology  
5. position in the supply chain  
6. material flow pattern  
7. method of supplying raw materials  
8. consumer market aspect  
9. degree of innovation

Botter argues that at least two characteristics should be used in order to distinguish between types of production situations. Strangely, however, he concludes that the list of characteristics above represent an accurate, complete generalization of the characteristics found in literature, but he uses only one characteristic from this group. Botter chooses another characteristic. His typology is based upon:

1. position in the supply chain  
2. the composition of the range of products

He then makes statements about his types which pertain to another characteristic found in literature: production situations. Particular attention is devoted to the path of the material flows. In addition, considerable attention is devoted to organizational and policy-related aspects.

Botter devotes more attention to information problems than Woodward and Harvey, albeit that the scope of his discussion is limited. Again, emphasis is place on general (organizational) aspects of production control.
Assessment of the typology proposed by Botter

A. Point of view

The typology proposed by Botter is oriented towards organizational structures, marketing aspects and also decision and information aspects. However, the typology is formulated only in general terms. Botter’s typology, to the extent that it deals with decision and information aspects, is primarily oriented towards strategic and tactical decisions, and less towards operational decisions and information aspects.

B. Objective

The objective of the typology, according to Botter, is to gain some structured insights into a number of characteristics which play a role in certain types of industries.

C. Objects

Botter distinguishes between types of industrial companies.

D. Distinguishing characteristics

Botter uses two characteristics (position in the supply chain and composition of the range of products) to distinguish between types of production situations. Neither of these characteristics results in a division according to types found in the construction industry. Botter also discusses a number of characteristics of the types discerned in his typology (procurement of raw and other materials, manufacture, market, organization and innovative orientation) which share a common ground with the information and decision systems.

E. Conclusion

The typology proposed by Botter (although better suited than the two previous typologies) is not suitable for distinguishing between types of construction orders in the construction industry within the framework of this study. Botter’s classification results in only a single type of production situation representing the construction industry, and little explicit information can be derived from it concerning the design of the decision and information system. References to the design of production control are too abstract to be useful here. The choice of distinguishing characteristics appears to be random.
THE TYPOLOGY PROPOSED BY WILD

A brief description of the typology proposed by Wild

Wild [Wild-1977] compiled a typology for operating systems, which he understands to mean a combination of the means for production, transportation, inventory or services. This actually means production situations.

Wild uses the characteristic of the structure of the production situation. He distinguishes between functions, inventory locations and flows of materials. Based upon the types of production situations subsequently derived, he draws conclusions concerning production control.

Assessment of the typology proposed by Wild

A. Point of view

The typology proposed by Wild focuses on the structure of production situations. He understands the structure to be the manner in which flows of materials, inventory locations and manufacturing operations are organized. Thus the typology proposed by Wild is solely oriented towards strategic and tactical decisions, not towards operational decisions and information aspects.

B. Objective

The objective of Wild’s typology is to distinguish between various types of production situations according to the control culture.

C. Objects

The objects of this typology are what Wild calls the operating systems. These operating systems are the same as production situations within companies. In principle, more than one operating system can be seen within a single company.

D. Distinguishing characteristics

Wild’s distinguishing characteristic is the structure of a production control situation in terms of functions, inventory locations and flows of materials. This classification would not distinguish between types of construction orders in the construction industry.
E. Conclusion

The typology proposed by Wild is not in keeping with either the objective or the point of view applied within the framework of this study of a typology for the construction industry. Construction orders in the construction industry would all be categorized as Wild's type 4.

Wild explicitly assumes that the structure of the control situation is determinant for the control method, therewith clearly indicating the chosen distinguishing characteristic. The typology proposed by Wild is particularly useful for determining how individual products should be made on a higher, abstract level.
THE TYPOLOGY PROPOSED BY NEW

A brief description of the typology proposed by New

The typology proposed by New [New-1977] was developed in order to describe the approach to production control in production situations. New recognizes that more than one type of production situation can exist in a single manufacturing company.

New applies the following characteristics:

* the organization of the physical flow system. With this, New has the choice of a line set-up in a factory production situation in mind. New also distinguishes between the functional and group set-ups.
* the nature of the product structure. This refers to the quantity of the materials used in the product.
* the nature of client orders. In this, a distinction is made between one-of-a-kind production, contract projects and repeat orders. He also recognizes the phenomenon of production for stock.

Although New distinguishes between twelve types of production situations based upon these characteristics, he actually only reviews a sub-classification based upon the third characteristic, discussing:

- product characteristics
  New understands this to mean the extent to which the manufacturer or consumer prepares the specifications.
- production facilities
  This is defined as the possibility to employ equipment and people for various activities.
- key performance variable
  This is understood to be the primary parameter for production control decisions.
- main operating problem areas
  New uses this characteristic to describe the major production control problems.

The typology proposed by New gives excellent insights (although not for all types of production situations) into the differences in production control problems without going on to discuss integral solutions for these problems. Individual solutions to the various problems discussed are presented elsewhere in the book.
Assessment of the typology proposed by New

A. Point of view

The typology proposed by New devotes extraordinary attention to (operational, tactical and strategic) decisions pertaining to production control. Information aspects are not discussed.

B. Objective

New's objective is primarily to gain increased insights into the consequences of strategic and tactical decisions on choosing the method of production control.

C. Objects

The typology proposed by New pertains to production situations in general. Different types of production situations can be seen within individual companies.

D. Distinguishing characteristics

The first and second characteristics used to distinguish between different types of production situations are not relevant to classification of construction orders in the construction sector. The third characteristic (the order type) is not directly applicable to the construction industry, but does provide some basis for distinguishing between different production situations. For application of this typology to the construction sector, only one distinguishing characteristic remains, which is not wholly satisfactory in that it does not apply to a large number of construction orders.

E. Conclusion

The objective and point of view of the typology proposed by New are not fully in keeping with the requirements within the framework of this study, in part because the information aspect is not discussed.

In particular, New's typology renders directions for the strategic choices which must be made in reference to control of the production process for a certain group of products.
THE TYPOLOGY PROPOSED BY SCHOMBURG

A brief description of the typology proposed by Schomburg

The typology proposed by Schomburg was developed in order to distinguish between types of production control situations in the mechanical engineering sector ("Maschinenbau").

This typology is derived from values for the distinguishing characteristics which Schomburg found in actual industrial practice. Schomburg applies the system-theoretical approach by Grosse-Oetringhaus for these characteristics. The influence of the values of these characteristics on production control and the information system is discussed.

The distinguishing characteristics which Schomburg uses are:
- erzeugnisspektrum
  This characteristic indicates the extent to which a client can exert influence on the product.
- erzeugnisstruktur
  This characteristic gives an indication of the number of components used for a product.
- auftragsauslosungsart
  This characteristic indicates the manner in which production of the product is planned (to stock or to order).
- dispositionsart
  This characteristic reflects the extent to which specific materials are used for a client order.
- beschaffungsart
  This characteristic reflects the extent to which company-made materials or externally-made materials are used.
- fertigungsart
  This characteristic indicates whether a repetitive effect is seen in the production.
- fertigungsablaufart
  This characteristic gives an indication of the physical set-up, the physical coordination requirements and the interrelated transport requirements of the production resources.
- fertigungsstruktur
  This characteristic reflects the number of production phases and the number of operations per production phase.

In order to arrive at different types of production situations, Schomburg analyzed and identified the combinations of values of the distinguishing characteristics which occur
in real situations. He arrived at a total of eighteen different types. For a number of control and information functions, he provides an explanation which is dependent on the type of production situation.

Assessment of the typology proposed by Schomburg

A. Point of view

The typology proposed by Schomburg [Schomburg-1980] is oriented towards both control and information aspects, and pertains to tactical, strategic and operational decisions.

B. Objective

The objective of Schomburg's typology is to indicate the company-related demands which are made in selecting and implementing an (automated) method for production control.

C. Objects

The typology proposed by Schomburg was developed for production situations in the mechanical engineering industry. In principle, Schomburg assumes that the typology can be used for a broader area, but this is not discussed. The characteristics which he lists for the objects (such as: one-of-a-kind production, primarily mechanical technology, production within the company organization and repetitive phased production), however, effectively limit the scope of this typology. Nevertheless, it is clear that a number of construction orders in the construction industry can be adequately described in terms of Schomburg's typology.

D. Distinguishing characteristics

Schomburg distinguishes his types of production situations based upon a combination of values for characteristics. One of the characteristics (the fertigungsablaufart) cannot be applied in distinguishing types of construction orders in the construction industry. The other characteristics cannot often be directly applied (they are formulated for mechanical engineering) but the idea they represent can be. An example in this respect is the erzeugnisstruktur; it has proven in practice to be extremely difficult to compile a bill of materials for a construction project (see for example Bürrmann's study [Bürrmann-1990]. The influence of the values of the distinguishing characteristics on construction orders in the building industry is clearly formulated.
E. Conclusion

The typology proposed by Schomburg is well-suited to the requirements within the framework of this study. However, the scope covered by this typology is to some extent too broad (a number of distinguishing characteristics cannot be applied to the construction industry). In addition, the typology - in keeping with the objective presented by Schomburg - is strongly oriented towards mechanical engineering situations in terms of terminology. This typology can therefore not be used to distinguish between types of construction orders in the construction industry.
THE TYPOLOGY PROPOSED BY VAN RIJN

A brief description of the typology proposed by Van Rijn

Van Rijn [van Rijn-1986] developed a typology for production situations in manufacturing companies. The typology is oriented towards both decision and information aspects.

Van Rijn distinguishes between five elementary types of production situations.

Van Rijn describes seven characteristics of the types of production situations thus identified:

a. the material structure of a product
   This characteristic places a value on the complexity of the structure of the product, taking the number of components into account.

b. the operational structure of a product
   This characteristic places a value on the complexity of the relationships between the operations for manufacturing a product.

c. the commonality of the material
   The characteristic indicates the extent to which materials are used for more products.

d. the versatility of the resource capacities
   This characteristic indicates the extent to which resource capacities can be employed for more operations.

e. the degree to which the resource capacities are independent ("uncoupled")
   This characteristic indicates the extent to which resource capacities must be independently controlled.

f. the scope of the range of products
   This characteristic indicates how extensive the range of products that can be produced in a production situation is.

g. the scope and nature of the uncertainty
   This characteristic indicates the extent of the uncertainty involved in making decisions pertaining to production control.

The distinguishing characteristics were derived through reasoning, analogous to Galbraith [Galbraith-1973], that the design of the production control and the information systems are dependent on the complexity and uncertainty. Like Grosse-Oetringhaus and Schomburg, Van Rijn relates the complexity factors to a system-theoretical approach to the control process.

The effects of the values of the distinguishing characteristics on the specification of
the decision systems and management information systems for production control are described in detail.

According to Van Rijn, the elementary production control situations are seen individually and in various combinations. More than one type of production situation may be seen within a single company. Striking is the fact that after his discussion of the effect of the values of the characteristics on the specification of the production control and information aspects, Van Rijn also discusses these aspects per type of situation at the multi-property level. What he is indicating (albeit not explicitly) is that the production control is affected not only by the values of the individual characteristics of the production situation, but also by the combination of values of characteristics which are related to a specific type.

Assessment of the typology proposed by Van Rijn

A. Point of view

The typology proposed by Van Rijn is oriented towards both decision and information aspects. The decision aspects concern strategic, tactical and operational decisions.

B. Objective

The objective of the typology is:

"to create a tool for diagnosis that can be used in company situations to quickly find a satisfactory and fitting combination of production control systems and information systems."

C. Objects

Van Rijn divides the production situations into two sub-groups: the elementary production control situations and the combinations of elementary production control situations. In principle, the typology is not limited to any certain group of companies. However, the chosen objects are such that the construction industry in its entirety would be one type (project-oriented).

D. Distinguishing characteristics

Van Rijn also derives the distinguishing characteristics from the influence they exert on production control and the related information system. His reasoning is based
upon common knowledge of production control in industrial, mostly mechanical engineering-oriented manufacturing companies.

F. Conclusions

The typology proposed by Van Rijn is well-attuned to the requirements which we have placed on a typology for the construction industry. The terminology used, however, is primarily based upon production control theory from industrial engineering. The terminology can sometimes be paralleled, but it is virtually "untranslatable" for use in reference to the construction industry.

The term "uncertainty" is used as a characteristic. The relevancy of this characteristic is related particularly to the approach which Van Rijn uses to describe the relationship between the decision system and the information system. As previously discussed in Section 2.4.4, the function of the information system as defined here is to support the decision system. The complexity of the control problem dictates how the decision-maker should make decisions. A relatively simple problem requires a smaller number of formal decisions than a more complicated problem. This is due to the fact that the decision-maker may not be able to recognize, immediately, all of the implications of a decision when the problem situation is complicated.

The way in which a decision is made can be represented by selecting a set of decision functions. A selected set of decision functions can then be associated with a certain type of decision situation which is characterized by a specific set of complexity factors. The information system should be designed to support these decision functions.

The quality of a decision is determined by:

a. the degree to which the choice of decision functions (i.e., the decision structure) is correct;

b. the degree to which a decision function is properly performed;

c. the uncertainty which exists concerning the information used by the decision function to make the decision.

If the complexity factors are based upon an accepted, applicable and theoretically correct framework for production control, then it can be implicitly assumed that the choice of the decision functions has been carried out properly. The design of the information system should be based upon these decision functions. The functions to be included in the information system are dictated primarily by the requirements of the decision system. This means that the complexity factors indirectly influence the design of the information system through their influence on the definitions of the
various types of decision situations.

In addition, the design of the information system is influenced by the desire to make the best possible decision (i.e., the highest quality). This means that the information system plays an important role in controlling the degree of uncertainty. To illustrate this point, assume that an information system is needed in two different construction order situations to support the same set of decision functions. The designs of the respective information systems may need to be different in order to make allowances for differences in the uncertainty. The uncertainty factor, thus, may lead to the definition of different types of information systems even when there is only one type of decision system. Following the example of Schomburg, it has been decided not to include the uncertainty factor within the framework of the typology for construction orders for the purpose of the research here.
PART 3: CASE STUDIES USING DESIGN RULES FOR PRODUCTION CONTROL IN CONSTRUCTION
1 INTRODUCTION

1.1 Prologue

A typology with associated design rules for production control in construction has been presented in Part 2. This typology and the design rules are applied to two specific case study situations in this third part of the book.

In connection with this it is shown that expected (and presumably limited) changes in the production process may lead to major changes in the form of production control in some situations. A detailed description of the respective control systems is also provided for both of these situations.

A model has been developed to quantify the effect which changes to the production process may have on the production control. This model is described here as a first step.

1.2 An Estimation Model for Quantifying the Effect of Changes in the Production Process on the Production Control

The final realization of a construction order takes place at the construction site. The direct control of the production process falls under the responsibility and supervision of the (head) foreman. The foreman may need to assume a variety of roles. In the case of extremely small-scale construction orders (primarily of the "Work Order Production" type of construction order), the foreman will normally have an active role as co-worker and may often be a company owner at the same time. In the case of a large-scale construction order (such as the "Unique Project" type of construction order), the chief foreman will normally function as a Production Manager at the construction site with several foremen reporting to him. The estimation model is applicable to the person who prepares the allocation plan in every instance. In the event that this decision-maker is also responsible for making other decisions (such as mobilization planning decisions), then this aspect will also be included in the model.

The foreman represents the "output" of the control system. If the production process is poorly controlled, then it is assumed that this will be measurable in terms of the foreman’s activities.
Example:

If Management has failed to draw up a proper resource capacity loading plan, then this may lead to a shortage of scarce resource capacities. This will, in turn, lead to delays in the production and/or an enormous overloading of the personnel and equipment. A significant amount of improvisation is also likely to occur.

In order to be able to determine the influence of changes in the production process, the effort spent by the foreman in controlling and directing the production process can be measured.

The production process is assumed to have a specific structure (the chosen production method). It is possible to determine how much time the foreman spends on controlling and directing the production process when the structure of this process is known. Subsequently, a change in the production process is proposed. The expected effect of this change in the production process on the control activities can then be quantified by applying the estimation model with the assumption that the method of control remains unchanged.

The estimation model is based upon a high-level activity plan for the construction order (see Figure 1.1).

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**Figure 1.1: Example of a High-level Activity Plan**
The development of a high-level activity plan is not actually required in every situation. Nevertheless, the information provided by this plan is necessary in order to be able to identify the activities which need to be performed to complete a given construction order. This basis is required for the assignment of quantitative properties to the construction order. These quantitative properties can be recorded on a form such as that illustrated in Table 1.1A and Table 1.1B.

<table>
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<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew No. &amp; Type</th>
<th>Number of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/Follow-up Material Calls</th>
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</tbody>
</table>

**Table 1.1A: Main Table for the Calculation Model**
WORK CREW INSTRUCTION AND CALL TIMES

<table>
<thead>
<tr>
<th>NAME</th>
<th>CHARACTERISTICS</th>
<th>INSTRUCTION TIME (MINUTES)</th>
<th>CALL TIMED (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Production Work Crew</td>
<td>• Multi-project learning curve</td>
<td>First time on project</td>
<td>First time on project</td>
</tr>
<tr>
<td></td>
<td>• Repetitive work on project</td>
<td>Follow-up order on project</td>
<td>Follow-up order on project</td>
</tr>
<tr>
<td>One-of-a-kind Production Work Crew</td>
<td>• Multi-project learning curve</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Varying work on project</td>
<td>Follow-up order on project</td>
<td></td>
</tr>
<tr>
<td>Batch Production Work Crew</td>
<td>• Project learning curve</td>
<td>First time on project</td>
<td>First time on project</td>
</tr>
<tr>
<td></td>
<td>• Repetitive work on project</td>
<td>Follow-up order on project</td>
<td>Follow-up order on project</td>
</tr>
<tr>
<td>Unique Production Work Crew</td>
<td>• No learning curve advantage</td>
<td>First time on project</td>
<td>First time on project</td>
</tr>
<tr>
<td></td>
<td>• Unique work on project</td>
<td>Follow-up order on project</td>
<td>Follow-up order on project</td>
</tr>
</tbody>
</table>

MATERIAL CALL TIMES

<table>
<thead>
<tr>
<th>MATERIAL CALL TIMES (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First call</td>
</tr>
<tr>
<td>Follow-up call</td>
</tr>
</tbody>
</table>

Table 1.1B: Subsidiary Tables for the Calculation Model

To start with, the activities from the high-level activity plan are entered into the first column of the main table.

The work crew assigned to each of these activities is then entered in the second column of this table. The work crew number as well as the type of work crew is indicated here. If the same work crew is assigned to more than one activity, then this is evident from the fact that the same work crew number is listed. The work crew type provides an indication of the quantity of information that the work crew requires for mobilization and direction. The following types of work crews have been defined here, based upon the distinctions made in Part 2, Sub-section 5.5.7:

• Mass Production Work Crew (M);
• One-of-a-kind Production Work Crew (O);
• Batch Production Work Crew (B);
Case studies

- Unique Production Work Crew (U).

How often the work crew is to be called up is noted in the third column. The number of work crew calls may be different for each type of work crew. In addition, it is important to know if a work crew is being called to the construction site for the first time or if the work crew has been used previously to complete work at the same construction site. (Example: an entry of "1/3" in this column would indicate one initial call and three follow-up calls; if more than one initial call is specified, then this means that more than one work crew has been scheduled to work on the same activity).

The total work crew call-up time for each activity is entered in the fourth column. The call-up times to be specified here are dependent upon the sector in which the work is to be carried out. For this reason, a subsidiary table with the call-up times is always included along with the main table.

The number of instructions to be given to each work crew (i.e., the work crew assignments) is entered in the fifth column. Each work crew receives instructions at least once per week. A distinction is also made here between the initial and follow-up assignments. (Example: an entry of "1/4" in this column would indicate one initial assignment and four follow-up assignments).

The total assignment instruction time for each activity is entered in the sixth column. This time is also determined based upon a subsidiary table associated with the main table.

The number of material calls are entered in the seventh column. (Example: an entry of "1/4" in this column would indicate one initial call and four follow-up calls; each call represents a separate shipment which is to be explicitly ordered. In this way a foreman may, for example, order a certain number of kitchen units, depending upon whether there are delays in the production, for delivery in the coming week. One shipment may consist of multiple truckloads.)

The total material call-up time for each activity is entered in the eighth column. A subsidiary table to the main table is used to determine the correct value.

The total effort which will be required from the foreman for controlling and directing the production can be estimated by adding up the columns of the main table.
2 RESIDENTIAL CONSTRUCTION CASE

2.1 Introduction

A case study of a project involving the construction of 100 new homes is presented in this chapter. To set the scene, a description of the construction order and the construction company designated to carry out this construction order is presented in Section 2.2. Based upon the technical work preparation plan and the underlying assumptions, the type of construction order which most closely corresponds with this construction order is determined in Section 2.3.

Subsequently, a change in this situation is introduced in Section 2.4. The contractor decides to change his production process as a result of sluggish sales in the new home market. The expected effect of this change on the control and direction of the production process is calculated based upon the estimation model presented in Section 1.2. Section 2.5 then discusses how changing to a different type of construction order in this situation can lead to an improvement in control. A detailed specification based upon one of the possible solutions (based upon the "Unique Project" type of construction order) is then provided to illustrate how the control structure and information structure can be realized in practice.

2.2 Description of the Construction Company and the Construction Order

The background information concerning the company and the construction order are presented, first, in this section before the issues of production control are discussed. Not all of this information will be used explicitly in the remainder of this Part. Nevertheless, this information provides a useful picture of the context within which the construction order must be seen.

The construction company

The construction order is to be carried out by the company "HOMEBUILDERS, INC." of Rotterdam. HOMEBUILDERS can be characterized as a medium-sized contractor in the Residential & Commercial Building Sector. It is a family-owned and family-run company with a strong presence in the regional market.
BACKGROUND INFORMATION ON HOMEBUILDERS, INC.

Annual Turnover

The annual turnover of HOMEBUILDERS, INC. is approximately $30 million and has been relatively constant over the past several years. The average gross operating profit (before taxes) has been approximately 3%.

Organizational Structure

HOMEBUILDERS, INC. is one of two operating companies of HOLDING, INC.. The other operating company of HOLDING, INC. is PROJECT DEVELOPMENT, INC.. The primary objective of PROJECT DEVELOPMENT, INC. is to generate a sufficient volume of work for HOMEBUILDERS, INC.. The complete organizational structure is presented in Figure 2.1.

The following functions and departments can be identified in Figure 2.1:

Management

The company Management Team consists of the General Manager and the Technical Director.

Sales

This department consists of one salesman who is responsible for bringing in a certain amount of construction business for the company each year via his network of contacts.

Office Services

Two secretaries are employed and are responsible for distributing and collecting the incoming and outgoing mail, copying, typing correspondence, answering the telephone, etc.

Financial Administration

This department is responsible for the payroll (1 Payroll Clerk), the financial accounting (1 accountant and 2 assistants) and the project administration (2 project administrators).

Estimating

This department is responsible for calculating the cost budgets for proposed construction work and issuing quotations for this work. The cost calculations are converted to a project budget when the contract is signed. Three persons are employed in the Estimating Department.

Purchasing

The Buyer is responsible for the procurement of materials and subcontracting arrangements based upon the requisition lists provided by the Estimating Department and an optimal price/quality ratio. Two Buyers work in this department.
Figure 2.1: The Organizational Structure of HOMEBUILDERS, INC.
Production Planning

This department is responsible for planning project activities and making advanced preparations as may be required. After the contract for the project is signed, they are also responsible for construction site support. Five Production Planners work in this department.

Realization

This department includes the Project Managers who are typically responsible for several projects at the same time. The Project Managers are supported by a Foreman at each of the construction sites. The Foremen are responsible for coordinating the completion of activities at the construction site.

There are 12 employees in this department who provide instructions and direction to an average of 120 construction workers. The construction workers are organized in relatively small work crews of 2, 3 or 4 persons per crew. The formation of work crews is based primarily on a particular skill and/or the employee's place of residence.

Maintenance & Storage

HOMEBUILDERS, INC. has only a limited Maintenance & Storage Department which is responsible for setting up the construction sites and providing well-maintained, modern equipment. Any equipment which potentially would be insufficiently utilized is rented as appropriate for the specific project. Special attention is paid to the development of various formwork systems for the larger residential construction projects.

This department consists of two mechanics, one administrative assistant and a manager.

Description of the Work-in-Progress

HOMEBUILDERS, INC. is active solely in the Residential and Commercial Building Sector. Approximately 60% of the company's revenue is derived from large-scale residential construction projects, 30% from commercial building projects and 10% from small-scale residential construction (luxury homes). The company has accumulated extensive experience with modern production techniques in the large-scale residential construction sector (e.g., formwork construction techniques).

An average of nine projects are under construction at any given point in time. The construction price may vary widely: anywhere from $100,000 for small-scale residential construction projects to $5,000,000 or more for large-scale residential construction projects and commercial building projects. Each of the Project Managers and Foremen are experienced in one or more of these sectors.

END OF THE BACKGROUND INFORMATION ON HOMEBUILDERS, INC.
The construction order

The construction order is for the realization of 100 new homes in Delft. The new homes are to be built in blocks of five. Two basic types of homes are to be built: sixty "Eagle" models and forty "Buzzard" models. The basic layout of both models is identical, however, the quality of the finishing work is different. Each block of homes will consist of only one model type, however, blocks with different models of homes will be interspersed on the construction site. This is possible since the basic construction and layout of both types of homes is identical. Major differences between the two models occur only during the finishing phase. The layout of the various blocks of homes within the construction site is presented in Figure 2.2.

![Diagram of apartment complex with blocks labeled]

Figure 2.2: Layout of the Construction Site

Both types of homes, Eagle and Buzzard, can be considered to be based upon traditional home designs. The homes consist of a ground floor and a second story with a standard roof construction. As previously mentioned, the major difference between the two models is the quality of the finishing work. The front view and the floor plan of the ground floor of these homes are presented in Figure 2.3.
Figure 2.3: Front View and Floor Plan for the EAGLE and BUZZARD Models
2.3 Technical Work Preparation and Determining the Type of Construction Order

In view of the company's expertise and equipment, the decision has been made to build the structures using tunnel formwork. A tunnel form is a special type of formwork which is movable and is handled by a dedicated work crew of construction site personnel. After the formwork is positioned and all of the pipes and conduits have been laid, the walls and floors can then be poured. The composition of the work crews is arranged in such a way that these crews can be utilized for full working days. In this way the concrete can be poured at the end of each day (so that fixed arrangements can be made with the suppliers of the concrete) and a consistent (and, thus, predictable) rate of production can be realized. A form of batch production process can be realized in this way.

The other construction activities are also the same for both types of homes (and for all homes within a block). Prefab elements are used for the inside wall sections (including the doors and window panes) as well as for the roofing, combined with roofing tiles. The finishing work for all of the homes of a specific type is identical. Special, separate work crews will be used for parts of the finishing work such as completing the floors, inside walls and plumbing.

A typical list of the construction steps associated with this kind of project is presented in Table 2.1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Construction Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GROUND WORK, SEWERS AND DRAINAGE</td>
</tr>
<tr>
<td>2</td>
<td>PILE-DRIVING</td>
</tr>
<tr>
<td>3</td>
<td>FOUNDATION WORK</td>
</tr>
<tr>
<td>4</td>
<td>GROUND FLOOR</td>
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<tr>
<td>5</td>
<td>TUNNEL FORMWORK</td>
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<tr>
<td>6</td>
<td>PREFAB INSIDE WALL ELEMENTS AND WINDOW PANES</td>
</tr>
<tr>
<td>7</td>
<td>WATER/GAS, PHASE 1 (ON/UNDER/THROUGH FLOORS)</td>
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<tr>
<td>8</td>
<td>ELECTRICAL, PHASE 1 (ON/UNDER/THROUGH FLOORS)</td>
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<tr>
<td>9</td>
<td>BRICKLAYING, JOINTS, ERECTION OF SCAFFOLDING</td>
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<tr>
<td>10</td>
<td>FLOOR FINISHING</td>
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<tr>
<td>No.</td>
<td>Construction Step</td>
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<td>-----</td>
<td>----------------------------------------------------------------------------------</td>
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<tr>
<td>11</td>
<td>INSIDE WALLS</td>
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<tr>
<td>12</td>
<td>ROOFING</td>
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<tr>
<td>13</td>
<td>DRAINS, GUTTERS AND DISMANTLE SCAFFOLDING</td>
</tr>
<tr>
<td>14</td>
<td>WATER/GAS, PHASE 2 (THROUGH WALLS)</td>
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<td>15</td>
<td>ELECTRICAL, PHASE 2 (THROUGH WALLS)</td>
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<tr>
<td>16</td>
<td>VENTILATION EQUIPMENT</td>
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<tr>
<td>17</td>
<td>TILING, PHASE 1 (TOILET)</td>
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<tr>
<td>18</td>
<td>LOCKS AND HINGES</td>
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<tr>
<td>19</td>
<td>WALL AND CEILING FINISHING</td>
</tr>
<tr>
<td>20</td>
<td>WATER/GAS, PHASE 3 (INSIDE CONNECTIONS AND PLUMBING)</td>
</tr>
<tr>
<td>21</td>
<td>ELECTRICAL, PHASE 3 (INSIDE CONNECTIONS)</td>
</tr>
<tr>
<td>22</td>
<td>KITCHEN UNITS</td>
</tr>
<tr>
<td>23</td>
<td>TILING, PHASE 2 (KITCHEN AND BATHROOM)</td>
</tr>
<tr>
<td>24</td>
<td>CENTRAL HEATING UNIT</td>
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<td>25</td>
<td>WALLPAPERING</td>
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<tr>
<td>26</td>
<td>LUTING</td>
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<td>27</td>
<td>PAINTING</td>
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<tr>
<td>28</td>
<td>PAVING AND OUTDOOR ITEMS</td>
</tr>
</tbody>
</table>

*Table 2.1: Typical Construction Steps in a Residential Construction Project*

Differences can be found between the *Eagle* and the *Buzzard* models with respect to the details and quality of the following points:
- water/gas and bathroom furnishings
- electrical
- layout of the inside walls
- tiling
- locks and hinges
- wall and ceiling finishing
- kitchen units
- central heating unit
- wallpapering.
In view of the fact that the homes of a given model are all identical, a rate of production of one week per activity per block of 5 homes has been planned. The size of the work crews assigned to complete the respective construction steps has been based upon this rate of production.

Based upon the background information on the construction company and the construction order, this construction order can now be analyzed to identify its "type" in terms of the theory presented in Part 2:

**Scarcity of the company resource capacities: + and -**

HOMEBUILDERS, INC. is confronted with only a limited number of scarce resource capacities. The most important scarce resources are the Project Managers, the Production Planners the Foremen and specialized work crews. Non-scarse resource capacities are e.g. scaffolding equipment and a number of subcontracted work crews.

**Employment/deployment period for the scarce company resource capacities: + and -**

The scarce resource capacities are utilized either for a relatively long (cranes, foreman, project manager) or a short period (specialized work crews) of time.

**Number of work crew assignments: > 1**

The construction order requires the completion of a large number of activities for which various (specialized) work crews are needed.

**Diversity and quantity of the materials and resource capacities: +**

The construction order has approximately 20 different construction steps, a large number of which require specialized work crews for their completion.

**Assignment-related information:-**

Each assignment in the construction order is repeated a large number of times. This means that relatively little assignment-related information needs to be communicated after the initial assignment. The initial instructions should be sufficient.

Based upon this evaluation of the relative importance of each of these factors and characteristics, the conclusion can be drawn that this most closely corresponds with a "Standard Construction Project" type of construction order.

A Project Manager, Production Planner and Foreman are allocated to this construction order for the realization of this project via the function "multi-project
planning of scarce resource capacities with a long employment/deployment period".

The project coordination task carried out by the Project Manager and the Production Planner is accomplished based upon monitoring the achievement of the milestones in the high-level project plan which has been agreed with the client. The client is primarily interested in the final "delivery" of the completed homes. This delivery will take place block by block. This means that:

1. The project coordination task will need to include making appointments with the clients for the delivery of the blocks of homes on 20 different delivery dates.
2. The project coordination task will need to include monitoring the progress of activities and the costs by calculating the consequences of any intermediate results (milestones) which have not been completed according to schedule. This should be a simple task since the specifications of all of the blocks of a particular model are identical. The Project Manager and the Production Planner are only needed on a part-time basis since the project coordination task can be simplified in this way.

Mobilization (combined with allocation) is carried out by the Foreman who is allocated on a full-time basis to this project. He is responsible for calling in the work crews and the materials needed to completed the next construction steps in the production process. Use is made of a mobilization plan (6-week plan) in connection with this. Specific information about each activity to be completed is given to the work crews only once for each model. A brief evaluation and follow-up instructions are given weekly, however, little additional information about the expected work effort is required. Nevertheless, special attention is focused on the work crew loading in order to determine the optimal cycle times for the batch work crews. Since the mobilization and allocation functions are combined, both of these aspects should be included in the calculation of the estimated time to be spent by the Foreman controlling and directing the production.

2.4 The Change

Sales of the Eagle homes are going well. In view of the arrangements made with the clients, the construction work will need to commence shortly. Sales of the Buzzard homes have been disappointing, however. This particular model is considered by potential home buyers as being too expensive. Since both types of homes are interspersed throughout the neighborhood (see Figure 2.2) and the tunnel form method of construction will be used, the Buzzard models must be built at the same time as the Eagle models. Because of the looming threat of having the wrong mix of homes, the management of HOMEBUILDERS decides to make a drastic change. The buyers of Buzzard models will now be given the opportunity to specify a majority
of the finishing aspects of these homes. The following components will now be customized based upon the client’s particular specifications:

**Prefab inside wall sections and window panes**
The buyer may choose to have a sliding door at the back of the house.

**Water/gas/toilet/bathroom/electrical/kitchen/tiling**
The buyer's own preference of toilet, kitchen and bathroom fixtures and units (including tiles) will be installed. The kitchen may be installed by any supplier and subcontractor that the buyer may choose.

**Inside walls, locks and hinges**
The buyer will be able to choose where the inside walls are to placed. The doors, locks and hinges will be delivered and installed based upon the buyer’s specifications.

**Roof**
The buyer may choose whether or not to have a dormer window installed. Extra roof windows or skylights can also be supplied.

A number of the aforementioned alternatives are included in the basic price. Other alternatives involve extra work and an additional payment.

The *Buzzard* models seem to change very little. The production control aspects will change dramatically, however. The implications of these changes can be analyzed by using the estimation model to calculate the expected amount of time to be spent by the Foreman on controlling and directing the production activities in the original situation (standard *Eagle* and *Buzzard* homes) and then comparing this to the new situation (standard *Eagle* homes and customized *Buzzard* homes).

The high-level activity plan for the original situation is presented in Figure 2.4.
**Figure 2.4: Original High-level Activity Plan for HOMEBUILDER, INC. Residential Construction Project to Build 100 New Homes in Delft**

The high-level activity plan is based upon the activities listed in Table 2.1. Most of the activities have a duration of one week per block. Some of the activities have a shorter duration, but are then repeated several times. For example, the plumber will not be able to carry out all of his tasks immediately at one time since there will be a requirement for laying new pipes at different points in time between the activities of the other work crews. This is indicated by replacing the bars in the activity plan bar chart with X’s. For the activities which are not exactly the same for both the Eagle and the Buzzard models, the Buzzard activities are shaded in the diagram.

Subsequently, a work crew is assigned to each activity. A work crew is either a mass...
production work crew or a batch production work crew. The major difference between these two types of work crews is that the mass production work crew is always involved with the same activity (such as pile-driving) while the batch production work crew performs a repeating series of activities (e.g., tunnel formwork construction).

A plan for the number of (initial and follow-up) work crew assignments and call orders is also worked out. There will always be either one or two initial work crew assignments for each activity in this case, depending upon whether the activity is identical for both models or is model-dependent. The number of follow-up assignments is dependent upon the number of blocks since a work crew always spends exactly one week per assignment per block and does not need to wait to receive any information which is specific to a particular home unit. The number of follow-up calls for material is an estimate. Based upon the information in the subsidiary tables, the various elements of the main table for the estimation model can now be completed. The tables which reflect the parameters defining the original situation are presented in Table 2.2A and B.
<table>
<thead>
<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew - No. &amp; Type</th>
<th>Number of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ground work, sewers and drainage</td>
<td>Work Crew 1 M</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/19</td>
<td>105</td>
</tr>
<tr>
<td>2. Pile-driving</td>
<td>Work Crew 2 M</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/39</td>
<td>205</td>
</tr>
<tr>
<td>3. Foundation work</td>
<td>Work Crew 3 B</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>205</td>
<td>1/99</td>
<td>505</td>
</tr>
<tr>
<td>4. Ground floor</td>
<td>Work Crew 4 B</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>205</td>
<td>1/59</td>
<td>305</td>
</tr>
<tr>
<td>5. Tunnel formwork</td>
<td>Work Crew 5 B</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>205</td>
<td>1/59</td>
<td>305</td>
</tr>
<tr>
<td>6. Prefab inside wall elements and window pans</td>
<td>Work Crew 6 B</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>205</td>
<td>1/59</td>
<td>305</td>
</tr>
<tr>
<td>7. Water/gas, phase 1 (on/under/through floors)</td>
<td>Work Crew 7 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>1/9</td>
<td>55</td>
</tr>
<tr>
<td>8. Electrical, phase 1 (on/under/through floors)</td>
<td>Work Crew 8 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>1/9</td>
<td>55</td>
</tr>
<tr>
<td>9. Bricklaying, erection of scaffolding</td>
<td>Work Crew 9 M</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/39</td>
<td>205</td>
</tr>
<tr>
<td>10. Floor finishing</td>
<td>Work Crew 10 M</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/39</td>
<td>205</td>
</tr>
<tr>
<td>11. Inside walls</td>
<td>Work Crew 11 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
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<td>305</td>
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<tr>
<td>12. Roofing</td>
<td>Work Crew 12 M</td>
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<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/59</td>
<td>305</td>
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<tr>
<td>13. Drains, gutters and dismantle scaffolding</td>
<td>Work Crew 13 M</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>100</td>
<td>1/9</td>
<td>55</td>
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<tr>
<td>14. Water/gas, phase 2 (through walls)</td>
<td>Work Crew 7 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>-</td>
<td>-</td>
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<tr>
<td>15. Electrical, phase 2 (through walls)</td>
<td>Work Crew 8 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16. Ventilation equipment</td>
<td>Work Crew 14 B</td>
<td>1</td>
<td>5</td>
<td>1/19</td>
<td>205</td>
<td>1/9</td>
<td>55</td>
</tr>
<tr>
<td>17. Tiling, phase 1 (toilet)</td>
<td>Work Crew 15 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>2/18</td>
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<tr>
<td>18. Hinges and locks</td>
<td>Work Crew 16 B</td>
<td>1</td>
<td>5</td>
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<td>210</td>
<td>1/3</td>
<td>25</td>
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<tr>
<td>19. Wall and ceiling finishing</td>
<td>Work Crew 17 B</td>
<td>1</td>
<td>5</td>
<td>2/18</td>
<td>210</td>
<td>1/9</td>
<td>55</td>
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<tr>
<td>22. Kitchen units</td>
<td>Work Crew 18 B</td>
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<td>5</td>
<td>2/18</td>
<td>210</td>
<td>2/38</td>
<td>220</td>
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<td>23. Tiling, phase 2 (kitchen and bathroom)</td>
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<td>-</td>
<td>2/18</td>
<td>210</td>
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<td>24. Central heating unit</td>
<td>Work Crew 19 B</td>
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<td>5</td>
<td>2/18</td>
<td>210</td>
<td>2/18</td>
<td>120</td>
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<td>25. Wallpapering</td>
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<td>-</td>
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<td>1/19</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>27. Painting</td>
<td>Work Crew 20 M</td>
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<td>100</td>
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<td>28. Paving and outdoor items</td>
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<td>-</td>
<td>1/19</td>
<td>100</td>
<td>2/18</td>
<td>120</td>
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</table>

**TOTAL**

| 125 min. | 4695 min. | 4065 min. |

**Table 2.2A:** Time Required by the Foreman for Controlling and Directing the Original HOMEBUILDERS, INC. Version of the Project for the Construction of 100 Homes in Delft

* Work Crew Type  
  B = Batch Production  
  M = Mass Production  
  O = One-of-kind Production
### WORK CREW INSTRUCTION AND CALL TIMES

<table>
<thead>
<tr>
<th>NAME</th>
<th>CHARACTERISTICS</th>
<th>INSTRUCTION TIME (MINUTES)</th>
<th>CALL TIME (MINUTES)</th>
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<td></td>
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<td>First time on project</td>
<td>Follow-up order on project</td>
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<td>Mass Production Work Crew</td>
<td>• Multi-project learning curve</td>
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<td>5</td>
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<td></td>
<td>• Repetitive work on project</td>
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<td></td>
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<tr>
<td>One-of-a-kind Production Work Crew</td>
<td>• Multi-project learning curve</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>• Varying work on project</td>
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<td>10</td>
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<tr>
<td>Batch Production Work Crew</td>
<td>• Project learning curve</td>
<td>15</td>
<td>10</td>
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<td></td>
<td>• Repetitive work on project</td>
<td></td>
<td>6</td>
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<tr>
<td>Unique Production Work Crew</td>
<td>• No learning curve advantage</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>• Unique work on project</td>
<td></td>
<td>10</td>
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### MATERIAL CALL TIMES

<table>
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<tr>
<th>MATERIAL CALL TIMES (MINUTES)</th>
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<tbody>
<tr>
<td>First call</td>
</tr>
<tr>
<td>Follow-up call</td>
</tr>
</tbody>
</table>

Table 2.2B: Subsidiary Table for the estimation model for the Construction of 100 Homes in Delft
After the change was introduced by company management, fundamental changes in the activity plan were also required. The intermediate deliverables to be monitored were redefined to be the individual home units instead of the original blocks of homes. A revised layout of the construction site is presented in Figure 2.5.

![Diagram of the construction site layout](image)

**Figure 2.5**: Layout of the Construction Site for 100 New Homes in Rozenaal

The revised activities have also resulted in changes to the high-level activity plan. This revised plan is presented in Figure 2.6.

The estimated effort required by the Foreman in the revised situation can be calculated as before. A number of the former batch production work crews will now need to be changed to one-of-a-kind production work crews as the result of the activities which now will be customized for each home. Another change is that a number of instructions which were originally planned as follow-up instructions or follow-up calls will now be initial instructions or calls in situations where they cannot be seen as repeats of earlier issued instructions. This leads to a significant increase in the time required for instruction and placing calls. The calculations for this new situation are presented in Table 2.3.
## Activities Duration (weeks)

| Activity                              | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Ground Work                          | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Pile-driving                          | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Foundation Work                      | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Ground Floor                          | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Tunnel Formwork                       | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Prefab Inside Wall Elements and Window Panes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Water/Gas, Phase 1                   | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Electrical, Phase 1                  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Bricklaying, Scaffolding             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Floor Finishing                      | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Inside Walls                         | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Roofing                              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Drains/ Gutters & Dismantle Scaffolding | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Water/Gas, Phase 2                   | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Electrical, Phase 2                  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Ventilation Equipment                | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Tiling, Phase 1                      | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Locks & Hinges + carpentry           | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Wall and Ceiling Finishing           | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Water/Gas/Toilet, Phase 3            | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Electrical, Phase 3                  | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Kitchen Units                        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Tiling, Phase 2                      | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Central Heating Unit                 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Wallpapering                         | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Luting                               | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Painting                             | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Paving and outdoor items             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |

Duration = 33 weeks
Instruction + calls = 330 + 15,295 + 8,355 = 23,980 minutes.
This means an average of 726 min./week = 12 hours/week.
Workload in week 17 = 1,485 min./week = 29 hours/week.

This means that each day the activity will be carried out for a different home in the specified block (2), e.g. Home 2.1 on Monday, Home 2.2 on Tuesday, etc.

**Figure 2.6: Revised High-level Activity Plan for the Construction Project to Build 100 New Homes in Delft**
<table>
<thead>
<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew No. &amp; Type</th>
<th>Number of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ground work, sewers and drainage</td>
<td>Work Crew 1 M</td>
<td>1</td>
<td>1/19</td>
<td>100</td>
<td>1/19</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>2. Pile-driving</td>
<td>Work Crew 2 M</td>
<td>1</td>
<td>1/19</td>
<td>100</td>
<td>1/39</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>3. Foundation work</td>
<td>Work Crew 3 B</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
<td>1/92</td>
<td>510</td>
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</tr>
<tr>
<td>4. Ground floor</td>
<td>Work Crew 4 B</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
<td>1/59</td>
<td>310</td>
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<tr>
<td>5. Tunnel formwork</td>
<td>Work Crew 5 B</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
<td>1/99</td>
<td>510</td>
<td></td>
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<tr>
<td>6. Prefab inside wall elements and window panes</td>
<td>Work Crew 6 A B  Bz Work Crew 6 B O</td>
<td>1</td>
<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/35</td>
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<tr>
<td>7. Water/gas, phase 1 (on/under/through floors)</td>
<td>Work Crew 7 A B  Bz Work Crew 7 B O</td>
<td>1</td>
<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/9</td>
</tr>
<tr>
<td>8. Electrical, phase 1 (on/under/through floors)</td>
<td>Work Crew 8 A B  Bz Work Crew 8 B O</td>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/9</td>
</tr>
<tr>
<td>9. Bricklaying, erection of scaffolding</td>
<td>Work Crew 9 M</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
<td>1/39</td>
<td>205</td>
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<tr>
<td>10. Floor finishing</td>
<td>Work Crew 10 M</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
<td>1/39</td>
<td>205</td>
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<tr>
<td>11. Inside walls</td>
<td>Work Crew 11 A B</td>
<td>1</td>
<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/35</td>
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<tr>
<td>12. Roofing</td>
<td>Work Crew 12 A B</td>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/39</td>
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<tr>
<td>13. Drains, gutters and dismantle scaffolding</td>
<td>Work Crew 13 M</td>
<td>1</td>
<td>1/19</td>
<td>205</td>
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<tr>
<td>14. Water/gas, phase 2 (through walls)</td>
<td>Work Crew 7 A B</td>
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<td>-</td>
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<tr>
<td>15. Electrical, phase 2 (through walls)</td>
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<td>16. Ventilation equipment</td>
<td>Work Crew 14 B</td>
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<td>1/19</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/9</td>
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<tr>
<td>17. Tiling, phase 1 (toilet)</td>
<td>Work Crew 15 A B</td>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/11</td>
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<tr>
<td>18. Hinges and locks</td>
<td>Work Crew 16 A B</td>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/11</td>
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<td>19. Wall and ceiling finishing</td>
<td>Work Crew 17 A B</td>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/5</td>
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<tr>
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<td>1/11</td>
<td>125</td>
<td>40/0</td>
<td>800</td>
<td>1/23</td>
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<td>21. Electrical, phase 3 (inside connections)</td>
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<td>-</td>
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<td>22. Kitchen units</td>
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<td>125</td>
<td>40/0</td>
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<td>23. Tiling, phase 2 (kitchen and bathroom)</td>
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<td>24. Central heating unit</td>
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<td>26. Lining</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>27. Painting</td>
<td>Work Crew 62 M</td>
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<td>100</td>
<td>1/1</td>
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<td>28. Paving and outdoor items</td>
<td>Work Crew 1 M</td>
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**SUBTOTALS**

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**TOTAL**

23960 minutes

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**Table 2.3:** Revised Model to Estimate the Time Required by the Foreman to Control and Direct the Original HOMEBUILDERS, INC. Construction Project to Build 100 New Homes in Delft

B = Batch Production
M = Mass Production
O = One-of-kind Production
Eg = Eagle
Bz = Buzzard
The effort required by the Foreman increases from an average of 4.5 hours per week in the original situation to 12.5 per week in the revised situation. If this estimation model is applied to both situations in a specific week in which a large number of construction activities are planned (e.g., Week 18), then it is apparent that a significant amount of time will need to be spent by the Foreman in this week (refer to Tables 2.4 and 2.5). In the original situation, there is no requirement for a special work crew to install the kitchens in the original situation, for example. In the new situation, however, if each home buyer designates a different supplier for the kitchen units, then the Foreman will need to call up five additional work crews. The 25 minutes reserved for this effort also appears to be optimistic!
<table>
<thead>
<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew * No. &amp; Type</th>
<th>Num. of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Num. of Initial/Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ground work, sewers and drainage</td>
<td>Work Crew 1 M</td>
<td>0/1</td>
<td>5</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Pile-driving</td>
<td>Work Crew 2 M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Foundation work</td>
<td>Work Crew 3 M</td>
<td>0/1</td>
<td>10</td>
<td>0/5</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ground floor</td>
<td>Work Crew 4 B</td>
<td>0/1</td>
<td>10</td>
<td>0/3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Tunnel formwork</td>
<td>Work Crew 5 B</td>
<td>0/1</td>
<td>10</td>
<td>0/5</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Prefab inside wall elements and window panes</td>
<td>Work Crew 6 B</td>
<td>0/1</td>
<td>10</td>
<td>0/3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Water/gas, phase 1 (on/under/through floors)</td>
<td>Work Crew 7 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Electrical, phase 1 (on/under/through floors)</td>
<td>Work Crew 8 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Bricklaying, erection of scaffolding</td>
<td>Work Crew 9 M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Floor finishing</td>
<td>Work Crew 10 M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Inside walls</td>
<td>Work Crew 11 B</td>
<td>0/1</td>
<td>10</td>
<td>0/3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Roofing</td>
<td>Work Crew 12 M</td>
<td>0/1</td>
<td>5</td>
<td>0/3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Drains, gutters and dismantle scaffolding</td>
<td>Work Crew 13 M</td>
<td>0/1</td>
<td>5</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Water/gas, phase 2 (through walls)</td>
<td>Work Crew 7 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Electrical, phase 2 (through walls)</td>
<td>Work Crew 8 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Ventilation equipment</td>
<td>Work Crew 14 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Tiling, phase 1 (toilet)</td>
<td>Work Crew 15 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Hinges and locks</td>
<td>Work Crew 16 O</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Wall and ceiling finishing</td>
<td>Work Crew 17 B</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Water/gas, phase 3 (inside connections and plumbing)</td>
<td>Work Crew 8 B</td>
<td>0/1</td>
<td>10</td>
<td>0/2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Electrical, phase 3 (inside connections)</td>
<td>Work Crew 9 B</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Kitchen units</td>
<td>Work Crew 18 B</td>
<td>0/1</td>
<td>10</td>
<td>1/1</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Tiling, phase 2 (kitchen and bathroom)</td>
<td>Work Crew 15 B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. Central heating unit</td>
<td>Work Crew 19 B</td>
<td>1/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25. Wallpapering</td>
<td>Work Crew 20 M</td>
<td>1/1</td>
<td>0</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. Lathing</td>
<td>Work Crew 21 M</td>
<td>1/1</td>
<td>5</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27. Painting</td>
<td>Work Crew 20 M</td>
<td>1/1</td>
<td>5</td>
<td>0/0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Paving and outdoor items</td>
<td>Work Crew 1 M</td>
<td>1/1</td>
<td>5</td>
<td>0/1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| SUBTOTALS | min. | 225 | min. | 205 | min. |
| TOTAL      | 475  |     |      |     |      |

* Work Crew Type
  B = Batch Production
  M = Mass Production
  O = One-of-kind Production

Table 2.4: Time Required by the Foreman to Control and Direct the Original Construction Project in Week 18
### ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN

<table>
<thead>
<tr>
<th>Activity Description</th>
<th>Work Crew No. &amp; Type</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ground work, sewers and drainage</td>
<td>Work Crew 1.M</td>
<td>0/1</td>
<td>5</td>
<td>0/1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2. Pile-driving</td>
<td>Work Crew 2.M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3. Foundation work</td>
<td>Work Crew 3.M</td>
<td>0/1</td>
<td>10</td>
<td>0/5</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>4. Ground floor</td>
<td>Work Crew 4.B</td>
<td>0/1</td>
<td>10</td>
<td>0/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>5. Tunnel formwork</td>
<td>Work Crew 5.B</td>
<td>0/1</td>
<td>10</td>
<td>0/5</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>6. Prefab inside wall elements and window frames</td>
<td>Work Crew 6.B</td>
<td>0/1</td>
<td>10</td>
<td>0/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>7. Water/gas, phase 1 (on/under/through floors)</td>
<td>Work Crew 7.B</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>8. Electrical, phase 1 (on/under/through floors)</td>
<td>Work Crew 8.B</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9. Bricklaying, erection of scaffolding</td>
<td>Work Crew 9.M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10. Floor finishing</td>
<td>Work Crew 10.M</td>
<td>0/1</td>
<td>5</td>
<td>0/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11. Inside walls</td>
<td>Work Crew 11.O</td>
<td>0/1</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>12. Roofing</td>
<td>Work Crew 12.M</td>
<td>0/5</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>13. Drains, gutters and dismantle scaffolding</td>
<td>Work Crew 13.M</td>
<td>0/1</td>
<td>5</td>
<td>0/1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>14. Water/gas, phase 2 (through walls)</td>
<td>Work Crew 7.O</td>
<td>0/5</td>
<td>75</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>15. Electrical, phase 2 (through walls)</td>
<td>Work Crew 8.O</td>
<td>0/5</td>
<td>75</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>16. Ventilation equipment</td>
<td>Work Crew 14.B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>17. Tiling, phase 1 (toilet)</td>
<td>Work Crew 15.O</td>
<td>0/5</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>18. Hinges and locks</td>
<td>Work Crew 16.O</td>
<td>0/5</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>19. Wall and ceiling finishing</td>
<td>Work Crew 17.B</td>
<td>0/5</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>20. Water/gas, phase 3 (inside connections and plumbing)</td>
<td>Work Crew 7.B</td>
<td>0/5</td>
<td>75</td>
<td>5/0</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>21. Electrical, phase 3 (inside connections)</td>
<td>Work Crew 8.B</td>
<td>0/5</td>
<td>75</td>
<td>0/1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>22. Kitchen units</td>
<td>Work Crew 19.B</td>
<td>5</td>
<td>25</td>
<td>0/1</td>
<td>10</td>
<td>5/0</td>
</tr>
<tr>
<td>23. Tiling, phase 2 (kitchen and bathroom)</td>
<td>Work Crew 20.B</td>
<td>0/1</td>
<td>10</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>24. Central heating unit</td>
<td>Work Crew 59.B</td>
<td>0/1</td>
<td>10</td>
<td>0/1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>25. Wallpapering</td>
<td>Work Crew 60.M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>26. Luting</td>
<td>Work Crew 61.M</td>
<td>0/1</td>
<td>5</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>27. Painting</td>
<td>Work Crew 62.M</td>
<td>0/1</td>
<td>5</td>
<td>0/0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>28. Paving and outdoor items</td>
<td>Work Crew 1.M</td>
<td>0/1</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

#### TOTAL

<table>
<thead>
<tr>
<th>Subtotal</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1495 minutes</td>
<td></td>
</tr>
</tbody>
</table>

* Work Crew Type
  - B = Batch Production
  - M = Mass Production
  - O = One-of-kind Production

---

**Table 2.5:** Time Required by the Foreman to Control and Direct the Revised Construction Project in Week 18
The work week of the foreman appeared to be completely filled in the original situation (considering miscellaneous administrative tasks, inspections within and outside of the construction site, consultations with the client, architect, etc.) This suggests that increasing the amount of time required for directing the production activities to approximately 25 hours per week is not really feasible in practice (refer to Table 2.5). An additional factor is that the uncertainty of delivery lead times, actual quantities to be delivered, etc. will increase as the diversity of products and suppliers increases. This construction project would, thus, quickly become uncontrollable based upon the original control approach (i.e., based upon the "Standard Construction Project" type of construction order) and the original rate of construction.

2.5 Modified Control of the Construction Order

The control can be improved in a number of ways:

1. by reducing the rate of production or increasing the information processing capacity so that the time needed by the Foreman can be reduced to the previous level;

2. by regrouping the activities in such a way that the unaffected activities can still be controlled as a "Standard Construction Project" and the changed activities controlled in a more suitable manner;

3. by using the design rules to determine a more appropriate method of controlling the changed construction order.

Regarding 1.(Reducing the rate of production or increasing the information processing capacity so that the time needed by the Foreman can be reduced to the previous level)

The most important factor contributing to an increased lack of control is that there is much more information to be collected and communicated within the same period of time. This leads to problems concerning the processing capacity of the collector of the information (the Foreman) such as how the data should be recorded and how the information can be retrieved. Other problems are related more to the data processing and storage capacity of the receiver of the information (the work crew leader). The quantity of data to be processed within the given period of time is too great. Even though there are obvious ways to automate the data entry and data retrieval functions, the net result of employing automated techniques should not be
overestimated. To start with, the working environment at a construction site is typically very dusty and ill-suited for most computers and computer terminals. In addition, the entry of data into a computer system will always consume a great deal of time. Control over the accuracy of such data would also be difficult, while errors made at this point could cause significant disruptions in the production process. The validation of input data requires general insights into the construction aspects (regarding what is feasible or infeasible) and into the specific construction project (regarding the acceptable level of complexity).

Reducing the rate of production is a possible alternative, but generally not desirable. This type of solution should be seen as a possible, additional measure to be taken rather than as the only solution.

Regarding 2. (Regrouping the activities in such a way that the unaffected activities can still be controlled as a "Standard Construction Project" and the changed activities controlled in a more suitable manner)

A number of activities (such as building the structure) will always have a batch production nature. This suggests that it might be useful to combine, for example, all of the activities involved in building the structural components (i.e., Activities 1 through 10 and 12, in this case). These activities can be carried out completely as batch production activities. In the case study example, here, no dormer windows and sliding doors would be installed. The "Standard Construction Project" type of control could then be used for this part of the construction project. Any complications resulting from the customized finishing work (e.g., problems with the delivery of materials) would not affect the control of this part of the project.

The finishing work would then be customized. All of the finishing activities for a specific home could be combined and issued as a single order to a multi-skilled ("all-round") finishing crew. Such an order would not be issued until all of the materials have been received. This type of all-round finishing crew can be directed from a central storage and supply area at the construction site. The finishing crew resembles a small, independent construction company in this way. The construction orders for finishing the homes (including the installation of sliding doors and dormer windows) can be characterized best as "Work Order Production" situations. In addition, the central storage and supply area could probably be used as a base for multiple projects. This particular subject has already been discussed at length in Part 2 in the "Intermezzo on the Applicability of Industrial Approaches to Production Control in Construction".
Regarding 3. (Using the design rules to determine a more appropriate method of controlling the changed construction order)

By applying the design rules once again, it becomes apparent that one of the factors has changed: the number of assignment instructions has increased significantly. This means that the character of the project has changed from a "Standard Construction Project" type of construction order to a "Unique Project" type. The design rules dictate that the mobilization and allocation planning activities should no longer be combined in the new situation. If the mobilization and allocation functions are no longer integrated, then it is now feasible to assign the responsibility for these functions to more than one person. In the case study situation, the Foreman is now seen as a Chief Foreman who is responsible for the mobilization and a number of foremen reporting to him have taken over the responsibility for the allocation activities.

2.6 Specification of the Control of HOMEBUILDERS, INC.

The HOMEBUILDERS, INC. construction order described above has changed from a "Standard Construction Project" type of construction order to a "Unique Project" type. Subsequent analysis shows that residential construction projects of HOMEBUILDERS, INC. can be characterized as "Unique Project" or "Standard Construction Project" types of construction orders. The total decision system found within HOMEBUILDERS, INC. is illustrated in Figure 2.7. This decision system has been clearly designed to support both of these types of construction orders.

An interpretation of the actual situation within HOMEBUILDERS, INC. is provided in the following sub-sections for each of the decision functions illustrated in Figure 2.7. In connection with this, the decision aspects and information aspects are treated as an integral whole.

2.6.1 Business planning

The company should have a clear picture of its strengths and weaknesses for the purpose of formulating its future business objectives. The analysis required for this can be derived from historical data and statistics (internal as well as external).

The revenue and profitability data could be compiled for each order category (e.g., residential construction, small-scale construction, commercial buildings) by totalling this data for all of the realized construction orders in past periods. This means that
the data regarding the construction price, the total costs and the market sector must be recorded in an appropriate way for each of the construction orders in order to be able to compile this information. It is, thus, important to establish a good classification scheme for coding the various types of construction orders.

Other useful data should also be recorded in an appropriate way. Useful data which is not associated with the realized construction orders includes data about potential orders for which no quotation was issued.

Examples of external information would be the published financial results reported by competitors and trends identified in the volume of new construction work (or, in the case of HOMEBUILDERS, INC., the decreasing volume of construction work in the subsidized residential construction sector). This data should be maintained per order category.
It is essential that the available internal and external data is readily accessible and can be analyzed easily. Analyzing the data per time period is useful for recognizing trends. An analysis of the strengths and weaknesses with respect to the competition can be carried out by combining the internal and external data (e.g., about the profitability of a specific market sector).

Business objectives can be formulated based upon the analysis of strengths and weaknesses. A normal strategy is to reinforce the strengths to make optimal use of the existing competitive advantages. At the same time, it is typically desirable to implement improvements to eliminate the recognized weaknesses or to reposition the company's activities in such a way that the weaknesses are no longer relevant. An example of this last strategy would be to decide that no new orders will be accepted of a certain type or within a certain sector which has proven to be unprofitable in the past.

**Example**

The strategic business objectives of HOMEBUILDERS, INC. were not explicitly mentioned as part of the company profile. It was noted (under the section on "Work-in-Progress") that HOMEBUILDERS, INC. is active solely in the Residential and Commercial Building Sector and that approximately 60% of the company's revenue is derived from large-scale residential construction projects, 30% from commercial building projects and 10% from small-scale residential construction projects (luxury homes). It was also mentioned that the company has accumulated extensive experience with modern production techniques in the large-scale residential construction sector. In addition, a significant amount of effort has been spent on the development of various formwork systems for use in large-scale residential construction projects.

It can be assumed that the revenue to be derived from residential construction projects will diminish significantly in the coming years, forcing HOMEBUILDERS, INC. to make some important strategic decisions. It is relevant to consider whether HOMEBUILDERS, INC. should rely on its strong expertise (experience in the residential construction sector and the use of efficient formwork techniques, etc.) or concentrate, instead, on generating future revenue in other sectors of the construction industry. We can, for example, assume that HOMEBUILDERS, INC. will wish to choose for a shift in emphasis with respect to the market sectors in which it will operate in the future. The business objective then needs to be reformulated to indicate that HOMEBUILDERS, INC. intends to reduce the percentage of the total revenue to be derived from the residential construction sector in favor of a higher percentage of revenue from the commercial building sector. By making this decision,
HOMEBUILDERS, INC. implicitly accepts the fact that the lower average profitability of construction projects in the commercial building sector (refer to Table 2.6) may adversely affect the company's total profits in the near term.

<table>
<thead>
<tr>
<th></th>
<th>Large-scale Residential Construction Projects</th>
<th>Large-scale Commercial Building Projects</th>
<th>Small-scale Residential Construction Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of revenue</td>
<td>45%</td>
<td>45%</td>
<td>10%</td>
</tr>
<tr>
<td>Profitability</td>
<td>4%</td>
<td>1.5%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 2.6: Basic Assumptions underlying the Business Strategy of HOMEBUILDERS, INC.

By accepting a lower level of profitability on a higher percentage of commercial building projects, the company as a whole will be faced with poorer financial results (assuming the same level of overhead expenses). In view of a basic need to ensure the continuity of the company, this development would not be desirable. To compensate for the consequences of this shift in the revenue, the total revenue in the coming year will need to be increased by approximately 35 million dollars to provide a better coverage of the overhead expenses. The distribution of revenue across the three important market sectors has, therefore, been planned as follows:

- large-scale residential construction: $15.75 million
- large-scale commercial building projects: $15.75 million
- small-scale residential construction: $3.5 million

Organizational aspects

The company management is, of course, responsible for the ultimate development of the business strategy. Various staff employees will need to support this effort by collecting and maintaining the required data.

2.6.2 Resource capacity planning for scarce resource capacities

This decision function is strongly related to the Business Planning function as indicated previously in Part 2. The underlying purpose of this function is to ensure that sufficient scarce resource capacity is available within the company in the future.
period covered by the Business Plan so that the objectives formulated in the Business Plan can actually be achieved. If it is apparent that the desired resource capacity cannot be made available in a timely manner, the Business Plan will need to take this into account.

A number of resource capacities cannot be easily expanded (even with external assistance) in the case of HOMEBUILDERS, INC.. Examples of these scarce resources are certain staff personnel (Foreman, Production Planner, Project Manager) and the work crew which is specialized in the construction of tunnel formwork.

To start with, it is necessary to determine to what extent the currently available resource capacity will also be available in the future. The factors of suitability (experience in carrying out certain types of construction orders, etc.) and availability are both relevant. Each year a certain amount of turnover in personnel can also be expected (due to early retirement, change of employer, illness, etc.). It is important to have a reliable forecast of the significance of both of these factors. Data is also required concerning the expected loading of the resource capacities resulting from the various construction orders. An example of this is noting the specific work experience for each foreman so that their specific experience with certain types of construction orders can be reviewed easily and evaluated objectively. This can provide a good basis for the preparation of the company's organizational development plan.

The resource capacity plan should focus on improving the availability and suitability of the resources over a period of a year or more, taking the aforementioned basic data into account. In addition to the recruitment of the required personnel, attention should also be paid to continuing education and training programs.

**Example**

The past revenue per sector was as follows:

- large-scale residential construction $18.0 million
- large-scale commercial building projects $9.0 million
- small-scale residential construction $3.0 million

An implication of the Business Plan example presented in the previous sub-section is that the revenue in the large-scale commercial building sector, in particular, will need to increase dramatically (by almost 50%). In view of the specific characteristics of this type of construction work, this change will have significant
consequences for the loading of the resource capacities within the company, such as:

- The Sales Department will need to be expanded to include additional expertise and contacts for the acquisition of commercial building projects. An additional Salesman specialized in this sector will be required.

- A similar situation exists with respect to the Production Planners in the Production Planning Department. The recruitment of an additional Production Planner for this department with specific experience in the commercial building sector will be required. The arrangement of training programs in techniques used specifically in the commercial building sector may also be needed.

- The number of foremen will need to be increased (with specific experience in the commercial building sector).

**Organizational aspects**

Similarly, this decision function should be carried out by company management.

### 2.6.3 Construction order acceptance

The first step included in this decision function involves determining the particular type of the construction order, the risks associated with the order and the specific types and quantities of staff needed to complete the order. This decision process will generally be carried out based upon a detailed specification document provided by the client. A cost estimate can be prepared along with an evaluation of the financial risk associated with the project in order to arrive at an indication of the total construction price for the project.

An evaluation must be made regarding the feasibility of completing the construction order in view of all of the risks and conditions imposed by the aforementioned plans. In other words: does this potential order fit within the constraints of the Business Plan and, just as important, will the key resource capacities be available during the period of time planned for carrying out the construction order? This last question is answered by the "Multi-project Planning for Scarce Resource Capacities with a Long Employment/Deployment Period".

The risk associated with the acceptance of the potential order is another aspect which
needs to be included in the evaluation. This risk evaluation should also take the risk of other (already accepted) orders into consideration.

If the order is accepted, the desired start and completion dates as specified by the client are then recorded on the order summary report. The data on this summary report is used by various departments within the company, including departments which are not directly concerned with production control aspects. One example of this is the cash flow projection data which is consolidated at the company level.

The resource capacities needed to carry out the construction order are reserved as part of the multi-project planning activity which is based upon internal orders.

Historical data and statistics are recorded which are important input for the Business Planning decision function. This data is also important even if the construction order is not accepted by the company or is not granted by the client. The result of the acceptance decision is also recorded on the order summary report.

Example

In the case of HOMEBUILDERS, INC., the Business Plan explicitly states that three market sectors are of importance for future business (large-scale residential construction, large-scale commercial building projects and small-scale residential construction). These strategic directions should be seen as important guidelines in evaluating to which invitations to tender to respond, and which quotations to price most competitively (being the most desirable construction orders). Renovation orders, for example, are not included in the strategic business plan and should, thus, never be given priority over the three types of strategic construction orders.

Organizational aspects

This decision function is also to be carried out by company management.

2.6.4 Multi-project planning for scarce resource capacities with a long employment/deployment period

The available resource capacities are reviewed, periodically, in connection with the Construction Order Acceptance function. As seen previously in the case of HOMEBUILDERS, INC., only the hours of the staff personnel need to be scheduled. This means that the plan developed here could also be referred to as a Staff Loading
Plan. As mentioned under Sub-section 2.6.3, there is a strong relationship between this function and the Construction Order Acceptance function.

Example

The Multi-project loading Plan for scarce resource capacities in the case of HOMEBUILDERS, INC. has a simple structure. Since there are only a few staff employees who need to be included in the schedule, it is relatively easy to maintain a good overview of the workload. This overview can then be used as the basis for decision-making about the future work planning for the personnel and providing information to the Construction Order Acceptance function concerning the expected availability of key resources. An example of a multi-project loading plan for the scarce resource capacities is presented in Figure 2.8.
**MULTI-PROJECT LOADING PLAN FOR SCARCE RESOURCE CAPACITIES**

**Date:** Nov. 30, 1992

<table>
<thead>
<tr>
<th>Project Managers:</th>
<th>Production Planners/Foremen:</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Bleeker</td>
<td>H. Koop F. Hoorspel</td>
</tr>
<tr>
<td>P. de Wit</td>
<td>P. Voets P. Klein</td>
</tr>
<tr>
<td></td>
<td>C. Brouwer J. de Wit G. kelzer G. Rijn</td>
</tr>
</tbody>
</table>

| week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 |
|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|      | 100 homes Delft | office building "De Pijp" Rotterdam | Yale trade center | 115 homes Eindhoven | prison Gouda | 600 homes Eindhoven |
|      |                |                                |                  |                |                 |                  |
|      |                |                                |                  |                |                 |                  |

(Staff Loading Plan)
Organizational aspects

The types of decisions described in this sub-section can only be made by a member of the Management Team. In the case of HOMEBUILDERS, INC., this would be the Technical Director. Regular meetings with the Project Managers are also important in connection with this function.

2.6.5 Project coordination

Project coordination consists of controlling the time and cost aspects. Project management techniques such as PERT and CPM are recommended for use in unique projects. The line-of-balance techniques, on the other hand, are more suitable for use in a "Standard Construction Project" situation. Both of these techniques have already been discussed in Part 2 (see also [Pilcher-1992]).

Example (project management technique)

The project is first decomposed using a "work breakdown structure". An suitable configuration is created in this way for structuring the cost data and scheduling data. A work breakdown structure can also be defined for the construction project in this case study.

The high-level activity plan for the revised situation in which the Buzzard homes are to be customized was discussed in Section 2.4. The revised plan shows that certain activities must now be scheduled for each individual home instead of per block of homes as in the original situation. A Preparation Diagram can be derived from the high-level activity plan for the purpose of obtaining an adequate overview of the specific decision and review points.

Example (line-of-balance technique)

The line-of-balance technique is especially suited for scheduling and monitoring the progress of a batch production process incorporating a series of activities (which progress in a linear fashion). This is exactly the situation with a "Standard Construction Project" type of construction order. This is specified in more detail in the project example involving the construction of 100 new homes in Delft (Figure 2.9).

The number of completed homes (with respect to a particular activity) is represented
by the vertical axis. The elapsed production time in weeks is represented by the horizontal axis. The anticipated number of completed homes for any of the charted activities in a given week can be found by reading the graph. Similarly, the respective weeks in which the charted activities are expected to be completed for any given home (numbered sequentially) can also be found. A line-of-balance graph can be produced to monitor the progress of the production activities. This type of graph displays the actual progress in relation to the production schedule (see Figure 2.10).

The schedule lines are all parallel to each other in the example shown here. This is a consequence of the assumption that all of the work crews work at a rate of five homes per week, regardless of the particular activity involved. This method of planning and scheduling is especially useful for analyzing what variances in this rate
of production will still be acceptable or, inversely, what the effect of variances in the production rate will be on the progress of the total project.

Organizational aspects

The Project Manager is responsible for carrying out the Project Coordination function in the situation of HOMBUILDERS, INC.. The Production Planner in responsible for supporting the Project Manager in this area.

2.6.6 Mobilization planning

The Mobilization Planning decision function is related to the detailed scheduling and monitoring the progress of the work crew assignments. Also included are the
deliveries of resource capacities and materials to the construction site, taking the actual progress and disturbances in the production process into account.

One or more work crew assignments may be identified, depending upon the type of activity under consideration. Particular attention is paid to any requirements for the transfer of information in connection with these activities. Whenever a new instruction is given to a work crew, this means that a new work crew assignment has been initiated. This occurs when, for example, different materials need to be used for an activity, even if the activity, itself, is being repeated (such as the installation of a different kitchen unit in a subsequent home). A work crew assignment may not take longer than one week to complete in this case study situation.

Up-to-date information is required about delivery dates (and any expected delays) in order to be able to schedule the work crew assignments. An additional important condition or limitation is imposed by the "Multi-project Planning for Scarce Resources with a Short Employment/Deployment Period" decision function as described in the next sub-section.

This data is used as the basis for preparing the detailed schedule of work crew assignments. The scheduling process should result in an optimal loading of the work crews, taking the goals and objectives as formulated in Part 2 into account.

The materials and work crews are called up at the appropriate time, based upon the assignment schedule, so that they will be available at the construction site when they are required. This procedure is the same for internal orders (the company work crews) as well as external orders (call orders).

Example

The Mobilization Plan for the resource capacities (equipment and work crews) is determined based upon the high-level activity plan. The number of calls for resource capacities will remain limited provided that the activities for a work crew or unit of equipment are coordinated to the extent that they follow one another without significant time gaps. A batch production process will be used to a great extent in the case study presented here. This means that each work crew will be able to remain at the construction site for a relatively long period of time. Each work crew will normally be scheduled for whole days at a time. In other conceivable situations (e.g., where a shovel might be needed during the construction of a road), a unit of equipment may only be needed for several hours each day. Coordinating the utilization of such equipment for different assignments within the period of a single day cannot be seen in the high-level activity plan. This type of optimalization must be
considered, where appropriate, when the mobilization plan is developed. An example of this is discussed in connection with a case study in the road construction sector (see Chapter 3).

A Mobilization Plan is often developed in practice by developing a plan for the coming four to six weeks, and then reviewing and revising this plan as necessary every two weeks. The high-level activity plan can be used as the basis for specifying the types and quantities of the materials to be used for each specific activity. The types and quantities of the materials for each activity could be specified once for each block of homes in the original situation (where there were only two standard home models to be considered). An example of a specification at this level would be "5 kitchen units in accordance with Drawing 20 for Block 2 (Buzzard model) to be supplied by Johnson Kitchens". The types and quantities in the revised situation must now be specified per home, for example: "1 kitchen unit in accordance with Drawing 25 for Home 2.1 to be supplied by Moss Kitchens, 1 kitchen unit in accordance with Drawing 28 for Home 2.2 to be supplied by Johnson Kitchens." The challenge now is to determine to what extent separate orders can be combined so that an efficient Mobilization Plan (for two to six weeks in advance) can still be developed.

The activities defined in the Project Coordination function may need to be split up into sub-activities and specified in more detail for the purpose of the 6-week schedule. The various material requirements and resource capacity requirements subsequently need to be related to the sub-activities. Each sub-activity must be related to one or more material and resource capacity requirements. The 6-week schedule and call schedules can be generated based upon this data and the defined relationships.

In addition, it must be possible to link specific work crew instructions to a given home in this case (e.g., eliminate the wallpapering for the ground floor). In certain instances (e.g., where abnormally long delivery lead times exist) it may be necessary to schedule activities more than six weeks in advance.

When a change in the specifications of a home are accepted by the Production Planner, he also needs to determine which work crew assignments are affected. The practical feasibility of making the requested changes can be determined based upon the high-level project activity plan and the 6-week schedule.

Organizational aspects

In the case of HOMEBUILDERS, INC., the performance of this function is the responsibility of the (chief) foreman. The project coordination activities carried out
by the Production Planner, however, include keeping track of the detailed specifications for each construction activity (or, in the revised situation for the Buzzard models, the detailed specifications for each activity for each home).

2.6.7 Multi-project planning for scarce resource capacities with a short employment/deployment period

This decision function is essentially the same as the "Multi-project Planning for Scarce Resources with a Long Employment/Deployment Period" decision function, with the only difference being that the resource capacities are only allocated for a short period of time (e.g., a work crew for drilling holes in concrete). Minor disruptions (such as a delay of one day) can become major problems when they are, relatively speaking, longer than the total employment/deployment period of the resource capacity. This means that the multi-project scheduling should normally be done with a limited planning horizon. This decision function is, therefore, closely related to the "Mobilization Planning" decision function rather than the "Construction Order Acceptance" decision function (as in the case of the "Multi-project Planning for Scarce Resources with a Long Employment/Deployment Period" function).

Example

In the case of HOMEBUILDERS, INC., this function is relevant for sharing the specialized work crews between the various construction projects (e.g., the work crew specializing in foundation work). This decision function is also applicable particularly in connection with large units of equipment (such as tunnel formwork equipment). This function is carried out in the same way as the "Multi-project Planning for Scarce Resources with a Long Employment/Deployment Period" decision function (refer also to Figure 2.8).

Organizational aspects

To the extent that the "multi-project planning for scarce resources" is applicable to human resources, the final decisions in this area will be made by the Technical Director in collaboration with his Project Managers. In most instances these decisions will be dealt with during the biweekly meeting between the Project Managers and the Technical Director.

When this decision function applies to the construction equipment, the Maintenance & Storage Department is then responsible.
2.6.8 Multi-project planning for readily available resource capacities

This decision function deals with monitoring the availability of resource capacities which the company has and can also easily expand when necessary by renting or subcontracting. This usually involves the relatively unskilled labor at the construction site and a large portion of the equipment in the storage yard.

The most important aspect of this decision function is monitoring how much capacity is still available and taking action as necessary to ensure that any additional capacity requirements are procured in a timely manner. The traditional inventory control decision rules typically found in the field of Industrial Engineering can be used here.

Example

This decision function applies to a large majority of the personnel at the construction site. Within HOMEBUILDERS, a regular meeting is held biweekly between the Project Managers and the Technical Director to discuss the personnel plan (among other things). In situations where it is apparent that there will be a shortage of personnel within a period of four weeks after the meeting, a decision is then made to recruit or otherwise arrange for new personnel. Similarly, any excessive personnel during this period are discharged. The multi-project plan is used only as a general indication of future requirements for the longer term.

Organizational aspects

To the extent that this decision function applies to human resources, the final decisions in this area will be made by the Technical Director in collaboration with his Project Managers. When this decision function applies to the construction equipment, the Maintenance & Storage Department is then responsible.

2.6.9 Allocation planning

As indicated in Figure 2.7, an allocation plan is required in the revised situation. Such an allocation plan not only shows who has been allocated to which activities, but also which detailed information needs to be communicated to a particular production unit.

In some instances it is sufficient to allocate a work crew to a given activity. In other instances it is necessary to allocate specific tasks to certain individuals within a work
crew, however, and to discuss the detailed work instructions individually. An allocation plan is normally prepared on a daily basis, but may specify allocations per hour if necessary.

*Example*

An example of an allocation plan is shown in Figure 2.11. A more detailed description of allocation plans (also referred to as work arrangements or task diagrams) can be found in [Twijnstra-1969].
<table>
<thead>
<tr>
<th></th>
<th>MO</th>
<th>TU</th>
<th>WE</th>
<th>TH</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground floor walls</strong> 8.3</td>
<td>Extra partition Home 8.1 according to Drawing 3072</td>
<td>Ground floor walls Home 8.3 according to Drawing 3079</td>
<td>Ground floor walls Home 8.4 according to Drawing 3081</td>
<td>Ground floor walls Home 8.6 according to Drawing 3089</td>
<td></td>
</tr>
<tr>
<td><strong>(standard)</strong></td>
<td>Drawing 3078</td>
<td>Drawing 3080</td>
<td>Drawing 3082</td>
<td>Drawing 3081</td>
<td></td>
</tr>
<tr>
<td><strong>Jansen</strong></td>
<td></td>
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<td><strong>Neefjes</strong></td>
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</table>

Walls Home 8.2 (standard)

2nd story walls Home 8.3 (standard)

2nd story walls Home 8.4 (standard)

2nd story walls Home 8.5 according to Drawing 3097
Organizational aspects

The responsibility for the Allocation Planning decision function rests with one of the foremen reporting to the Chief Foreman. The most important reason for developing an allocation plan is to have a control instrument which can be used at a lower level (with more detailed information) than the Mobilization Plan, but still within the framework of the Mobilization Plan. The foreman can schedule, monitor and direct the activities of the work crews and work crew members in this way, based upon the resources (materials, equipment and personnel) assigned to him by the Chief Foreman.

2.7 Reviewing the Totality of the Information System

Complexity of the composition of the decision information

The information system within HOMEBUILDERS, INC. should be designed to support the unique project as well as the "Standard Construction Project" types of construction orders. Both of these types of projects use the same decision functions, for the most part - thus, a single information system is used. Separate support modules are required in the special cases of "Mobilization Planning", "Allocation Planning" and the combined "Mobilization Planning/Allocation Planning" decision function. Special attention is paid to the automated support of all of these decision functions in Section 2.8.

Uncertainty of the decision information

Since each home buyer is allowed to specify his own particular wishes in the unique project situations, there is a large degree of uncertainty with respect to the final requirements. The information system, therefore, needs to provide extra support in this area to improve the controllability of this problem. One possibility is to make use of a Preparation Diagram which can be generated based upon the high-level activity plan. An example of a Preparation Diagram is presented in Figure 2.12 for the revised situation for the construction of the 100 new homes in Delft.

The uncertainty associated with delivery dates exists for a "Unique Project" as well as for a "Standard Construction Project". This is primarily due to the fact that much of the work is performed by subcontractors. Disruptions in the production work being carried out by one work crew typically have a direct effect on the work of another work crew.
### Activities

| Activities                                      | Duration (weeks) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| First pile: Week 1, 14:00 hours               |                  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Orientation meeting per home #2               |                  | 2 | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Outside view specifications finalized per home|                  | 2 |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Inside walls and hardware specifications finalized per home |          | 2 |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Gas/water/toilet/bath fiture specifications finalized per home |              | 2 |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Roofing specifications finalized per home     |                  | 2 |   |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Tiling specifications finalized per home      |                  | 2 |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Kitchen unit specifications finalized per home|                  | 2 |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Wallpapering/ceiling specifications finalized per home |              | 2 |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Completion/Acceptance per block (Friday afternoon) |           | 2 |   |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Arrange appointments with City Hall           |                  | 2 |   |   |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |
| Arrange appointments for utility connections  |                  | 2 |   |   |   |   |   |   | 8 | 9 | 10 | 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 18 | 18 | 18 |

* Home 1 in the block at 14:00 hours
Home 2 in the block at 14:45 hours
Home 3 in the block at 15:30 hours
Home 4 in the block at 16:15 hours
Home 5 in the block at 17:00 hours

# Home 1 in the block at 20:00 hours on Monday
Home 1 in the block at 20:00 hours on Tuesday
Home 1 in the block at 20:00 hours on Wednesday
Home 1 in the block at 20:00 hours on Thursday
Home 1 in the block at 20:00 hours on Friday

---

**Figure 2.12**: Preparation Diagram for the Revised Project to Build 100 New Homes in Delft

### 2.8 Reviewing the Automated Information System

The general architecture of HOMEBUILDERS, INC. can best be reviewed using an illustration of the two types of projects (unique and standard) which is presented in Figures 2.13a and 2.13b.
A number of the applications are identical for both types of projects. The same transaction processing and decision support processes are performed in both situations. This involves three of the functions, namely: "multi-project planning for readily available resource capacities", "multi-project planning for scarce resources with a short employment/deployment period" and "multi-project planning for scarce resources with a long employment/deployment period".

In the other functions, similar information is treated in a different way, depending upon the type of project. For example, a characteristic of a "Standard Construction Project" is that the activities are comparable, even when they are associated with different construction orders. This means that experience, statistics, reference models
and reference activities are extremely useful for planning and estimating purposes.

The mobilization and allocation applications exhibit even more differences between the two types of projects. This is due primarily to the fact that allocation and mobilization are combined in the case of a "Standard Construction Project", but separated for a "Unique Project". This difference was discussed in the previous subsections describing the decision functions.
2.9 Automated Information System Locations

The implementation of the complete general architecture of the automated information system implies a geographical distribution of the applications and the data base. This means that data needs to be transferred between various locations.

Office automation

Most of the automated processes within a construction company are typically found within the central office. This is also the case within HOMEBUILDERS, INC. Most of the traditional applications involve transaction processing in connection with the administrative areas of the business. The proposed architecture shows that certain data elements are required in multiple applications (transaction processing as well as decision support applications). This suggests that the software as well as the data base should be based upon an integrated concept.

Construction site automation

The mobilization and allocation planning applications as well as the data entry applications for recording operations and work crews (e.g., what is called up, what has been delivered, the number of hours spent) are used by the foreman at the construction site. Reliable and efficient protocols for exchanging data need to be established by the software vendor in view of the extensive use of data which is common with, for example, the project coordination function and the administrative support services. It is possible to make use of the existing data communications protocols of the large international network providers, however, an extra complicating factor would be introduced in this way for the exchange of data between physical locations (such as the construction site and the central office) via an external data network. Nevertheless, the use of external data communications networks for the internal communications within a single company has become more popular within the construction industry in recent years.

Automation at the supplier

Some of the data referred to in the general architecture is maintained by the suppliers. This data typically concerns the information about materials and external resource capacities. This type of data is largely independent of any particular situation as far as the contractor is concerned. This means that this data will normally be maintained as project-independent data within his own general architecture.
Current price data, product availability, etc. are, nevertheless, definitely dependent upon the specific situation and can be provided by the supplier upon request. The need to request information each time from the supplier can be reduced by establishing a link between the internal general architecture and external data bases. The quantity of data which is available about suppliers continues to increase. A number of different developments are providing useful results (such as the CIN-Bouw, a construction industry data base and network in the Netherlands and COBOTEL in France). It should be possible to communicate interactively with these data bases making agreements about standard electronic messaging protocols (Electronic Data Interchange). Refer also to [Van der Vlist et al.-1992].
3 ROAD CONSTRUCTION CASE

3.1 Introduction

A case study of a road construction project is presented in this chapter. This chapter is organized similarly to the structure of Chapter 2 in which the residential construction case study was presented.

A profile of the construction order and the construction company designated to carry out this construction order is presented, first, in Section 3.2. Based upon this profile, the design rules developed in Part 2 are then applied to this situation. The technical work preparation and the type of construction order which most closely corresponds with this construction order is then discussed in Section 3.3. Subsequently, a change in the construction order is introduced in Section 3.4 which then leads to the need for a different control approach. The revised control approach for this construction order is discussed in further detail in Sections 3.5 through 3.7).

3.2 Description of the Construction Company and the Construction Order

Similar to the previous case study description, the background information concerning the company and the construction order are presented, first.

*The construction company*

The construction order is to be carried out by the company "ROADBUILDERS, INC." of The Hague. ROADBUILDERS can be characterized as a regional, medium-sized contractor specialized in the road construction sector. The company is owned by the children of the original founder.

**BACKGROUND INFORMATION ON ROADBUILDERS, INC.**

Name

ROADBUILDERS, INC.
Annual Turnover

The annual turnover of ROADBUILDERS, INC. varies from year to year. ROADBUILDERS, INC. realized a turnover of approximately $45 million in the most recent fiscal year, while the previous year showed a total revenue of $33 million. The forecasted revenue for the coming year is in excess of $100 million. The average gross operating profit (before taxes) has been approximately 5%.

Organizational Structure

The organizational structure of ROADBUILDERS, INC. is presented in Figure 3.1.

The following functions and departments can be identified in Figure 3.1:

Management

The company Management Team consists of the Financial Controller, the Sales Director and the Technical Director.

Office Services

Three secretaries are employed and are responsible for distributing and collecting the incoming and outgoing mail, copying, typing correspondence, answering the telephone, etc.

General Administration

Six persons are employed in this department which is responsible for the payroll, the financial accounting and the project administration.

Production Planning

This department is responsible for carrying out the preparatory activities for projects (including calculating the cost budgets for proposed projects) and supporting the activities at the construction site (project planning during the application phase). The purchasing function is also included in the Production Planning Department.

Maintenance & Storage Yard

The Maintenance & Storage Yard is, first of all, responsible for maintaining all of the equipment. The Equipment Operators also belong to this department. The reason for this arrangement is that some of the equipment is not used continuously because of its highly specialized nature and resulting low utilization percentage. The various projects hire equipment, including the operators, from the Maintenance & Storage Yard. The exceptions to this are the All-round Work Crews which take care of incidental projects and have their own personnel and equipment (such as trucks, vans, shovels) and the Asphalting Work Crews which also have their own equipment (such as paving equipment, insulated trucks, trailers, asphalting machines, spreading and adhesion trucks and rollers). The Maintenance & Storage Yard takes care of the maintenance of the equipment belonging to these special work crews.
The asphalt plants, which are 40% owned by ROADBUILDERS, INC., are managed by the Maintenance & Storage Yard.

**Realization (Production Managers and Foremen)**

This department includes the Production Managers who are typically responsible for several projects at the same time. The Production Managers are supported by a Foreman at each of the construction sites. The Foremen are responsible for coordinating the completion of activities at the construction site. There are two specialized Production Managers with dedicated Foremen who are responsible for the asphalting work and the incidental projects, respectively. The Incidental Construction Orders Group has been created as a flexible troubleshooting team to resolve unanticipated problems and requirements of (existing) clients. This Group typically handles small-scale maintenance work (such as damaged road markers, sunken curbs and grooves worn in the pavement) as well as jobs which need to be started quickly (e.g., in connection with subsidies). This requirement frequently occurs in the road construction sector where clients are often dependent upon the political decision-makers. The existence of this specialized group for handling emergency work is a key factor supporting a strong, lasting relationship with major clients. In addition, higher fees can generally be charged for emergency work of this nature.

There are a total of 37 staff employees in these departments. Approximately 195 construction workers are employed in the high season and 95 in the low season. These construction workers are assigned to work crews which vary in size.

**Description of the Work-in-Progress**

ROADBUILDERS, INC. is active solely in the Civil Works sector. In principle, work is only accepted which involves ground work, road construction and/or laying pipelines.

An average of eight large projects and three smaller projects are under construction at any given point in time. The construction price may vary widely. The small projects typically involve asphalt ing private driveways for a price starting at $1000. A large project may represent several million dollars in revenue.

_END OF THE BACKGROUND INFORMATION ON ROADBUILDERS, INC._

**The construction order**

The construction order in this case study is the modification of the layout of a 250-meter section of the County Highway in the town of Gouda. The client is the county government, one of ROADBUILDERS, INC.'s most valued clients. The county's public bidding procedure was followed in granting the contract for this construction work to ROADBUILDERS, INC..

The current layout of this section of the County Highway is illustrated in Figure 3.2.

The county has decided that in order to encourage the use of bicycles that this section of the road needs to be restructured to include a bicycle path on each side of the highway. This means that it will be necessary to remove the strips of grass and
the rows of trees, add a layer of sand and lay the pavement for the bicycle paths. Since the main road will also need to be reconstructed, the decision has been made to raise the level of the highway and the public sewer lines under the pavement at the same time. The pavement material is brick. The layout of the desired new situation is illustrated in Figure 3.3.

The duration of the construction activities may not be longer than six weeks. In the event that the construction activities take longer than this, a penalty equal to 0.05% of the construction price will be levied by the county for each day in excess of the specified six weeks. The contractor is obligated to provide the following information to the client at regular intervals:

- daily reports which include a specification of the completed activities per day, per contract item and per location as well as a specification of the construction materials, equipment and tools which have been delivered to and removed from the construction site;
- detailed measurement data;
- weekly summaries of quantities, including the same information as the daily reports, but then with cumulated totals per week;
- weekly summary of the hours spent by personnel and the equipment-hours spent per day, per contract item and per location. This summary must also include the quantities of delivered, used and removed materials. The personnel and equipment of any subcontractors, suppliers and rental companies must similarly be included.
In addition, a list of information about the personnel must be provided (e.g., wage categories, work crew schedules, overwork allowances, travel allowances) along with a list of the identifying characteristics of the equipment used (such as type, make, model, horsepower).

The construction work has been contracted based upon a fixed price for each type of result-unit. Examples of the result-units in this case are "a meter of installed sewer pipe", "a square meter of new pavement" and "a removed tree". The fixed price agreement based upon these result-units means that variances in the quantity of work performed will be reflected in the final payment. Payment for a certain number of the activities specified in the contract are not based upon the actual number of result-units in this way. These instances do not pose a significant financial risk, however.
3.3 Technical Work Preparation and Determining the Type of Construction Order

The construction requirements specification for this construction order can be translated into the following construction steps (Table 3.1).

<table>
<thead>
<tr>
<th>No.</th>
<th>Construction Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>REMOVE ROAD SIGNS</td>
</tr>
<tr>
<td>2</td>
<td>TRIM HEDGES AND PRUNE TREES</td>
</tr>
<tr>
<td>3</td>
<td>EXCAVATE FOOTPATH AND CULVERTS</td>
</tr>
<tr>
<td>4</td>
<td>INSTALL CULVERTS AND SEWER PIPES</td>
</tr>
<tr>
<td>5</td>
<td>PAVE FOOTPATH</td>
</tr>
<tr>
<td>6</td>
<td>EXCAVATE ROAD SURFACE, ADD SAND LAYER</td>
</tr>
<tr>
<td>7</td>
<td>PAVE ROADWAY</td>
</tr>
<tr>
<td>8</td>
<td>ADD TOPSOIL, PLANT GRASS &amp; HEDGES, INSTALL ROAD SIGNS</td>
</tr>
</tbody>
</table>

Table 3.1: Typical Construction Steps Needed to Complete the Construction Order

This construction order has relatively few construction steps. The construction techniques related to these construction steps will be fairly consistent for the total duration of the project, however, the detailed specifications will often differ from one meter to the next (due to the need for occasional intersections, the presence of pipelines, etc.). This means that the production process is similar to a Mass Production situation (since the same production process is performed on a continual basis) but also similar to a One-of-a-kind Production situation (since each meter of the construction is different and many of the details are not included in the drawings and must be investigated as the work is being carried out). It is not sensible to define separate milestones for each of the construction steps since the production process will be carried out at a steady pace until the work is completed. Coordinating the construction steps should be relatively easy since the progress of all of the activities is easy to follow in this case. It should be possible to monitor the progress of the project in "real time" without the need for a formal activity plan.

Based upon the background information on the construction company and the construction order, this construction order can now be analyzed to identify its "type" in terms of the theory presented in Part 2.
Scarcity of the company resource capacities:

ROADBUILDERS, INC. is confronted with a large number of scarce resource capacities. The most important scarce resources are the units of equipment and the equipment operators.

Employment/deployment period for the scarce company resource capacities:

The scarce resource capacities are normally utilized for only a short, sometimes extremely short (several hours), period of time.

Number of work crew assignments:

1

The construction order is viewed as a single work crew assignment since it will be carried out completely by only one all-round work crew.

Diversity and quantity of the materials and resource capacities:

The construction order has only a few construction steps which are relatively simple and involve the use of a limited number of different materials.

Assignment-related information:

Each assignment in the construction order is repeated a large number of times. This means that relatively little assignment-related information needs to be communicated.

Based upon this evaluation of the relative importance of each of these factors and characteristics, the conclusion can be drawn that this most closely corresponds with a "Work Order Production" type of construction order.

In view of the short duration of this project, ROADBUILDERS, INC. has decided to assign this work to the Incidental Construction Orders Group. As soon as the construction order is signed, all of the necessary and available information will be given to the responsible Foreman so that he can initiate the project. An all-round work crew (consisting of the Foreman, five ground workers who can also double as equipment operators/drivers, a van, a shovel, a truck with a claw arm and a mobile shelter) is at his disposal for carrying out this work. The Foreman moves from construction site to construction site with this special work crew. With the full availability of this work crew for the six week duration of the construction project, the only additional resources and materials he will need to call up will be a road workers crew, some sand and some additional road construction materials. The Foreman will allocate specific tasks to the individual members of his work crew on an ad hoc basis since he will be able to maintain a continual supervision over the complete construction project.
3.4 The Change

It appears that a larger budget than originally anticipated is now available for the construction of new bicycle paths. The county government has, therefore, decided to contract for the reconstruction of a much larger section of the highway than originally planned. The initial assumption is that only one 250-meter road section would be reconstructed. The intention now is to reconstruct six contiguous 250-meter road sections of this highway. Even though the order has now been increased by a factor of six, the county has added the stipulation that the allowable period of time for completing this project will only be four times as long as the original period specified (thus, 24 weeks). The size of the order is illustrated in Figure 3.4.

![Diagram of road sections](image)

Figure 3.4: The Original Construction Order versus the Revised Order

The county government has decided in the meantime to also grant the construction order for the additional five road sections to ROADBUILDERS, INC. based upon the same terms and conditions specified in connection with the first section of the highway. An additional stipulation is that the work must be carried out road section by road section, and that a maximum of two road sections may be under construction.
at any time to minimize the inconvenience to traffic. They have also stipulated that any work causing disruptions to traffic (i.e., all of the construction steps with the exception of the step "Remove road signs, etc.") may not be started with respect to the second section of the highway until at least four days later than the commencement of work on the first section.

It is clear that ROADBUILDERS, INC. is pleased with this additional order (which is approximately six times larger than the original order) but it is also clear that this order has suddenly become much more complicated.

As previously mentioned, the original intention was to use one of the all-round work crews to carry out this construction order. This single crew would not be able to complete the revised order within the specified time restrictions, however. In addition, there are now many more restrictions and conditions to be taken into consideration. Each completed construction step for each section of the highway will need to be included in the project plan as a separate milestone.

The increase in complexity can be seen by comparing the project plan for the original order with the project plan for the revised order. As previously mentioned, a formal project plan for the original order was never actually prepared due to the simplicity of the control in this situation. The proforma plan presented below in Figure 3.5, nevertheless, represents the intentions of the Foreman in the original situation.

The project plan is much more complex for the revised order. There are two reasons for this:

1. To start with, each construction step now has six milestones and accompanying activities, corresponding to the six road sections as specified by the client. Coordinating the construction steps is an important aspect which will require a significant amount of attention due to the restrictions imposed by the client in connection with the acceptable inconveniences for traffic and the start and completion dates for the construction steps for the various road segments.

2. A second reason for the increased complexity is that the construction order will no longer be carried out by a single all-round work crew, but rather by several independent work crews, units of equipment and equipment operators to be called up as needed. This new approach is required due to the longer duration of the construction project which, in the opinion of ROADBUILDERS, INC., is too long for the dedicated use of the Incidental Construction Orders Group. If one of the all-round work crews were to be assigned to a project of this length, then the flexibility of the company would be adversely affected, making it impossible to provide a responsive service with respect to small construction orders and
### Figure 3.5: Proforma Project Plan for the Original Order

<table>
<thead>
<tr>
<th>Activities</th>
<th>Duration (days)</th>
<th>week 1</th>
<th>week 2</th>
<th>week 3</th>
<th>week 4</th>
<th>week 5</th>
<th>week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove road signs</td>
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<tr>
<td>• 2 ground workers</td>
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<td>• van</td>
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<tr>
<td>Trim hedges and prune trees</td>
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<td>• 5 ground workers</td>
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<td>• foreman</td>
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<tr>
<td>Excavate footpath and culverts</td>
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<td>• 2 ground workers</td>
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<td>Install culverts and sewer pipes</td>
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<tr>
<td>Pave footpath</td>
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<tr>
<td>• 1 ground worker/supervisor</td>
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<tr>
<td>• 1 ground worker/road worker</td>
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<tr>
<td>Excavate road surface, add sand layer</td>
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<td></td>
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<tr>
<td>• 2 ground workers</td>
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<td>Pave roadway</td>
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<td>• 2 ground workers</td>
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<tr>
<td>• 1 road workers crew (external)</td>
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<td>• shovel</td>
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<tr>
<td>Add topsoil, plant grass &amp; hedges,</td>
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<td></td>
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<tr>
<td>install road signs</td>
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<td></td>
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<tr>
<td>• 3 ground workers</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• foreman</td>
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<td>• shovel</td>
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<td>• truck</td>
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</tr>
</tbody>
</table>

Work crew consisting of a foreman + 5 ground workers who also drive/operate the truck, van and shovel. The truck, van and shovel are permanently available. Subcontractors (road workers) are called up at the discretion of the foremen.
unanticipated client problems. In addition, the use of a single all-round work crew would not be able to cope with the varying requirements for various types of workers, resulting from the complex inter-dependencies between the construction steps. The allocated resource capacity would be insufficient at some points in time and excessive at other times.

A portion of the project plan for the revised construction order is presented in Figure 3.6.
<table>
<thead>
<tr>
<th>Activities</th>
<th>Duration (days)</th>
<th>week 1</th>
<th>week 2</th>
<th>week 3</th>
<th>week 4</th>
<th>week 5</th>
<th>week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove road signs</td>
<td>2 workers with van</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trim hedges and prune trees</td>
<td>4 workers, 1 truck (part-time), 1 (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate footpath and culverts</td>
<td>4 workers, 1 power shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install culverts and sewer pipes</td>
<td>4 workers, 1 shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pave footpath</td>
<td>4 workers, 1 shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate road surface, add sand layer</td>
<td>4 workers, 1 shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td>2 trucks (full-time)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pave roadway</td>
<td>2 road workers crews (external), 1 shovel (part-time), 1 truck (part-time)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add topsoil, plant grass &amp; hedges, install road signs</td>
<td>4 workers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remove road signs</td>
<td>2 workers with van</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trim hedges and prune trees</td>
<td>4 workers, 1 truck (part-time), 1 shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate footpath and culverts</td>
<td>4 workers, 1 shovel (part-time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install culverts and sewer pipes</td>
<td>4 workers, 1 shovel (part-time)</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

The work crews and units of equipment are not permanently available at the construction site, but are called up at the discretion of the Foreman.
In addition to the anticipated problems with the project coordination (and developing a feasible project plan), larger problems can be expected with respect to the mobilization activity. This can be illustrated through the use of the estimation model presented in Section 1.2.

Using this estimation model, the time requirements for the original order situation can be calculated based upon the proforma project plan presented in Figure 3.5. The results of this calculation are presented in Table 3.2.

<table>
<thead>
<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew No. &amp; Type</th>
<th>Number of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove road signs, etc.</td>
<td>Work Crew 1 O</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trim hedges and prune trees</td>
<td>Work Crew 1 M</td>
<td>-</td>
<td>1/1</td>
<td>10</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate footpath and culverts</td>
<td>Work Crew 1 M</td>
<td>-</td>
<td>1/2</td>
<td>15</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install culverts and sewer pipes</td>
<td>Work Crew 1 O</td>
<td>-</td>
<td>1/2</td>
<td>20</td>
<td>1/0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Pave footpath</td>
<td>Work Crew 1 O</td>
<td>-</td>
<td>1/0</td>
<td>10</td>
<td>1/0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Excavate road surface, add sand layer</td>
<td>Work Crew 1 M</td>
<td>-</td>
<td>1/2</td>
<td>15</td>
<td>1/0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Pave roadway</td>
<td>Work Crew 2 M</td>
<td>1/0</td>
<td>5</td>
<td>1/2</td>
<td>15</td>
<td>1/0</td>
<td>10</td>
</tr>
<tr>
<td>Add topsoil, plant grass and hedges, install road signs etc.</td>
<td>Work Crew 1 O</td>
<td>-</td>
<td>1/1</td>
<td>10</td>
<td>1/0</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**SUBTOTALS**

**TOTAL** 10 min. 105 min. 50 min.

* Work Crew Type: B = Batch Production  
M = Mass Production  
O = One-of-kind Production

**Table 3.2A: Time Required by the Foreman for Controlling and Directing the Production according to the Original Construction Order**

This Table is based upon the assumption that the foreman provides instructions to the individual members of his work crew (which are, in turn, subdivided into work details) at least once each week. It is also assumed that only one call for construction materials will be made for each type of material (e.g., a call for multiple truckloads of the same material is counted as one call).

It is clear from this Table that only a limited effort on the part of the Foreman is required. The average time required for controlling and directing the production in this situation amounts to only 27.5 minutes per week. A further assumption
 WORK CREW INSTRUCTION AND CALL TIMES

<table>
<thead>
<tr>
<th>NAME</th>
<th>CHARACTERISTICS</th>
<th>INSTRUCTION TIME (MINUTES)</th>
<th>CALL TIMED (MINUTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Production Work Crew</td>
<td>• Multi-project learning curve</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• Repetitive work on project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-of-a-kind Production Work Crew</td>
<td>• Multi-project learning curve</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• Varying work on project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch Production Work Crew</td>
<td>• Project learning curve</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• Repetitive work on project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique Production Work Crew</td>
<td>• No learning curve adv</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>vantage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Unique work on project</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MATERIAL CALL TIMES

<table>
<thead>
<tr>
<th>MATERIAL CALL TIMES (MINUTES)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First call</td>
<td>10</td>
</tr>
<tr>
<td>Follow-up call</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3.2B: Subsidiary Tables

The underlying this estimate is that the Foreman knows all of the members of his own work crew to the extent that very little instruction time is required. It should be clear that the majority of actual work instruction would take place "on-the-job" and that the existence of specific work details (similar to the project plan) would be difficult to recognize in practice. It is also expected that the Foreman will contribute directly to the realization and completion of a number of construction tasks.

The complexity increases in the revised construction order situation primarily due to the fact that numerous work crews and resource capacities are employed/deployed for a short duration, and that each of these crews will require a certain amount of instruction. The Mobilization Plan for Week 2 of the revised construction order is presented in Figure 3.7 to illustrate this aspect.
### Figure 3.7: Mobilization Plan for the Revised Construction Order in Week 2

<table>
<thead>
<tr>
<th>Duration (days)</th>
<th>MONDAY</th>
<th>TUESDAY</th>
<th>WEDNESDAY</th>
<th>THURSDAY</th>
<th>FRIDAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

**Work Crew Assignments**

- **Install culverts and sewer pipes**
  - SECTION 1
    - shovel 1 (assistance)
    - work crew 7 (4 workers)
  - **A**

- **Pave footpath**
  - SECTION 1
    - work crew 9 (2 workers)
    - shovel 1 (assistance)
  - **A**

- **Excavate road surface, add sand layer**
  - SECTION 1
    - shovel 2 (assistance)
    - trucks A and B
    - work crew 2

- **Trim hedges and prune trees**
  - SECTION 2
    - truck A
    - shovel 1 (assistance)
    - work crew 3 (2 workers)
    - work crew 2 (2 workers)
  - **A**

- **Shovel 1 on-site**
  - **A**

- **Shovel 2 on-site**
  - **A**

- **Truck A on-site**
  - **A**

- **Truck B on-site**
  - **A**

---

**A** = Arrival of equipment/work crew  
**R** = Removal of equipment/work crew

The work crews and units of equipment are not permanently available at the construction site, but are called up at the discretion of the Foreman. Subcontractors (road workers) are also called up by the Foreman.
The number of calls and instructions to be given to the work crews can be determined simply by referring to this Mobilization Plan. This is illustrated in Figure 3.8.

<table>
<thead>
<tr>
<th>ACTIVITIES FROM THE HIGH-LEVEL ACTIVITY PLAN</th>
<th>Work Crew No. &amp; Type *</th>
<th>Number of Work Crew Calls</th>
<th>Work Crew Call Time (minutes)</th>
<th>Number of Initial/ Follow-up Crew Assignments</th>
<th>Work Crew Instruction Time (minutes)</th>
<th>Number of Initial/ Follow-up Material Calls</th>
<th>Material Call Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove road signs</td>
<td>Work Crew 7 O</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Shovel 1 O</td>
<td>1/0(^1)</td>
<td>50</td>
<td>1/1</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pave footpath in section 1</td>
<td>Work Crew 9 O</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>10</td>
<td>1/0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Power Shovel 1 O</td>
<td>1/0(^1)</td>
<td>1/4</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate road surface, add sand layer</td>
<td>Work Crew 2 M</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Power Shovel 2 M</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck A M</td>
<td>1/0(^2)</td>
<td>35</td>
<td>1/0</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck B M</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trim hedges and prune trees</td>
<td>Work Crew 2 M</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work Crew 3 M</td>
<td>1/0</td>
<td>5</td>
<td>1/0</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck A M</td>
<td>1/0(^3)</td>
<td>1/5</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Shovel 1 O</td>
<td>1/0</td>
<td>1/5</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUBTOTALS TOTAL 115 min.</td>
<td></td>
<td>170 min.</td>
<td>20 min.</td>
<td></td>
<td></td>
<td>5 hours</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>905 minutes</td>
<td>= 5 hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\* Work Crew Type: B = Batch Production  
M = Mass Production  
O = One-of-kind Production

1) Total number of calls for Power Shovel 1  
2) Total number of calls for Truck A

**Figure 3.8: Time Required by the Foreman for Controlling and Directing the Production for the Revised Construction Order in Week 2**

Use of the estimation model leads to two conclusions:

1. The Foreman will now need to spend a substantial part of his time dealing with the mobilization of personnel and equipment. When this situation is compared with the original situation, it is clear that the Foreman will have less time to participate directly in the realization and completion of various activities. The time required for controlling activities has increased to the extent that a separate mobilization plan is now required because the situation has become too complex for controlling based purely on intuition.

2. The situation has not become so complex that it cannot be handled adequately by a single foreman (in contrast with the case study situation of HOMEBUILDERS, INC.). A separate allocation function is similarly not required.
3.5 Modified Control of the Construction Order

Also in the case of ROADBUILDERS, INC., a number of ways can be found for improving the control over the realization of the construction order:

1. by reducing the rate of production to the extent that it is then possible for the all-round work crew to handle all six of the road sections;

2. by treating the six road sections as separate construction orders which can then be handled by several different all-round work crews;

3. by using the design rules to determine a more appropriate method of controlling the changed construction order.

Regarding 1. (Reducing the rate of production so that the all-round work crew can handle all of the road sections)

This solution appears to be straightforward and simple, however, it would not be a feasible alternative in this situation due to the maximum allowable construction period specified by the county government.

Regarding 2. (Treating the six road sections as separate construction orders)

This solution is feasible, however, it is not compatible with the normal working methods followed by ROADBUILDERS, INC. The policy followed by ROADBUILDERS, INC. is to maintain a certain number of flexible production units for use in incidental projects. This essentially means that these special work crews may not be dedicated to the realization of a single, large construction order. With this approach it would also be necessary to find some means of coordinating the production between the various road sections. In view of the complexity of this coordination problem, the "Work Order Production" type of control approach is not the most suitable approach to follow in this situation.

Regarding 3. (Using the design rules to determine a more appropriate method of controlling the changed construction order)

By applying the design rules once again, the following distinguishing characteristics can be identified:
Scarcity of the company resource capacities: + and -

Scarcе resource capacities are now utilized to an even greater extent (e.g. certain work crews). Beside that non-scarce resources are used (e.g. trucks)

Employment/deployment period for the company resource capacities: + and -

Some of the equipment and work crews are used for a longer period. Some of them are used for a very limited period (see al

Number of work crew assignments: > 1

The construction order can be split into a large number of work crew assignments since multiple work crews will be employed and directed separately.

Diversity and quantity of the materials and resource capacities: +

A large number of different resource capacities will now be employed/deployed. The diversity in materials will remain limited.

Assignment-related information: -

Each assignment in the construction order is repeated a large number of times. This means that relatively little assignment-related information needs to be communicated.

Based upon the application of the decision rules in this way, the conclusion can be drawn that this most closely corresponds with a "Standard Construction Project" type of construction order.

3.6 Specification of the Control System for ROADBUILDERs, INC.

The ROADBUILDERs, INC. construction order described above has changed from a "Work Order Production" type of construction order to a "Standard Construction Project" type of construction order. These two types of construction orders actually represent all of the types of work performed by ROADBUILDERs, INC.: the smaller construction orders can be controlled as "Work Order Production" orders and the larger construction orders as "Standard Construction Project" construction orders.

The complete decision system found within ROADBUILDERs, INC. is illustrated in Figure 3.9.
Figure 3.9: The Decision System of ROADBUILDERS, INC.

Similar to the discussion of the HOMEBUILDERS, INC. case, an interpretation of the actual situation within ROADBUILDERS, INC. is provided here for each of the decision functions. An example is included in a number of instances and indications of the expected organizational requirements are provided.

References are made to the case study of HOMEBUILDERS, INC. where appropriate.

3.6.1 Business planning

The specification of the Business Planning decision function for a practical situation in the case of ROADBUILDERS, INC. is identical to the situation previously described for HOMEBUILDERS, INC.. For this reason, these details are not be repeated here.
Example

The strategic business goals and objectives of ROADBUILDERS, INC. were not explicitly mentioned as part of the company profile. It was noted (under the section on "Work-in-Progress") that ROADBUILDERS, INC. is active solely in the Civil Works Sector, however. Construction work is generally only accepted in the areas of ground work, road construction and laying pipelines.

ROADBUILDERS, INC. has kept statistics for the past year regarding the distribution of its business over the various order categories. A distinction has been made between the larger and smaller road construction projects in addition to the ground work and pipeline sectors. Several of the key statistics are presented below in Table 3.3 for these order categories.

<table>
<thead>
<tr>
<th></th>
<th>Small-scale Road Construction</th>
<th>Large-scale Road Construction</th>
<th>Ground Work</th>
<th>Pipeline Laying Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of revenue</td>
<td>10%</td>
<td>45%</td>
<td>30%</td>
<td>15%</td>
</tr>
<tr>
<td>Profitability</td>
<td>10%</td>
<td>2%</td>
<td>5%</td>
<td>2%</td>
</tr>
</tbody>
</table>

*Table 3.3: Key Statistics per Order Category*

After analyzing these statistics, ROADBUILDERS, INC. has come to the conclusion that the revenue in the small-scale road construction sector should be increased to 20% of the total company revenue. The revenue derived from the large-scale road construction projects should under no circumstances suffer from this new strategy, however. It is important to maintain the current level of work in this area due to the major investments which have been made in specialized resource capacities (such as large asphalt ing equipment and the minimum processing capacity of the asphalt plant) which cannot be reduced nor divested in the near term. This is an example of the strong relationship between the Business Plan Development function and the Resource Capacity Planning function for the Scarce Resources.

One of the business objectives is to maintain the present revenue levels for the work generated in the ground work and pipeline sectors. The consequence of these objectives is that the total revenue of ROADBUILDERS, INC. will need to increase to the level of approximately $50 million per year.
Organizational aspects

The company management is, of course, responsible for the ultimate development of the business strategy. Various staff employees will need to support this effort by collecting and maintaining the required data.

3.6.2 Resource capacity planning for scarce resources

This decision function is strongly related to the Business Planning function. The underlying purpose of this function is to ensure that sufficient scarce resource capacity is available within the company in the future period covered by the Business Plan so that the objectives formulated in the Business Plan can actually be achieved. If it is apparent that the desired resource capacity cannot be made available in a timely manner, the Business Plan will need to take this into account.

For the same reasons mentioned previously in the case of HOMEBUILDERS, INC., the scarce resources are certain staff personnel as well as a number of the units of equipment which would be extremely difficult to replace on short notice. The most important example of this in the situation of ROADBUILDERS, INC. is the asphalting equipment.

The human resource capacities which belong to the group of extremely scarce resources include the foremen, production managers and specialized personnel such as the equipment operators and asphalting work crews.

Three types of capacity loading plans can be identified:
1. Staff Loading Plan (the capacity loading plan for foremen, production managers, project planners, etc.)
2. Equipment Loading Plan (the capacity loading plan for capital equipment which is difficult to procure on short notice)
3. Workmen Loading Plan (the capacity loading plan for specialized personnel).

The business processes which can be identified are similar to the business processes described previously in the HOMEBUILDERS, INC. case situation.

Example

One of the consequences of the business strategy is that the total resource capacity will need to be expanded and improved in a number of specific areas, in particular by:
- increasing the number of foremen with specific experience in the small-scale road construction sector;
- the procurement of additional equipment which is designed specifically for small-scale road construction (such as asphaltig equipment for narrow roads);
- extra training of younger construction workers who have ambitions to be an equipment operator (or other skilled function which is in short supply) and have already demonstrated a certain level of dedication to the company. There is a clear link between the development plan for construction workers and the equipment loading plan (since the equipment will always require a qualified operator). In view of the different nature of these two types of resources, it is sensible to evaluate and plan these aspects separately. An equipment operator cannot be depreciated and written off in the same way as the equipment which he operates.

*Organizational aspects*

Similarly, this decision function should be carried out by company management.

3.6.3 Construction order acceptance

The processes which can be identified in connection with Construction Order Acceptance are the same here as in the case of HOMEBUILDERS, INC. The evaluation of whether to accept a potential construction order is carried out based upon the "Multi-project Planning for Scarce Resources with a Long Employment/Deployment Period" function.

*Example*

The Construction Order Acceptance function tries to arrange suitable start dates, terms and conditions such that this fits optimally within the strategy and policies formulated in the Business Plan (including the control of overhead expenses and the profitability) and similarly fits within the limitations imposed by the multi-project planning for scarce resources. One of the consequences is that the overhead expenses, profitability and business risks will be lower when the resource capacities are poorly loaded. A high loading percentage, on the other hand, tends to increase the overhead expenses, profitability and business risks.
Organizational aspects

This decision function is also to be carried out by company management.

3.6.4 Multi-project planning for scarce resources with long or short employment/deployment periods

These decision functions are essentially the same as the equivalent functions in the case of HOMEBUILDERS, INC..

Example

The multi-project planning function for the scarce resource capacities with a long employment/deployment period is a relatively insignificant activity in the case of ROADBUILDERS, INC.. This is due, first of all, to the fact that there are only a few resource capacities which are actually utilized for longer periods of time. In addition, these resources (particularly, the production managers and the foremen) do not always need to be present at the construction site and can usually take on an extra construction order whenever necessary.

The "Multi-project Planning for Scarce Resources with a Short Employment/Deployment Period" decision function is much more important, on the other hand. A road construction company typically has a significant number of units of equipment and optimizing the availability of this equipment is of critical importance. The use of various algorithms to optimize the loading of these resource capacities is much more important in this case than in the case of HOMEBUILDERS, INC., where the number of similar or interchangeable resources is much more limited. In this case, algorithms can be used which are based upon minimizing the transport times. This implies that the primary objectives associated with the construction orders are considered to be less important than the interests of the construction company. For example, a shovel should be used continuously whenever possible to carry out a series of construction activities at a given construction site instead of carrying out different construction steps with unproductive pauses for the delivery and removal of the equipment (refer also to [Dane-1990]).

Organizational aspects

The multi-project planning function for the scarce resource capacities with a long employment/deployment period is carried out by the Technical Director. The multi-project planning function for the scarce resource capacities with a short employment/deployment period, on the other hand, is the responsibility of the
Storage Yard Manager.

3.6.5 Project coordination

Specification of the decision function

The Project Coordination function can best rely upon the use of the line-of-balance technique in the case of the road construction production situation. This technique is typically characterized by the use of time-result diagrams. This technique is particularly useful due to the continuous nature of the production process (which, thus, has a fairly linear result curve). This method was described earlier in connection with the residential construction case study.

Example

Time-result diagrams can be used effectively, for example, to coordinate the use of trucks and draglines. The production activity can be modelled as a linear function of time when the constant availability of the necessary resource capacity can be assumed. Transport times can also be modelled. If the transport distance gradually increases (due to the progress of the construction on a given road), the number of trucks needed to remove the excavated ground will also need to increase in order to allow the production to continue at a constant pace. A set of simple formulae can be used to determine exactly when extra trucks will be needed (refer also to [Rovers-1984]).

Organizational aspects

The Production Manager is primarily responsible for carrying out the Project Coordination function, with the active support of the Production Planner.

3.6.6 Multi-project planning for readily available resource capacities

Specification of the decision function

This decision function is similar to the equivalent function described in the residential construction case.
Example

The resource capacities which are readily available will normally only be employed/deployed for a short period of time within ROADBUILDERS, INC.. The Maintenance & Storage Department normally supplies these types of resource capacities for use by the construction projects on short notice in this case. These resource capacities can generally be procured from outside the company whenever necessary without undue delay. This means that the decision function consists of essentially reserving units of equipment. Whenever the last unit of a specific type of equipment is allocated, steps are taken immediately to procure additional units of the same type of equipment (a structured decision!).

Organizational aspects

The multi-project planning function for readily available resource capacities is the responsibility of the Maintenance & Storage Yard Manager.

3.6.7 Mobilization planning & allocation planning

Specification of the decision function

The Mobilization Planning decision function is related to the detailed scheduling of the activities resulting from the Project Coordination function. The planning horizon is shorter than the planning horizon used in the Project Coordination function, however.

An important difference between the function here and the similar function in the case of HOMEBUILDERS, INC. is that these activities can be performed within only a short period of time prior to the realization activities. In addition, the resource capacities are often allocated repeatedly for relatively short periods of time (refer also to the discussion of the mobilization planning in Section 3.4). Note that a strong relationship exists between the scheduling of the work crews and the Equipment Loading Plan. Work crews are called up based upon the work crew assignment schedules (sometimes based upon the availability of a critical unit of equipment). This schedule also provides the basis for issuing the required notifications to the client (e.g., notifications of sand deliveries).

Example

The Mobilization Plan for the revised construction order for Week 2 is presented
again in Figure 3.10.

It is clear from this diagram that Shovel 1 must be delivered and removed from the construction site a large number of times. In this type of situation the Foreman should make every effort to reschedule certain activities so that the Shovel can be used to carry out a series of construction steps at one time without the need for the intermediate delivery and removal transport activities. A summary of the estimated transport costs would also help the Foreman in making the optimal decisions concerning whether to reschedule certain activities.

Organizational aspects

The Foreman is responsible in practice for the detailed specification and scheduling of work crew assignments within ROADBULLERS, INC..

3.6.8 Work order coordination

Specification of the decision function

The Work Order Coordination function deals with recording the construction order, including all of the order data, equipment requirements and resource capacity requirements. The suppliers are then selected based upon this information. The Work Order Coordination function is strongly related to the Multi-project Planning function for Scarce Resource Capacities with a Short Employment/Deployment Period. This is due to the fact that the starting date and the duration of the project are typically determined to a large extent by the availability of the necessary equipment.

Example

For a number of construction orders and in certain situations, ROADBULLERS, INC. may be able to negotiate a starting date with the client which fits well with the existing personnel loading plans and equipment loading plan. This is more likely to be negotiable with the smaller-sized orders (e.g., paving private driveways). This flexibility, when available, can be used effectively to optimize the loading of the scarce resource capacities.
### Work Crew Assignments

<table>
<thead>
<tr>
<th>MONDAY</th>
<th>TUESDAY</th>
<th>WEDNESDAY</th>
<th>THURSDAY</th>
<th>FRIDAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (days)</td>
<td>8 9 10 11 12 13 14 15 16</td>
<td>9 10 11 12 13 14 15 16</td>
<td>9 10 11 12 13 14 15 16</td>
<td>9 10 11 12 13 14 15 16</td>
</tr>
</tbody>
</table>

**Install culverts and sewer pipes**

**SECTION 1**
- shovel 1 (assistance)
- work crew 7 (4 workers)

**Pave footpath**

**SECTION 1**
- work crew 9 (2 workers)
- shovel 1 (assistance)

**Excavate road surface, add sand layer**

**SECTION 1**
- shovel 2 (assistance)
- trucks A and B
- work crew 2

**Trim hedges and prune trees**

**SECTION 2**
- truck A
- shovel 1 (assistance)
- work crew 3 (2 workers)
- work crew 2 (2 workers)

**Shovel 1 on-site**

**Shovel 2 on-site**

**Truck A on-site**

**Truck B on-site**

A = Arrival of equipment/work crew  
R = Removal of equipment/work crew

The work crews and units of equipment are not permanently available at the construction site, but are called up at the discretion of the Foreman. Subcontractors (road workers) are also called up by the Foreman.
3.7 Reviewing the Totality of the Information System

Complexity of the composition of the decision information

The information system within ROADBUILDMERS, INC. consists of two systems which are largely independent of each other. The functions of Business Planning and Resource Capacity Planning are, of course, closely integrated. With respect to the multi-project planning function for the scarce resource capacities, a single system could be found to support both the "Work Order Production" and the "Standard Construction Project" types of construction orders, but this integration is not strictly necessary. In view of the fact that the resource capacities used in the "Work Order Production" type of construction orders are carried out by a separate department, it is logical to assume that this department will want to maintain its own multi-project plans.

Since it is not practical to use automated systems to support all of the specialized decision functions, the distinction between transaction processing and decision support will be discussed in more detail in connection with the description of the automated information systems in Section 3.8.

Uncertainty of the decision information

ROADBUILDERS, INC. is confronted with a large degree of uncertainty in virtually all of its construction projects. There is a large amount of uncertainty regarding requirements, however the financial risk associated with this uncertainty is minimal since a large part of the construction price is based upon fixed prices per standard unit of completed work. The amount of uncertainty regarding the availability of sufficient resource capacities is also large. The major cause of this is the fact that the employment/deployment period of most of the resource capacities is relatively short, leading to a situation in which the resource capacities are allocated to a large variety of different projects during a given period of time. This means that the transport times to move the resource from one construction site to another may be a significant factor (with the added risk of queues developing) and a large number of interdependencies (e.g., when a delay at one construction site causes a delay at a subsequent construction site.) There is also a significant amount of uncertainty surrounding the production process. Much of the equipment employed requires a significant amount of maintenance and is typically susceptible to unexpected problems. The construction work always takes place outdoors so that there is an additional risk of major (and unpredictable) problems and delays arising from poor
weather conditions. The information system can only play a minor role in reducing the various types of uncertainty by signalling any disturbances in the production process in a timely manner and supporting the diagnosis of the problem.

3.8 Reviewing the Automated Information System

The general architecture of ROADBUILDERS, INC. can best be reviewed by comparing this with the standard general architectures of the two types of construction orders (Work Order Production and Standard Construction Project situations). Refer to Figure 3.11.
As previously mentioned, a choice can be made to implement a common system to support both the "multi-project planning for scarce resources with a short employment/deployment period" and the "capacity loading plan". In view of the fact that a separate department exists within ROADBUILDERS, INC. for incidental projects, it would be logical to choose for separate systems. The only major interface for these two systems would then be a link between the modules for recording material usage, subcontracting arrangements and hours worked and the financial administration. The other automated applications to be considered in this situation are described in the previous sections describing the automation possibilities for the respective types of construction orders.
Figure 3.11B: General Architecture for Standard Construction Project

In connection with the system modules for transaction processing, a specific solution is available for a number of the requirements which have been imposed by the government. These are the:

- daily reports which include a specification of the completed activities per day, per contract item and per location as well as a specification of the construction materials, equipment and tools which have been delivered to and removed from the construction site;
- detailed measurement data;
- weekly summaries of quantities, including the same information as the daily reports, but then with cumulative totals per week;
- weekly summary of the hours spent by personnel and the equipment-hours spent
per day, per contract item and per location. This summary must also include the quantities of delivered, used and removed materials. The personnel and equipment of any subcontractors, suppliers and rental companies must similarly be included. In addition, a list of information about the personnel must be provided (e.g., wage categories, work crew schedules, overwork allowances, travel allowances) along with a list of the identifying characteristics of the equipment used (such as type, make, model, horsepower).

The aforementioned requirements for the recording and maintenance of specific transaction data and fixed data represent additional requirements for the automated system. This means that the final requirements specification for the application modules is not only dependent upon the type of construction order, but also dependent upon the environment (the market sector, such as the Civil Works sector in this case) in which the system must function. In the event that a decision is made to implement a type-dependent application system for a specific type of construction order based upon generic components (e.g., standard transaction processing or decision support systems), then a market sector oriented applications layer will always be required as an add-on to the basic system.

3.9 Automated Information System Locations

A number of the applications are used at geographically distributed locations within this case study in the road construction sector. The implications and consequences of this are discussed here.

Office automation

Most of the office automation applications will be implemented as stand-alone applications. An optimal integration of the applications in each instance can be achieved by ensuring that a properly defined data model is used. With both of the types of construction orders, sufficient attention will need to be paid to the implementation of a common interface with the financial administration.

Construction site automation

It may be desirable to provide the Foreman at the construction site with a supporting application for "Mobilization Planning and Allocation Planning" for the "Standard Construction Project" type of construction orders. The most important aspects of this application should be the analysis of how mobilization decisions made for other projects affect the project activity schedules, and how changes in the scheduled
activities of other projects affect the mobilization decisions.

*Automation at the supplier*

In addition to the comments made in connection with the case study in the residential construction sector, it is worth mentioning that one of the most promising developments in the area of data base services concerns information about providers and suppliers of resource capacities. Making agreements with respect to the previously mentioned Electronic Data Interchange protocols are important to ensure a reliable interactive exchange of data. This type of application of information technology is only practical when such a facility can be sufficiently integrated within the company's own general architecture. For this reason, the implementation of EDI has not yet be realized in the case study situation.

*Automation in conjunction with other companies in the construction industry*

The central government ("Rijkswaterstaat" in The Netherlands) is currently experimenting with a model ("PDI") for transferring construction order data. In connection with this, contractors such as ROADBUILDERS, INC. could have in-house applications which interface with such networks. This particular network will be used initially for the exchange of drawings and related information.
PART 4: EVALUATING THE RESULTS OF THIS STUDY
1 INTRODUCTION

The motivation, objectives and approach to this research study has been discussed in Part 0. There has been a continual effort to translate these objectives into an efficient and effective research approach during the course of this study. The degree to which the stated objectives have been achieved will be evaluated in this part of the book.

The research approach used in this study is evaluated in Chapter 2. In addition to the evaluation of the approach, it is also important to evaluate the results of using this approach in terms of the scientific contribution as well as the practical business implications.

Scientific contribution of this research

The degree to which the scientific objectives of this research have been achieved can be evaluated primarily by determining to what extent this research has made a contribution to the existing base of knowledge within the various scientific disciplines. Two areas of specialism have been involved directly in this research as a result of the multidisciplinary approach: Civil Engineering (in particular, Civil Engineering & Management), and Industrial Engineering. The implications of this research for both of these areas of discipline will be covered further in Chapter 3.

Practical business implications of this research

The above-mentioned scientific disciplines are both design-oriented sciences in which the practical application of research results in the "real world" is an important aspect. This means that it is important to determine whether the results of the research can be used in some way by, in this case, those involved in production control in the construction industry. The implications of this research for construction companies, management consultant firms and software houses is discussed in Chapter 4.
2 EVALUATION OF THE STUDY APPROACH

2.1 Summary of the Study Approach

The phased research approach followed in this study was discussed previously in Part 0. Three phases were identified. These phases are presented again, below, in the form of a diagram in Figure 4.1.

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Figure 4.1: The Three Phases of the Study Approach

It should be mentioned that the division of this study into phases has not led to the observance of strict boundaries between the phases as suggested in Figure 4.1. There has been a certain amount of interaction and overlapping activities between the phases.
These phases can be summarized as follows:

**Orientation**

The initial orientation phase was carried out during the first years of this study (1988-1990). A variety of subjects were reviewed during this phase and a significant portion of the time was spent on analyzing the approaches to production control which were currently being used in the construction industry [Melles & Wamelink-1990,a]. This resulted in the development of several models which could be used as the basis for further analysis. Many of these models were developed based upon eight different research projects which were lead by the authors.

In addition to this, reference theories concerning decision systems and management information systems for production control were established. The important assumptions for the further development of theories on decision systems and management information systems for production control in the construction industry were documented at this point. Finally, a review of the methods and techniques employed by manufacturing companies for the purpose of production control was carried out. Here, also, a portion of the research was performed in connection with two research projects which were supervised by the authors.

**Theory Formulation**

Design rules for decision systems and management information systems for production control were established during this phase for use in the construction industry. This was carried out by combining a selection of the assumptions formulated in the reference theories, the collected knowledge of production control methods used by manufacturing companies and knowledge of the approaches to production control currently used in the construction industry.

**Application**

Various details of the design rules were defined based upon two practical situations formulated as case studies.

### 2.2 Orientation Phase

The first year of this study was spent primarily developing a description of the current method of production control used in the construction industry. This effort lead to a
detailed compilation of information on this subject [Melles et al.-1990,a]. Qualitative data as well as quantitative data was collected about the degree of control (numbers of schedules, diagrams, registrations, etc.). Important insights were gained with respect to the basic subject matter. When one considers to what extent the information derived from these analyses of the current method of control was actually used in the subsequent phase of the study, it is clear that a less detailed analysis would have been sufficient. It is also worth mentioning that a good software tool ("Workbench") is required to adequately carry out an analysis at this level of detail, especially when combined with the use of a diagramming technique (IDEF-0). The tools which were available at that time (partly self-developed and partly based upon commercially available software) were insufficient.

A significant amount of effort was also spent on evaluating the techniques and methods related to decision systems and management information systems for production control which are typically found in the field of Industrial Engineering. Initially, attention was focused on using the control approaches which have been developed within this discipline (MRP, JIT and OPT) or to translate these in some way to a construction industry situation [Melles & Wamelink-1990,b], [Wamelink et al.-1991]. After a period of time, however, it became clear that only a certain number of the basic principles were applicable. This conclusion is also consistent with the current opinion often found in the manufacturing industry which maintains that the classic techniques provide good examples for structuring and designing the required control approach. A straightforward implementation of classic techniques is not really possible [Koskela et al.-1992]. The analysis needed to arrive at this conclusion also consumed a great deal of time. Nevertheless, this analysis has contributed significantly to the choice of the right assumptions for developing the typology.

2.3 Theory Formulation Phase

Two relevant comments can be made regarding the Theory Formulation Phase.

1. The fundamental decision of making a distinction between the decision system and the information system

The approach used to develop a reference theory for this study has been borrowed from systems theory. A clear distinction has been made in this respect between the decision system, which is seen as a subsystem, and the management information system. It turns out, however, that making this distinction is not really relevant when defining the design rules to be applied in practical situations. The original assumption that insights into both of these components would be enhanced by viewing them as separate entities, is indeed valid. On the negative side, however, the recognition of
separate entities in this way has made it more difficult to develop simple design rules in practice since the decision processes and the processing of information tend to be integrated in practice. Ultimately, in connection with the description and analysis of the case studies in Part 3, the differentiation between these two system entities virtually disappeared. This raises the question of whether it was worthwhile to develop better insights in this way. This conclusion is consistent with the opinion which was popular at the end of the eighties in the field of industrial engineering [Wortmann-1992].

2. Developing a typology

The idea of using a typology of construction orders as a primary basis for formulating new theories was first introduced during the Orientation Phase of this study in 1989. The actual development of this typology took a relatively long time, however, since several alternatives of the typology were developed.

The original versions of the typology were based upon an algorithmic approach [Melles & Wamelink-1990,a] which provides a "unique" solution for all possible construction orders based upon the relative importance (values) of the distinguishing characteristics. This kind of typology is referred to as a continuous typology. The level of detail required for this typology proved to be a major complication when an effort was made to use this approach in practice, however. It was not possible to develop a simple specification of the various types of construction orders found in practice using this typology. The required level of detail led to the inclusion of so many design aspects that it became impossible to avoid inconsistencies in the specification of some of these aspects.

Based partly on the results of an opinion survey held among practitioners in this field, the decision was taken to develop an "ideal" typology. The main feature of this approach is the definition of basic types. It turned out that it was possible to develop a consistent and practical typology by following this approach.

2.4 Application Phase

The application of the typology to a number of case study situations provided a basis for evaluating the practical applicability of the typology. The selected case studies all refer to actual situations in which control problems are evident. These case studies provide a clear indication of how the control of certain aspects should be changed. In particular, the case studies focus on the transition between the phases of a construction order (project) and the associated changes in production control which are required.
The development of these case studies went quickly and effectively. This was likely due to the fact that a sufficiently developed and stable version of the typology was available for use as a basis for developing the case studies.

2.5 General Conclusions

Summarizing, it is possible to draw the conclusion that the objective of the study has been achieved: the provision of a theoretical basis to construction companies to assist them in their efforts to improve the control of production activities in terms of decisions and information systems.

This objective was not been achieved without a number of digressions, however. Such digressions are not necessarily a bad thing within the context of scientific research. Nevertheless, there are a number of lessons which could be learned from this experience to improve the effectiveness of future research activities in this area. It is important to point out in connection with this that the Civil Engineering Faculty had very little experience carrying out research studies in the field of Civil Engineering & Management when this research project was initiated. Several comments on this topic are included in Chapter 3.
3 RESULTS OF THE STUDY FROM A SCIENTIFIC PERSPECTIVE

3.1 Introduction

This research study has incorporated a strong multi-disciplinary approach. A combination of control theories has been used which have been derived from the construction industry (Civil Engineering & Management) and from the area of Industrial Engineering. This combination of applicable theories from different disciplines represents one of the important aspects in terms of the scientific contribution provided by this research study.

By combining the two disciplines in this way, the field covered by Civil Engineering & Management has been extended to include the basic theories often used in the field of Industrial Engineering. In addition, these theories have been applied here, for the first time, to a sector of industry which presents new and different research topics for studies which are typically initiated in the field of Industrial Engineering.

3.2 Significance of this Study for the Field of Civil Engineering & Management

As previously indicated in Sub-section 2.3.2 in Part 1, scientific research in the construction industry is typically based upon the approach originally proposed by Taylor. This approach tries to improve the primary business process (i.e., increase the productivity of labor involved in the production process) by carrying out a detailed study of the various operations which take place within this process (such as cementing a wall or placing a window frame). In spite of the fact that this approach dates back to the beginning of the century, it has proven to still be a viable approach in the Nineties, leading to surprising conclusions in certain situations [SAOB-1988]. An explanation for this is the fact that whenever new technology is introduced (with respect to new types of equipment as well as new types of materials), the question should be posed of exactly how this new technology can be used most efficiently.

After 1960, the interest increased with respect to the topic of controlling the construction process through the supplementary activities carried out within a construction company. The scientific research during that period was focused
primarily on evaluating the practical applications of network modelling techniques (e.g., CPM and PERT). This trend was recognizable within scientific circles as well as in practice. A noticeable difference between these two groups was that the practitioners were able to see the shortcomings in the network scheduling approaches before many of the researchers were willing to admit this. These researchers were of the opinion that the failure to make full use of network scheduling techniques was due to conservative attitudes and a lack of education of the persons responsible for using such techniques. The researchers also expected huge improvements from the promised developments in information technology (computer software) which would resolve the various objections to the original software packages which were used for network scheduling.

As the researchers (throughout the world) concentrated on further investigations into the applications of network scheduling approaches, the practitioners were already convinced that using network modelling techniques only made sense in a limited number of situations, namely, for the large, complex commercial building projects. It should also be mentioned that even in many of these large, complex projects, network scheduling techniques are still not used due to the prevailing conservatism in the construction industry. Very little research in the area of network scheduling was carried out in the Netherlands during the Seventies and Eighties. Research efforts continued in this area in other countries, however. Numerous experiments were carried out as new developments in computer technology became available (e.g., the use of expert systems and applications of neural network techniques). Applications of the results of this research in practical situations turned out to be possible on rare occasions, however.

A significant change took place in the published English-language research in this area halfway through the Eighties. In addition to the studies which focused on the further development of specific details (such as with the aforementioned expert systems), the results of other types of studies were reported in which theories were discussed which added certain nuances to the existing control techniques. This can be recognized, for example, with respect to:

A- a growing awareness that differences in construction processes should normally lead to differences in the control of these processes and differences in the management information systems. This awareness became more tangible as different scheduling techniques and sets of conditions were formulated for different production situations. Birrell [Birrell-1988], for example, provides a summary of different types of buildings and the special scheduling considerations related to each type. Koskela [Koskela-1990] describes the need for developing a framework for defining the control requirements of various types of construction processes.
B- an increased interest in control techniques stemming from other parts of the industry such as the proponents of MRP and JIT. Some people view this as being a revolutionary new development. The meeting of Working Commission 65 of the International Council for Building Research, Studies and Documentation (CIB) in October, 1992, proved this point. One of the two featured presentations at this congress was on the topic of "What can we learn from the manufacturing industry?". The aforementioned requirement for developing a framework as expressed by Koskela, the Finnish researcher, also is based upon studying the methods and techniques used in the manufacturing industry.

C- the analysis and description of the information requirements related to controlling the production process [Cheetham et al.-1991]. This can be seen primarily as the result of an increasing complexity of information systems in practice which, in turn, has been driven largely by new developments in information technology. It appears that the only way to successfully counteract this growing complexity is to gain better insights into the theoretical basis of the information structures. There are recent examples in the Netherlands and elsewhere of extensive research projects in which this topic has been defined as the primary objective (e.g., "IOP Bouw" [Van Merendonk & van Dissel-1989]).

In spite of the fact that these recent developments were not considered when the research plan for this study was prepared, the large number of similarities between the research carried out in Delft and the developments described above is surprising. The following contributions provided by these studies can be identified in the three aforementioned areas:-

Regarding A.

This research study resulted ultimately in the definition of a typology of construction orders in which a link was identified between the nature of a company and its production process and the method of control. This typology can provide a useful basis for further research.

Regarding B.

The manufacturing industry was used as the model for this research study. It is clear in retrospect that the Industrial Engineering research approach followed here proved to be effective. The direct application of techniques such as MRP and JIT is not possible. Nevertheless, this approach resulted in a better understanding and realization of the need to include aspects which are not normally found in research in
the construction industry (for example, a more materials-oriented scheduling technique).

Regarding C.

The results of this research support the opinion that it is extremely important to design and structure information systems from a tactical point of view. In addition, it is apparent from the occasional major differences in the data structures of the basic types of construction companies and construction projects identified in this study that an important recommendation for future research is not to search for a single, common data structure which is applicable in all circumstances. Any attempt to define a suitable common data structure is likely to be a waste of time. It is important to realize that standards are only useful to a limited extent, even though new developments in information technology (such as 4GL's) can help to alleviate some of the problems associated with the use of a standard. This conclusion also applies to the use of expert systems. Similarly, any attempt to define a single, common data structure for use in the construction industry will not lead to an improvement in the information systems.

Summarizing, the conclusion can be drawn that the research has been able to provide a clear answer to a number of questions. In addition, the most important contribution to the field of Civil Engineering is that a sound basis has been established for further research in specific sectors. It will be important to carry out joint research projects at an international level in order to ensure that the outmoded approaches currently found in various Civil Engineering and Management sectors are replaced as soon as possible by newer, modern approaches. Even though not all of the research efforts carried out by foreign research institutions have led to tangible results which can be applied in practical situations, these institutions still have accumulated a wealth of experience and knowledge which provides them with valuable insights into this subject matter. If the Delft University of Technology were to make use of this base of knowledge, then new research projects could be initiated to find solutions to current problems. Ultimately, the envisioned research studies should be carried out based upon well-defined research proposals with a limited scope. In this way it should be possible to acquire a better feeling for the subject matter and also to make it possible for the researcher to control the research, himself (refer also to Section 2.5 in this Part).

3.3 Significance of this Study for the Field of Industrial Engineering (Eindhoven)

The definition of the typology and the design rules have been based primarily on the
work carried out within the Industrial Engineering and Management Science Faculty of the Eindhoven University of Technology. The joint researchers (Bertrand, Wortmann and Wijngaard) have reached the conclusion after several years of study that it is virtually impossible to find just one single approach to control and information systems which will work in all types of manufacturing companies. Discussions about the techniques such as MRP, JIT and OPT which are typically used in their field are only deemed to be relevant when the most important underlying concepts are considered. These discussions are no longer focused on determining which technique is better than the other.

In spite of the fact that their theory has been developed based upon companies outside of the construction industry, they believe that the basic model should also be applicable to companies in the construction industry.

The research carried out by the authors of this book provides a direct answer to this question: the model referred to above, albeit in a somewhat modified form, is definitely applicable to companies in the construction industry. The required changes to this model are partly due to the different terminology which is used in the construction world. Other adaptations are required due to the lack of a clearly recognizable factory or production unit level and the integration of various decision functions. The basic premise used by the researchers in Eindhoven is that different production situations need to be controlled in different ways. This premise is fully supported by the research presented here. This premise is also valid for the required data structure.

This research study additionally provides a further interpretation of the basic theories which are typically used in Industrial Engineering concerning project management. There are a number of important differences between a construction project and a project as defined in the field of Industrial Engineering. The theories which deal with project management in the manufacturing industry are not fully applicable to construction projects due to the fact that a total new organization is established in the construction industry for each new project and the primary activities are carried out at a specific construction site where the workers and work crews are continually changing. A significant difference in this connection is the fact that materials coordination in the construction industry typically consists of two separate components: project coordination and mobilization.
4 RESULTS OF THE STUDY FROM A PRACTICAL BUSINESS PERSPECTIVE

4.1 Introduction

The implications of applying the results of this research in practice are discussed in this chapter. The questions of to what extent and under which conditions the design rules can be applied in practice are covered, first, in Section 4.2. Then, in Section 4.3, these design rules are translated into a Phase Plan. This Phase Plan can be used by a construction company (and, optionally, by an external consultant) to improve the production control in a practical situation, phase by phase. To conclude this chapter, a number of recommendations are provided in Section 4.4 with respect to the development of production control software.

4.2 Applicability of Design Rules in Practice

The design rules presented in this book for use in production control (decision systems and information systems) are intended to be used as a basic starting point for implementing improvements in practical situations. The case studies presented in Part 3 provide examples of how these design rules can be used.

The design rules have not yet been formulated in a way which facilitates their use in practical situations. An easy-to-use "handbook" is needed to support the use of these design rules in practice. This research study has provided the basic components for inclusion in such a handbook. With this basis, the detailed instructions can now be produced to explain, step by step, how these components should be combined and which conditions are required. This is discussed further in Section 4.3.

In addition to these considerations, a number of points should be mentioned with respect to applying the proposed design rules in practice. A certain number of prerequisites and conditions are normally assumed in the formulation of design rules, which is also true in this case.

The decisions made by the management of a construction company are generally based upon ensuring the continuity and the long term profitability of the company. This implies that decisions may need to be made which do not provide an optimal
solution for a specific activity, but do provide an optimal solution for the company as a whole. Thus, decisions which lead to an optimal production control and a proper use of the information systems may not contribute to achieving the company's business objectives and goals. It is even possible that the objectives of one area of the business may conflict with the objectives of a different area of the business. This aspect of decision-making has not been included within the scope of the present study.

It is also important to consider the actual purpose and intention of a design rule. The use of a design rule will normally never lead to the realization of a properly controlled production situation when it is not used by someone with sufficient knowledge and experience. The desired results will only be attained when someone with the proper background information is in a position to use and interpret the design rules in an appropriate way. This could be compared to a situation of a chef and his cookbook. A recipe used by an experienced chef will generally lead to a better result than the same recipe in the hands of an inexperienced novice in the kitchen.

The conclusion here is that following the Phase Plan as discussed in Section 4.3 will only lead to the desired result when it is used by someone who is thoroughly familiar with the particular construction company (in terms of history, company culture, type of employees), has at least a basic knowledge of Management Science subjects and is also able to dissociate himself from the current way of working. This means that he should be able to anticipate and deal with comments such as "We have always done it this way." The proper environment for dealing with change is often created in practice through the combination of an external management consultant and employees of the construction company. A successful design team consists of external as well as the in-house disciplines.

A Phase Plan is described in Section 4.3 which can be used by such a design team to formulate an appropriate method of production control and to specify which information systems will be required to implement this within a given construction company.

In addition to this Phase Plan for the detailed implementation and realization in a practical situation, this study also provides suggestions for the development of the required software. These recommendations are included in Section 4.4.
4.3 A Practical Phase Plan for Improving Production Control in Construction

The basic idea and premise underlying the design rules described in Part 2 is that it is possible to relate a practical construction order to the appropriate theoretical type of construction order. Once the appropriate type of construction order has been identified, the basic design of the production control can be specified.

This basic idea can be translated into a more specific Phase Plan for use in practical situations. The Phase Plan proposed here is diagrammed in Figure 4.2.

![Diagram of Phase Plan](image)

Figure 4.2: Phase Plan for Determining the Production Control and Information System Requirements

The phases defined in Figure 4.2 are described in more detail in the following subsections.
4.3.1 Describe the company and the construction orders

As suggested in Part 2, a number of essential factors can be seen as the basic determinants for the design of the production control. The company and the construction orders typically carried out by the company need to be analyzed, therefore, in terms of these essential factors. It should be obvious that it is not really possible to determine an absolute value to quantify the importance of each factor, objectively, in a practical situation. Nevertheless, it is usually possible to determine whether a certain evaluation of importance results in a value which is higher or lower than the importance value associated with a specific reference situation.

It is important to note that an ideal-typical typology has been developed and presented in Part 2. This means that there are often more possibilities with respect to determining the importance values of the distinguishing characteristics in practical situations. In addition, it will normally be possible to identify more than one type of construction order within a single construction company. An example of this was the Residential Construction Case presented in Part 3. Multiple types may occur in the form of different types of construction works being carried out at the same time, such as different types of projects carried out by a single construction company, and also in the form of different types of construction orders within a single project (e.g., in the different phases of a project). Providing a description in terms of units of measure which can actually be measured in practice is discussed below. This makes it possible to draw conclusions about decision systems and management information systems for production control in practical situations. A significant point is that this description does not necessarily need to be directly related to the distinguishing characteristics mentioned in Part 2. Additional factors such as the profitability of certain business activities often need to be added. The underlying reason for this was indicated in Section 4.2: decisions concerning production control are often linked with other decisions within the company and should not, as such, be dealt with as isolated decisions in practice.

1. Company resource capacities

It is useful to establish a classification scheme before trying to describe the internal company resource capacities. An initial distinction can be made between equipment and personnel. Within the equipment category, it is useful to make a further distinction between capital-intensive equipment and bulk materials. The personnel category can be split into the sub-categories of staff and construction workers. Each of these sub-categories can then be described in terms of the following factors:
capacity loading percentage

This factor represents the average loading percentage of the resource capacities during a specified period of time.

scarcity

This factor represents the amount of time required to procure a similar type of resource capacity from an external supplier at a competitive price.

employment/deployment period

This factor represents the average employment or deployment period of any resource capacity needed to complete a certain task. This is the inverse of the average number of different assignments or tasks within a given period of time.

quantity

This factor represents the number of resource capacity units allocated to a particular sub-category.

2. Classification of construction orders within a company

It is also useful here to make a distinction between (a maximum of four) different categories of construction orders which are readily identifiable within a construction company. Examples of criteria which could be used to define these categories include: sector, type of client, production method used, revenue per construction order, number of orders and profit per construction order. Note that this classification scheme does not necessarily need to correspond with the theoretical types of construction orders! The following aspects can be quantified for each category:

number of construction orders

This factor represents the quantity of orders accepted or completed per category over a given period of time (e.g., a year).

total revenue

This factor represents the sales revenue realized per category over a given period of time.
profit margin

The company’s general overhead expenses should be allocated to the appropriate types of construction order to calculate the profit margin for each category of construction order. The general overhead expenses need to be included in this calculation since most construction companies charge certain expenses to "overhead" which should actually be charged directly to the projects. A typical example of this is when project administration costs (which are often significant) are charged to general overhead even when it is clear that project administration costs can be directly charged to one or more project accounts. Such costs, thus, need to be allocated to the respective projects in order to obtain a proper evaluation of the profitability of each category.

percentage of the revenue spent on control and information systems

The company’s general overhead expenses again need to be allocated to the respective categories of construction orders to allow for a correct calculation of the control and information systems costs as a percentage of the total sales revenue for each construction order category. The costs referred to here also include the (labor) costs associated with production planning, project administration and data processing.

percentage of company resource capacity

This factor represents the extent to which the company resource capacities are used, on the average, for each category of construction orders.

scarcity of the utilized resource capacities

This factor represents the extent to which the equipment and personnel utilized by the respective construction order categories can be considered to be specialized. By definition, it is difficult to procure specialized resources on short notice to resolve a shortage of capacity and it is similarly difficult to sell excess specialized capacity to another construction company.

work crew information requirement

This factor represents the extent to which the work crew assignments associated with a construction order require specific additional information before the work crew assignments can be completed.
**number of work crew assignments**

This factor represents the number of work crew assignments which can be identified within a given construction order. This also provides an indication of a potential need to divide a complex construction order into multiple parts to improve the controllability.

**employment/deployment period of the resource capacities**

This factor represents the average employment or deployment period of resource capacities, whereby two extreme situations may exist. One extreme is when a resource is allocated to a construction order for the total duration of this order. The other extreme is when a resource is allocated to a construction order for only a short period of time (e.g., several hours).

**degree of uncertainty within the construction order**

This factor represents the extent to which uncertainties exists with respect to the activities to be performed, the materials to be used and/or the procedures to be followed.

### 4.3.2 Determine the basic types of construction orders

At this point it is possible to determine which of the basic types of construction orders is most appropriate for use as a reference model. These are the basic types of construction orders as derived in Part 2. This phase can be carried out based upon the steps diagrammed in Figure 4.3.

An example of a description of the characteristics of several construction orders to be carried out by an arbitrary construction company is presented in Figure 4.4. The determination of the appropriate basic type of construction order is also included in this example.
Figure 4.3: Determining the Appropriate Basic Type of Construction Order
### Description of the Construction Orders for Company "Arbitrary"

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Residential Construction, series (rental)</th>
<th>Residential Construction, series (purchase)</th>
<th>Schools</th>
<th>Small-scale Construction</th>
<th>Apartments</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of orders per year</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>210</td>
<td>3</td>
</tr>
<tr>
<td>total revenue per year (million)</td>
<td>26</td>
<td>19</td>
<td>5</td>
<td>10.5</td>
<td>24</td>
</tr>
<tr>
<td>profit margin</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>control and information systems cost percentage</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>scarcity of utilized resource capacities</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>percentage of company resource capacities</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>information requirement of work crews</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>number of work crew assignments</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>&gt;1</td>
<td>1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>employment/deployment period of resource capacities</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>uncertainty</td>
<td>-</td>
<td>requirement uncertainty</td>
<td>+</td>
<td>requirement uncertainty</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.4:** Description of the Construction Orders of an Arbitrary Construction Company

### 4.3.3 Compare control methods in the basic types with the current control methods and information systems

The next phase in this analysis process is to compare the control methods currently used within the construction company with the control methods incorporated in the appropriate theoretical basic types of construction orders. To accomplish this, an analysis per category as indicated in Figure 4.4 should be carried out to determine which activities are currently performed in connection with control and information processing (including the automated systems). This analysis can be performed in an unstructured manner, however, it is preferable to make use of a decision flowchart which forces the analyst to structure his thought process. The actual form of such a flowchart diagram is not really relevant, especially in view of the fact that there is no
agreement within the field of informatics regarding which type of diagram is most appropriate. With respect to this, it should be noted that several aspects of the diagramming technique used during the orientation phase of this study (IDEF-0) also turned out to be unsatisfactory [Melles et al., 1990a].

It is of primary importance that a technique be selected which can be understood easily by the user (i.e., construction company personnel). They need to be able to read and understand the diagrams and also to draw new diagrams, themselves. The traditional flowcharting technique provides sufficient possibilities, in our opinion, to document the essential aspects of the current method of control and the current information systems which exist within the company. An example of this type of diagram is presented in Figure 4.5.

Once the current procedures are sufficiently documented, it is then possible to compare them with the methods of control prescribed in the theoretical types of construction orders. This comparison can be made for each identified category using a table similar to the example presented in Figure 4.6.
Figure 4.5: Example of a Diagramming Technique
Comparison between the selected Basic Type and the Category Residential Construction (rental property) for Construction Company "Arbitrary"

<table>
<thead>
<tr>
<th>Selected basic type: Standard Construction Project</th>
<th>Identified in practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business planning</td>
<td>Prepare Business Plan</td>
</tr>
<tr>
<td>Construction order acceptance</td>
<td>-</td>
</tr>
<tr>
<td>Project coordination</td>
<td>Prepare and Revise Project Plan</td>
</tr>
<tr>
<td></td>
<td>Record Status of the Work</td>
</tr>
<tr>
<td></td>
<td>Evaluate Monitoring Summary</td>
</tr>
<tr>
<td>Mobilization/Allocation</td>
<td>-</td>
</tr>
<tr>
<td>Resource capacity planning</td>
<td>-</td>
</tr>
<tr>
<td>Multi-project planning</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 4.6: Comparison Table

The example of a Comparison Table presented in Figure 4.6 is based upon the category Residential Construction (rental property) in Figure 4.4. The analysis presented in Figure 4.4 led to the conclusion that this category could best be compared to Basic Type of Construction Order: Standard Construction Project in the typology. The decision functions associated with this Basic Type are listed in the first column in Figure 4.6. The second column then shows which control instruments (e.g., plans and reports) have been identified in practice (in the diagrams developed by the staff, themselves). In this case, for example, a project plan is drawn up for each project in the category Residential Construction (rental property). This could be seen as a specific interpretation of the "Project Coordination" decision function which appears in the first column.

By attempting to complete a Comparison Table in this way, the missing production control components can be identified easily. The analysis in Figure 4.6 suggests that insufficient attention is paid currently to control aspects (in comparison to the theoretically ideal situation) with respect to resource capacity planning, the procurement of materials and the use of subcontractors.
4.3.4 Review/Change the strategic positioning

After completion of the aforementioned phases, a clear picture of the differences between the current procedures and the theoretically recommended method of control can be obtained. The conclusion will often be that the theoretical solution in which a wide diversity of control methods is deemed to be appropriate, may not be practical to implement. This could be the case whereby, for example, Types A, C and D are all found to be appropriate since various categories of work can be identified within the company. Normally only one form of control will be selected for all categories of work, especially in small and medium-sized construction companies. The major reason for this is typically that the control functions need to interface with other functions (e.g., the financial administration functions) within the construction company. Another reason could be that individuals often find it difficult to recognize more than one form of control. By limiting the number of control methods, the costs incurred in connection with control and information systems can also be kept under control. A portion of these costs can be seen as "costs of failure" such as the cost of correcting errors resulting from a lack of preparation. This could be the case in figure 4.4 with respect to the category Residential Construction (purchased property).

The existence of this type of situation can provide a sufficient reason to follow the theoretically recommended method of control. If, however, the comparison shows that current practice is in line with the theoretical model, then the question could be asked of whether the construction order category under review fits in sufficiently with the core business activities of the construction company under consideration. In this case, a strategic repositioning should be considered.

A strategic repositioning of the company and its activities should generally be considered whenever more than one basic type of construction order is identified. The reason for this is that the costs of control and information systems will always be significantly higher when multiple categories of construction orders exist. These higher costs are the result of the fact that an optimal control of the construction orders, individually as well as combined, is only possible when the various basic principles of all of the relevant types of construction orders can be identified. This means that an extensive management information system must be maintained in practice. All of the specific properties of the information system must be identified, generally leading to a level of general overhead expenses which is too high in relation to the revenues of the construction company.

The maintenance of multiple basic types of production can also lead to a situation in which one part of the company overshadows the other part(s) of the company. In addition, the required control and information system for each type of construction order will typically not be fully implemented due to cost considerations. This means
that one or more of the categories of business activities will receive insufficient management attention, potentially leading to a unprofitable activity within the company.

It is important to evaluate the ratios of the revenue to the profit and the general overhead expenses. This evaluation can only be carried out effectively when the general overhead expenses can be related to the different business activities within the company. If this calculation shows that the profitability of a certain business activity is relatively low and the associated general overhead expenses are high, then the possibility of spinning off this activity from the core business should be seriously considered as the best course of action. Increasing the profitability of the activity by spending more attention to control and information system aspects will not be possible under these circumstances since this would just increase the level of the general overhead expenses.

*Acquisition of a new business activity*

A strategic repositioning of the company need not necessarily lead to the divestment of one or more business activities. The same type of evaluation should take place when the possibility of acquiring another business arises. In addition to considering the normal financial aspects (e.g., the profitability of the company), an investigation should be carried out to determine how well the new business activity will fit into the existing control structure of the acquiring company.

4.3.5 Complete the details of the approach using the basic types of construction orders

The details of the approach associated with the selected basic types of construction orders can be developed after the need for strategic repositioning has been considered and, if necessary, carried out. The completion of these details can be performed in a number of steps. It is important to recognize here, too, that the control of construction orders cannot be isolated from the control of other relevant functions within the company. The details of the control functions should, therefore, be defined for the total company seen as an integrated whole. This could also be performed within the context of a Total Quality Management project within the company. The added complications of an integral approach in which the other business functions are taken into account are not addressed in the steps described in the remainder of this sub-section, however.

The different steps which can be identified to define the details for the control
approach are as follows:

1. define a company control model;
2. translate the company control model into process models, procedures and job specifications;
3. implement and evaluate the new control structure;
4. design and develop the supporting tools.

Regarding 1. Define a company control model

Following the example shown in Figure 4.4 leads to an identification of the number of different basic types of construction orders which exist within a company. There is always some overlap between the different categories. This can be seen in the example in Figure 4.4 where the "Project Coordination" decision function is apparent within the "Unique Project" as well as the "Standard Construction Project" type of construction order.

The company control model consists of a combination of the different basic types of construction orders such as shown in Figure 4.4, whereby the overlapping functions only need to be included once. The case studies presented in Part 3 (Figures 2.7 and 3.9) illustrate how this can be done.

Regarding 2. Translate the company control model into process models, procedures and job specifications

The company control model is specified in more detail in this step. For the same reasons given in Sub-section 4.3.3 with respect to describing the current methods of control, a suitable diagramming technique should be chosen for use in completing this step. The process model to be developed here can be seen as a translation of the company control model into explicit business processes. The following questions should be addressed in defining how each of the decision functions should be implemented:

- **What needs to be accomplished** to achieve the objective of the decision function? What data is required (via which data entry processes)? What decisions are required?

- **Who will be performing the process**? Which person is responsible for the actual work? Who is ultimately responsible?
• *Where will the process be carried out?* Should the process be performed at the construction site or at the office?

• *When will the process be performed?* How often will the process be carried out? What initial conditions are necessary for this process? Are there any exceptions?

When all of the questions, above, have been answered satisfactorily, the translation of the control model into process models can be considered to be complete. It is important that the design rules described in Part 2 are taken into account. The process models can be used, subsequently, as the basis for developing procedures and descriptions of the functions. These are then used to implement the new control structure within the organization in the next step.

Regarding 3. Implement and evaluate the new control structure

It is assumed that a new control structure will need to be implemented within the organization. This may have far-reaching consequences in some situations. One of the important aspects is that new tasks and responsibilities may be assigned to a number of the company employees. This means that sufficient information and guidance will also be important both prior to and during the implementation period.

One method of convincing the persons involved that the new methods and procedures will lead to actual improvements is to measure performance before and after the implementation of the new control structure. Examples of suitable measurements could be the number of complaints received, the number of incorrect deliveries at the construction site (including delayed deliveries) and the equipment loading factors. Training programs (in-house or external) could also be included as an integral part of the implementation plan.

A significant amount of attention should be focused on an adequate support and guidance of company personnel in view of the complexity of this implementation phase in which various (social and other) problems may occur. Nevertheless, this aspect has not been included within the scope of this research since it involves a totally different field of expertise. Further information on this subject can be found in [Veen et al., 1991] and [Robbins-1988].

Regarding 4. Design and develop the supporting tools

This step can be performed at the same time as steps 2 and 3, even though it is
described here as the fourth step. In some situations, this step may need to be carried out prior to step 3 in order to ensure that sufficient tools are available to allow the timely completion of step 3.

The use of modern information technology is seen as the most appropriate tool in most situations. Other types of tools should, of course, also be considered. A careful evaluation should be carried out in practice in every instance to determine exactly how the new possibilities offered by information technology could contribute to an optimal control of the production. Better alternatives than the use of computers may exist in some cases. The evaluation of the available alternatives should be carried out as an explicit step in the Phase Plan.

Decisions regarding investments in computer systems (hardware and software) often become an area of controversy within many companies when it is apparent that automated data processing is required. In view of the importance of the company-specific requirements, it is logical to assume that customized software should be preferred above standard solutions. This implies that the resulting automated systems will then always provide the required information as dictated by the company's own control model. The price that a company may need to pay for the best theoretical solution in this sense is often prohibitive, however. The development of tailor-made software is typically extremely expensive. In addition, the specification of the software requirements in the case of a small or medium-sized company requires a certain expertise which may not be readily available.

The consequence of this is that construction companies often (almost always) rely upon the products offered by software houses which specialize in developing standard application software for the construction industry. This introduces a new problem of deciding which product from which software house provides a solution which best meets the information requirements of the company's own control model.

The construction company should carry out this evaluation and selection process based upon a set of objective criteria. This is not an easy task. The system requirements can be derived from the company control model defined in the first step of this phase, including a specification of the data structure. It is extremely important to follow an iterative process with short intervals and a limited number of easy-to-measure evaluation criteria to narrow down the list of potential suppliers of software to two or three candidates. When possible, prototyping should be used to determine whether (parts of) the company control model can be satisfactorily implemented based upon the supplier's standard software with minor modifications.
4.4 Suggestions for the Software Industry

The objective of the Phase Plan described in Section 4.3 is to improve the control situation within a construction company. This Phase Plan is, thus, designed to be used by the company, itself, and any external consultants involved in this effort. The last step of the last phase as described in Sub-section 4.3.5 involves the evaluation of the tools which could be used and the potential involvement of an external software house. Ideally, representatives of the software house will be involved during this phase to the extent that they assist with the evaluation of the applicability of the standard software and the advantages and disadvantages of automating certain processes. This should be in the interest of all parties concerned, since the implementation of unnecessary functions will lead to practical problems in practice which will be ascribed to the software vendor, sooner or later. In order to be able to participate actively in this way, software houses will need to be aware of which types of businesses (and, more specifically, projects) can use their software most effectively. This implies that they will need to develop methods for measuring the applicability of their products in a specific business situation (for example, during the software evaluation phase).

An additional important suggestion for the software industry is to develop software which is control-oriented rather than sector-oriented (as is now the case). The manufacturing industry, where control-oriented software packages have proven their success, can be used as a case in point. The various basic types of construction orders presented in Part 2 could be used as the basis for a subsequent control-oriented development of software for the construction industry. This would mean in practice that standard software would be developed based upon a specific type of production control.

Nevertheless, it is still important that specific sector-related requirements can be satisfied in the form of optional add-on modules. An example of a specific sector requirement can be found in the civil works sector where standard rates per project are used and government regulations exist for the coding of data. Figure 4.7 illustrates the essential differences between the current approach and the proposed future approach to structuring standard software.

It is envisioned that an analysis of the current business (e.g., based upon the proposed Phase Plan) can be used to determine which control module provides the best solution for a particular company. Then specific sector-oriented modules can be added to ensure that the standard software is suitable for use in the specific sector in which the company operates.
This control-oriented approach should mean more than just entering the appropriate data into a computer system and then being able to get the required information out of the system. Recent developments in 4GL tools have led to claims that "anything is possible, the sky's the limit". This is a gross exaggeration since the interface between the user and the system will become increasingly more important. Much more is involved here than just the traditional aspect of user-friendliness. User-friendliness is important, but is not the only interface issue. The interface should be designed to optimally support the proper formulation and solution of decision problems. The proper data (i.e., pre-selected) should be provided to the decision-maker in such a way that the data can be readily interpreted. In some cases this interface problem may need to be addressed by the optional sector-oriented modules. Attention should be focused primarily on a correct and efficient communication of information between various locations such as the construction site, the storage yard, the office and the suppliers (refer also to the cases in Part 3).
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B. Melles

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Upon completion of his studies in 1988, he was asked to participate in the research program concerned with Production Control in Construction. In connection with this research, he has published many articles on the subject of production control in construction, including articles dealing specifically with the application of industrial production control techniques in this sector. He has also participated in a number of international research groups and was instrumental in organizing a meeting of Work Commission 65 of the International Council for Building Research, Studies and Documentation (CIB). In addition, he has taught several of the standard university courses.

He is one of the founders/owners of INFOCUS Management Consultants B.V. (Nieuwegein, Netherlands), specializing in the construction industry. As a consultant he has been involved in several assignments concerning the effective use of information, restructuring organizations and quality improvement projects for large as well as small companies in the industrial building, commercial building and civil works sectors.
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In addition, he is one of the founders/owners of INFOCUS Management Consultants B.V. (Nieuwegein, Netherlands). As a consultant he has been involved in several system development and quality improvement projects for both medium and large sized construction companies specializing in the commercial building sector, residential construction and road construction. He has also given an international training course for the staff of construction companies.