Lead time technology

Citation for published version (APA):

Document status and date:
Gepubliceerd: 01/01/2004

Document Version:
Uitgevers PDF, ook bekend als Version of Record

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
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• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Download date: 10. Jun. 2020
Intreerede

Uitgesproken in verkorte vorm op 10 december 2004
aan de Technische Universiteit Eindhoven

lead time technology

prof.dr.ir. J.C. Fransoo
Mijnheer de Rector Magnificus, Dames en Heren,

Wealth grows by a continuous improvement in more efficient use of scarce resources in order to satisfy increasing needs of a continuously more wealthy population. The Netherlands has seen an enormous growth in wealth over the last century. While the trade and banking sector have contributed substantially to this development, industry has had a considerable impact on the growth of this wealth. Consumers are interested in products which can enrich their lives, products that may be able to carry services to serve their ever-increasing needs against lower cost and against a decreasing environmental impact. The usage of scarce resources gains in efficiency because of developments in technology. In this technology, I would like to distinguish between the developments in product technology and those in conversion technology. Product technology is the carrier of the added value perceived by the customer. A Sony Playstation provides the opportunity to play games for children and possibly many adults. Conversion technology provides the opportunity to produce or manufacture those products. ASML wafer steppers allow for large silicon wafers with very tiny components and an amazing amount of circuits to be produced. In some industries, product technology is the dominant technology and the conversion technology appears to be fairly trivial and technologically not very advanced. It is striking that this is particularly true for what is commonly denoted as high-tech manufacturing, for instance the assembly of mobile phones. In other industries, it is primarily the conversion technology that determines the characteristics of the product. Typically, this is true for those conversion processes that can be found further upstream in the supply chain, such as the chemical and petrochemical industry, the steel industry, and the pharmaceutical and biotech industries.

In supply chains that have been dominated by product technology rather than conversion technology, the physical structure of the supply chain has been primarily determined by the cost structure of the product. Over the last few decades, this has lead to a process that I have heard
described by Victor Fung, Chairman of the Li & Fung apparel empire, as ‘slicing up the supply chain’. In Li & Fung’s strategy, the complete supply chain of apparel is sliced up into small pieces and the challenge for the supply chain owner is to outsource each piece in such a way that the incurred costs are minimized. As such, Li & Fung’s supply chain consists of more than a dozen steps, each of which are executed at a separate location and by a separate manufacturer. Furthermore, for each product range these locations and manufacturers could potentially be different. This model outlined for an apparel manufacturer serves as an example for many manufacturers that rely on product technology rather than conversion technology. As a consequence, major improvements that have been realized on lead time reduction in manufacturing plants in the last few decades of the 20th century have been compensated by substantial increases in lead times along the supply chain due to this slicing up. Coupled with the decrease in product life cycle, this implies that a product can only be replenished a few times during its life cycle. With these lead times, this will either mean obsolete products or lost sales. Note that the overall lead time is not due to the actual conversion process; in total this may take a few hours, with the exception of some complex operations. The actual lead time is primarily due to waiting times on the shop floor, business process lead times, and inventory waits. The dominance of these lead times on the actual performance leads to the ever increasing importance of what I will denote as lead time technology. This is the technology of designing decision structures, accompanying software and making the actual decisions that in most modern supply chains really determine lead time, customer service experience, and increasingly product cost. Lead time technology can be compared to product and conversion technology in that it is aimed at increasing wealth, in its broadest sense, it is an engineering discipline, and it is soundly based on scientific analysis, primarily Operations Research.

Having heard this, it may sound as a revival of the time-based competition hype of the early 1990s [1]. Having studied the practice of Japanese manufacturing firms, George Stalk of the Boston Consulting Group proclaimed that the main source of their competitiveness were the short lead times, which enabled them to quickly respond to changing customer needs. The manufacturing base of most Japanese companies was local, allowing very short lead times into the plant. Furthermore, the manufacturing lines were mixed-model, allowing different models to be produced on the very same manufacturing line (typically these were assembly lines). Stalk later on discovered in less-publicized papers – papers with a more critical message appear to be disregarded by management hypes – that in fact Japanese companies managed to compete on time by drastically reducing product variety. Studies of Eindhoven Industrial Engineering students at Japanese plants further demonstrated that Japanese companies in the late 1990s reached very short throughput times by freezing the production schedule for three months – thus drastically increasing the lead time of the business process. Although champions in manufacturing, the Japanese turned out to be poor masters of the supply chain; again documented by various confidential reports of Eindhoven Industrial Engineering students. The supply chain slicing operations that have been conducted by Japanese manufacturers over the last ten years have thus lead to a further decrease in response similar to the increase in lead times that I just mentioned.
Lead time technology in the supply chain

With this introduction, I hope to have raised your awareness that apart from the product technology and the conversion technology, it is now additionally, and in many cases primarily, the lead time technology that determines a firm’s operational and financial performance. The relationship between the three is different depending on the position of the company in the supply chain. I will illustrate this by briefly describing this for three different industries. At the top end of the supply chain, I will consider a chemical plant, at the center of the supply chain an assembly line in the PC industry, and at the bottom of the supply chain a grocery retail outlet. This is by no means complete but serves well to illustrate the various relationships between product technology, conversion technology and lead time technology at those different levels in the supply chain.

Prior to this description, I would like to stress that in this lecture I will assume initially the neoclassical economics point of view – which I do not necessarily support, but it serves well as a starting point of thought – which states that all behavior is guided by rational utility maximization. This means it is of primary importance to understand the cost structure of such an operation [2]. For production companies at the top end of the supply chain, typically denoted by operations management researchers as ‘process industries’ the equipment is the predominant cost factor and cost is primarily determined by the conversion process [3]. Conversely, at the retail end of the supply chain the added value is determined by the delivery process, which can be considered part of lead time technology. Similarly, in PC assembly, the availability of components drives the operational performance, material coordination is the key issue, and this is driven by product technology.

The process industry has traditionally been characterized by a strong emphasis on conversion technology. The processes in bulk chemicals are the main driver for the eventual performance of the product and research and engineering has focused on the last thirty years on improving conversion technology to the extent to which in bulk chemicals the added value of conversion is now more or less equal to added value in logistics and distribution. Lead times in these industries are however mainly determined by change over cycles or production wheels, and inherent inflexibilities in the conversion technology. A major step is needed within which the operations of the supply chain in terms of its lead times performance under uncertainty needs to be a major factor in the early engineering phases of production. This is a field in which I hope my chair will closely work together with the recently created chair in Process Systems Engineering in the Department of Chemical Engineering and Chemistry. In earlier presentations, I have denoted this field as anticipatory process engineering, in which process engineering decisions are directly related to the later operation of the supply chain. Since increasingly heuristics and advanced modeling techniques are used in process synthesis and process systems engineering, it seems natural to develop those models in close collaboration with models for supply chain planning.

In the assembly of Personal Computers, conversion technology is less relevant. It is product technology that dominates the industry, and Supply Chain and Operations Planning deal primarily with two issues, namely the coordination of the release decisions of the many components over time, which is the focus of the chair of my colleague De Kok, and the control of the product development process, to which my colleague Bertrand has made significant contributions. It is interesting to note that one of the industries where I have been involved with significant modeling work of the operations planning and control process, the pharmaceutical industry, appears to increasingly develop into an industry in which conversion technology becomes less important. Simultaneously, the development of biotechnology also leads to a situation within which processes are less well understood and controlled, and lifecycles of products are reduced.

Finally, in grocery retail it is only lead time technology that determines current operational performance. This demonstrates the primary attention for logistics and operations planning and control in this industry. The development of smart tags (RFID) will lead to a situation in which product technology will become more important and may lead to new opportunities for lead time technology to develop further.

In the remainder of this talk, I will first detail out the principles of
operations planning and control in the view of hierarchical planning structures, which is one of the basic theories of a science of lead times. Since my chair primarily focuses on the relationship between lead time technology and conversion technology, I will detail out that relationship in further detail and list a few opportunities for research in that area. As a final research topic, I will address the relationship between lead times science and empiricism. Since I have also been appointed as Program Director of a number of programs in the industrial engineering domain at this university, I will also briefly outline my view on educating Industrial Engineers.

An Operations Planning and Control system in a company is the set of procedures involved in all operational decisions regarding the time and quantity aspects resulting in a certain • cost (operational financial performance), • service level (operational logistics performance) and • environmental burden (operational environmental performance), together with the relations between these procedures. The operations planning and control system determines what is executed when, by whom and with what resources.

Researchers have traditionally analyzed the components of supply chain planning operations independently from one another. Research addressing the scheduling problem, the (multi-echelon) inventory problem, and the aggregate capacity planning problem has hardly been interconnected while maintaining their own characteristics [4]. Managers were however still faced with this multitude of different problems in the supply chain planning domain. They resolved these issues by organizing these decisions in a hierarchical manner [5]. The idea for hierarchical production planning was captured formally by Anthony [6]. He introduced three levels of hierarchical control: Strategic Planning, Management Control, and Operational Control. The principal ideas for developing this planning hierarchy into a set of formal models supporting coordinated decision making at these levels were developed by Gabriel Bitran, Arnoldo Hax and Harlan Meal at MIT in the early 1970s. Essentially there are two types of constraints at each of the levels of their formulation:

1. Primary process constraints: these are ‘hard’ constraints that are derived from physical constraints in the process, such as resources.
2. Decision process constraints: these are ‘soft’ constraints that are imposed upon a level by its immediate higher level in the decision hierarchy.

At the highest level, the aggregate resource constraints form the basis
of the resource hierarchy, with the decision how much time to allocate in regular time and in overtime, in line with the original aggregate planning model developed by Holt, Modigliani, Muth and Simon [7], although the cost in the models by Bitran and his colleagues are linear and not quadratic as Modigliani and his colleagues did. A distinction between the primary process constraints and the decision process constraints is not made in the model formulation, leading to the fact that, for instance, a decision to produce a certain quantity of a product family is fixed, despite possibly ‘better’ feasible solutions once the more detailed planning starts at a lower level.

Decisions with regard to the planning of supply chain operations have traditionally been taken at the operational level. Harlan Meal argues in his seminal paper in Harvard Business Review, ‘Putting production decisions where they belong’ [8], that this was necessarily decentralized due to the lack of good information processing technology. In this approach, which he names the ‘conventional approach’, operations planning decisions were an integral part of the decision making power of the line managers in all parts and at all levels in the organization. Decisions were only coordinated marginally, and certainly not in a systematic manner. Due to the emergence of large-scale information processing technology in the 1970s, initiatives were taken to create large-scale comprehensive models of planning operations. Meal calls this the ‘centralized approach’, which is based on a tendency to create central decision functions which are given the power to control in detail the planning decisions of the operational process in all parts of the organization.

There are a number of difficulties associated with these centralized monolithic decision models. The models tend to be very big and complex. This makes the analysis of the models and finding an optimal solution very difficult and requires a decomposition of the model in order to be able to solve this. Model decomposition is a widely used strategy in solving optimization problems. Apart from the complexity in the mathematical sense, there are however also a number of organizational and people-related difficulties associated with the centralized approach. The most important difficulty is that there appears to be no owner of the monolithic model. Responsibilities within organizations tend to be distributed over a number of people.

The monolithic model assumes it is a single organizational unit deciding on a large number of details across the entire organization. If we assume that the higher-level management would actually own the model and make these decisions, a number of people and model related difficulties come about:

1. detailed figures do not mean much to higher-level managers
2. detailed figures give a false sense of security because they may be highly unreliable, not only if they refer to some future state of the system (e.g., forecast of exogenous data), but also if they refer to the current state of the system (data quality problems)
3. centralized planning takes away authority from local managers further down the hierarchy and reduces their responsibility, which is not in line with the dominant management philosophy of self-containedness and autonomous groups. Apart from that, it is also contradictory to a principle from control theory, which states that responsibility and decision authority should be matched with the opportunity to control [9].
4. A model never captures the complete richness of a situation. As a consequence, a local planner down the hierarchy will always have more information and a better representation of the actual processes than a (higher-level) model.

All this leads to the fact that a decomposition of the problem is required in order to be able to find a solution to the planning problem that can also be implemented within an organization. If a decision problem is decomposed and a hierarchy is constructed, higher levels of the hierarchy will need to aggregate the lower level models. This aggregation is necessary to overcome the difficulties just listed. Furthermore, this decomposition will lead to more or less independent units along the supply chain, that are self-contained with regard to their control within the unit, but receive objectives and constraints to be taken into account from an aggregate and centralized control function. This is in line with the idea of separating goods flow control and production unit control, as developed by Will Bertrand and Hans Wortmann [10]. A consequence of this approach is that lead times of the various production units are fixed and are input to the system rather than output. Thus, hierarchical decomposition of the supply chain planning problem has two essential characteristics, namely:
reflecting the decision, different for different
asymmetry, which underlie the notion of obtaining supply chain control by working with planned lead times.

Effectuation lead times
Asymmetry in the decision making hierarchy and the necessity to anticipate is primarily caused by the fact that it takes time to implement a decision: the effectuation lead time. The effectuation lead time is the time that passes between the moment a decision is made and the moment that the consequences of this decision can be observed in the operation of the supply chain.

I will now discuss the concepts of effectuation lead times and information asymmetry, which underlie the notion of obtaining supply chain control by working with planned lead times.

Figure 1

Effectuation lead time and information asymmetry

An example of an effectuation lead time is the procurement time of components. If the procurement lead time for a component \( i \) is \( L_i \), then \( r_i(t) \), the quantity procured at the start of period \( t \) is supposed to be available for further assembly or sales at the start of period \( t+L_i \).

The immediate decisions \( \{ r_i(t) \} \) are dependent on the exogenous demand forecasts \( \{ \hat{D}_i(t+s,t) \} \) (for item \( i \) in period \( t+s \) as decided on at the start of period \( t\), \( t \geq 0 \), \( s \geq 0 \), \( \forall i \))

Assuming supply is reliable and \( L_i \) is realized, we may expect that

\[
\hat{p}_i(t+1, t+s) = r_i(t), \quad \text{where we define } \hat{p}_i(t,t+1) \text{ as the forecast of the quantity of item } i \text{ that becomes available at the start of period } t+1 \text{ as determined at the start of period } t, \quad t \geq 0, \quad s \geq 0, \quad \forall i \end{equation}

reflecting the decision of the supplier to ship as late as possible. Note that \( \hat{p}_i(t,t+L_i) \) is only a planned decision from the perspective of the organization ordering the item. For the supplier this may be either a firm decision, in case the supplier has to start immediately with processing and transporting the order for item \( i \), or a planned decision, in case the effectuation lead time incorporates some slack time.

Suppose that at time \( t \) the planned decision is taken according to the above equation. At the start of period \( t+1 \) we generate new forecasts, \( \{ \hat{D}_i(t+1, t+s) \}, s \geq 1 \). It is now well possible that, e.g. due to a decrease in demand for item \( i \) it is decided to change the decision made earlier, i.e. \( \hat{p}_i(t+1, t+L_i) = \hat{p}_i(t,t+L_i) \)

Following the discussion of planned versus firm decisions, we can see that dependent on the incorporation of slack time into the procurement time, it is possible or not to change the earlier decision.

Information asymmetry itself can be described using the following example. Consider again item \( i \) with planned lead time, i.e. the effectuation lead time of the material order release decision, \( L_i \). Often suppliers receive forecasts about future orders in some period \( t \) multiple times in order to take consecutive decisions on e.g. buying production equipment, hiring and training people and procurement of materials.

As stated above the forecasts \( \{ \hat{D}_i(t+s,t) \} \) for period \( t \) made at the start of an earlier period \( t-s \) differ for different \( s \). Thus the procurement orders derived from these forecasts change over time, so that the supplier’s decision to buy production equipment is based on different information than the supplier’s decision to procure materials. This asymmetry in information needs to be taken into account when designing the decision hierarchy or supply chain control structure. The effectuation lead time thus leads to differences between the moments in time that certain decisions must be taken. Also, it means that decisions are often taken a substantial time before the actual action in the physical process takes place. As a consequence the decision maker in fact feeds forward in terms of control theory rather than feeds back as is often suggested in hierarchical production planning frameworks. In order to feed forward,
Hierarchical planning framework proposed by Schneeweiss

A useful framework that describes this anticipatory decision cycle is presented by Schneeweiss [12], whose interesting work has unfortunately had little impact outside Germany. In Schneeweiss’s model, a decision structure within an organization can be represented as a series of decision tandems, i.e., two decision levels interacting with each other with the first of the two levels (the top level) giving an instruction to the second of the two levels (the base level), and the base level responding by giving a reaction to the top level. Before giving its instruction, the top level anticipates the base level’s reaction by either implicitly or explicitly modeling the behavior of the base level in the top level’s model. This is called the anticipated base model [13]. In general, the anticipated base model can be constructed based on aggregating information and/or on aggregating the base level model itself.

An interesting feature of the modeling concept of Schneeweiss is that although the term ‘hierarchical’ is used, it can be applied in a wide variety of settings in which two decision makers interact. For instance, much of the game-theoretic work in supply chain contracting fits well into his modeling concept. In fact, in a later version of his work, the concept of hierarchical planning is renamed as distributed decision making.

The need for control
Anticipation models need to capture the base level behavior in a sufficiently accurate manner. In this sense, accurate refers to the predictive quality of the anticipation model. When designing a decision structure, two different approaches can be taken when constructing the anticipation functions. The first approach is to try and capture the base level behavior as completely as possible by enriching the anticipation function by as many details as known about the base level. The second approach is to design the decision function at the base level in such a way that the actual anticipation becomes straightforward. In this case, the objective of the base level is to realize a set of targets set by the top level. I will refer to this situation as a controlled situation. An example of such a design is the reliance on planned lead times maintained by workload control methods, as developed by Bertrand in our group [10].

It is neither obvious nor conclusive whether working with planned lead times is a correct approach, since current research is not conclusive and there are researchers that advocate the use of variable lead times, including my colleagues Henk Zijm at the University of Twente and Hartmut Stadtler at the University of Hamburg. One of the main theoretical research topics that we are currently addressing is this research question. Especially interesting questions with relation to newly applied technologies like Radio Frequency Identification techniques and the availability of the internet and broadband telecommunication channels raises interesting questions how this information should be used in operations planning and control, since straightforward unlimited updating of information leads to very poorly controlled systems. Recent results in our group suggest that frequent updating will lead to stability conditions that are stricter than in systems that are less frequently updated. All we can further say at this time is that the issue is far from trivial.

Asymmetry in supply chain planning
After constructing a hierarchical planning structure, oftentimes the resulting planning situation is characterized by asymmetry of information. Essentially having different levels of control being owned by different organizational units leads to different information statuses.

the decision maker essentially anticipates the events over the period of time until his decision is effectuated [11].

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Our models focus on a common situation in the production of specialty pharmaceuticals. Typical characteristics of this production are the large number of processing steps, specific requirements on the resources, relatively long processing times and physical limitations on the waiting time between consecutive operations due to possibly degrading product quality or instability of the intermediate product. In this line of research, we focused on building models that can anticipate the expected completion time of a set of diverse jobs that is processed in...
Lead time technology and execution

The current state of the art in queuing models is insufficient to support this anticipation, due to the transient state of the system, the large variety in jobs, and the large influence of the scheduling logic applied at the shop floor on the operational performance. Regression models, coupled with an understanding of the important factors that determine performance, have proven to perform very well, and to be quite robust in production situations as uncertain as in the pharmaceutical industry. Recent work has further demonstrated that using a modified bootstrapping technique can even allow us to build models with a very small number of historical data. Since product lifecycles decrease and experience is built very slowly, the further development of these techniques is very important. For operations planning and control, a next step in this research line would be to extend the experimental validation to an empirical validation. Experimentally, now further extensions are needed to take into account the process characteristics as described in the field of process systems engineering. This will not only allow us to build more reliable models, but also to make the link between operations planning and process control in Manufacturing Execution Systems more explicit. Furthermore, it will also be a first step to build models that make the implication of process technology choices for the actual operation of the supply chain explicit.

As I indicated earlier in my lecture, this relationship between conversion technology and lead time technology is one of the most promising avenues for further research in this area. I would like to argue that establishing this link is of similar and possibly more importance than the current trend in chemical engineering to make the link between product technology and process technology more important. For instance, due to the poorly controlled supply chain from clinical trials down to the sale at the pharmacy, the total inventory in the supply chain of pharmaceuticals, may account for up to 20% of the length of the patent protection time. Similarly, models from the domain of operations planning & control need to be used to further evaluate the promising developments in the area of microreactors.

Theoretical advances in operations planning and control are increasingly evaluated based on their formal performance within the model context. In my view this development has been driven by the – primarily US – business schools that now govern most of the top journals in our field. I am proud to say that our research group in Eindhoven, from its very inception by Monhemius and continued by Bertrand, has maintained a firm standing that this is not sufficient for an operations planning and control group in an engineering school. First of all, performance evaluation in computer simulation and numerical experiments is necessary to evaluate the performance of simplified models in more complex environments. Second, a sound knowledge of the empirical domain is needed to develop these experimental conditions. And finally, true empiricism is needed to really evaluate the validity and performance claims of the models we develop; this will also help us to develop models that are not purely based on the neoclassical economic point of view as I mentioned earlier, but do take into account aspects of gaming and behavioral decision making under assumptions of bounded rationality. While our research group maintains close contact with many industries to conduct these empirical studies, it is particularly the retail environment which enables us to link model development with empiricism. There are two very clear reasons for this. The first one is that conversion and product technology are virtually irrelevant in this industry. This means that the models based on lead time insights very clearly match the actual operations taking place, since they are actually themselves a direct implementation of this process. Second, driven by marketing and the developments in information technology, large amounts of data are available. This allows us to conduct studies based on new methodologies. I am very excited by these recent developments and I will illustrate an important discovery by our group that could only have been reached by empiricism.

The general assumption in inventory research in retailing is that shelf space is expensive and scarce, and that handling cost are linear to the number of products. We gathered empirical data at a grocery retail...
chain and were able to combine marketing and operations data into a single database. This provided us with the opportunity to conduct a unique analysis. We could compare the results of the space allocation decisions of the marketers with a basic analytic model that incorporates aspects of marketing and operations. Based on this comparison, we could demonstrate that significant amounts of excess shelf space exist for a large part of a retailer’s assortment. Excess shelf space is retail space that is not required to carry out the current operations with respect to customer service and costs. We also observed that the cost of replenishment is non-linear and dominates the inventory holding cost. Therefore, excess shelf space cannot easily be eliminated. Instead, excess shelf space in the presence of a non-linear cost of replenishment offers enormous opportunities for the development of new supply chain coordination mechanisms. The existence of excess shelf space can be used to develop different replenishment methods and reduce the number of deliveries to the store.

Similar to recent discoveries in retail, empirical studies that we have conducted in Advanced Planning Systems and in the behavior of human planners, have delivered us very interesting new insights. In general I am convinced that a better empirical understanding of business processes are key to make significant steps in the development of new techniques for operations planning. I consider it as one of my main missions to extend this empirical research line in our group and develop this as one of the additional strongholds of our group in the international operations management research community.

Since my appointment as an Assistant Professor at Technische Universiteit Eindhoven in 1996 I have enjoyed transferring the knowledge in Operations Planning & Control we have developed at Eindhoven to our students. I believe it is one of the key strengths of our program that we have a strong link between the research conducted within the Department and the content of the Program. This will increasingly distinguish us from our competitors. I am convinced that the newly developed Master of Science Program in Operations Management & Logistics will further sharpen our cutting edge.

One of the important developments that will take place over the next few years is to further develop the PhD program. I believe the traditional emphasis on research work and the master-pupil relationship must partially be replaced by a more extensive course program than the current 35 ECTS. The increase of the teaching load should however then also be reflected by decoupling the PhD program of the currently associated appointment as research assistant. PhD candidates should be regarded as graduate students, with research fellowships and teaching assistantships being available to them. This change is necessary for our research school to become more competitive in attracting top students to our PhD program, and for increasing the size of the program.

Our Bachelor Program in Industrial Engineering & Management Science (Technische Bedrijfskunde) provides a sound disciplinary basis in the disciplines of organization science, marketing, operations planning & control, management accounting, information systems, quality & reliability engineering, and organizational behavior & human performance. This disciplinary basis is the core value of our program, and the commonality in these disciplines is not so much their methodology or research tradition, but the common domain that is addressed by these disciplines, namely business processes. In my view, the common misunderstanding to position industrial engineering as a single or multi-disciplinary discipline is not grounded for a bachelor program. The key concept we teach in the Bachelor program is that a
business process can be studied from many different disciplinary angles. Apart from the disciplinary foundations, we thus need to teach our students that these disciplinary angles exist, and each of them has its own position of truth. This is the basis for the academic development of our students, and provides them with an excellent basis to continue their Master’s program with an emphasis on research-driven design. In the design process, different disciplines are integrated into a single design for a particular situation. Design projects in our program are thus always closely tied to research. I am happy that we continually receive the recognition for the quality of our program. Although we – like other engineering disciplines – have been faced over the past years with a decreasing interest of high school students, I have a firm belief that quality will prevail. Delivering that quality while using a variety of modern and traditional ways of knowledge transfer is therefore the road ahead, and the guiding principle for the way in which I direct the program.

Voordat ik mijn rede besluit, wil ik een aantal mensen bedanken.

Heren van het College van Bestuur, het College van Promoties en het Bestuur van de Faculteit Technologie management,

Ik wil u bedanken voor het vertrouwen dat ik heb gekregen om deze leerstoel te mogen vervullen en dit te combineren met het leiding geven aan de opleiding Technische bedrijfskunde. Ik realiseer me dat deze vrijwel onmogelijke combinatie van taken niet alleen mijzelf een enorme druk oplegt, maar ook tot een grote druk leidt op mijn omgeving. Een bijzonder woord van dank daarom voor Werner Rutten, zonder wie het voor mij echt onmogelijk zou zijn om mijn functie van Opleidingsdirecteur uit te voeren.

Voor het vakgebied logistiek is het essentieel om goed ingebed te zijn in een Technische Universiteit. Dit stelt ons in de gelegenheid om daadwerkelijk bijdragen aan het vakgebied te leveren die bij inbedding in een business school niet mogelijk zijn. De samenwerking met andere faculteiten, waarbij dat voor mij in het bijzonder de Faculteit Scheikundige technologie en de Faculteit Wiskunde en Informatica zijn, is zeer belangrijk en ervaar ik als bijzonder stimulerend. Ik ben trots om aan deze Universiteit te mogen werken en zal al het mogelijke doen om onze uitstekende positie nog verder te versterken.

Hooggeleerde Bertrand,

Dit is een goede gelegenheid om je en public te bedanken voor het leermeesterschap op vele fronten. Je bent degene geweest die mij wetenschappelijk heeft gevormd. De rechtlijnigheid in je karakter lijkt in het geheel niet op mijn inborst; tegelijkertijd heeft jouw rechtlijnigheid mij heel veel geleerd waar ik wel en niet aan vast moet houden. Dat kwaliteit uiteindelijk het enige is wat ons verder brengt, is mij door jouw vasthoudendheid bij de onderzoeksomslag van de Faculteit in de afgelopen 15 jaar duidelijk geworden. Het is jammer dat slechts
weinig mensen beseffen welke cruciale rol je daarin hebt gespeeld. Ik hoop dat we de komende jaren de tijd vinden om nog een aantal wetenschappelijke uitdagingen op te pakken.

**Dames en Heren collega-onderzoekers,**

Mijn onderzoeksactiviteiten kenmerken zich door samenwerking met vele mensen, zowel binnen onze groep als daarbuiten. Ik wil hen allen danken voor de grote hoeveelheid kennis die ik hierdoor mag opdoen en voor het plezier dat ik daaraan beleef. In het bijzonder wil ik me daarbij richten op Ton de Kok. Wij hebben in de afgelopen jaren zeer veel samengewerkt. Het meest merkwaardige in onze relatie is dat wij volledig complementair zijn qua disciplinaire achtergrond, maar sterk overeenstemmende ideeën hebben over de projecten waar we mee bezig zijn. Ik denk dat onze samenwerking een uitstekend voorbeeld is van hoe bedrijfskundig onderzoek zou moeten zijn. Ik ontdek dat bij veel van onze jonge collega’s datzelfde enthousiasme aanwezig is en dat stemt mij bijzonder verwachtingsvol over de toekomst van onze groep.

I would like to thank Hau Lee of Stanford University for introducing me into the world of scientific research in North America. The collaboration we have started in research, industry initiatives and in education about ten years ago has had a substantial influence on our research group, my research activities, and the position we currently have in the operations management research community.

**Dames en Heren studenten en promovendi,**

Ik dank de vele studenten en promovendi met wie ik in de afgelopen jaren heb mogen werken. Ik heb van hen veel geleerd en hun inzet en interesse behoren tot de belangrijkste redenen waarom een universiteit nog altijd een veel interessantere omgeving is dan een zuiver onderzoeksinstiutuut. Hoewel jullie mij de eerstkomende jaren nog weinig voor de groep zullen zien, zal ik met veel energie mijn functie van opleidingsdirecteur vervullen om onze opleidingen nog verder te versterken.

Ik dank mijn ouders voor de vrijheid die zij mij hebben gegund om mijn eigen pad te kiezen.

Ten slotte Nicolette. Dank voor je liefde, steun, en je begrip als je weer eens alleen moest zijn omdat ik toch maar wat later naar huis kwam.

Ik heb gezegd.
Notes


2 It is regretful that the lack of well-founded scientifically accepted cost structure analysis methods have lead to the virtual elimination of cost structure analyses from a university-level industrial engineering degree.

3 It should be noted that also raw material cost are a high cost component but they are generally not influentiable by the operations planning decisions. However, in purchasing improvement projects, large benefits have been recorded.


9 This issue is extensively discussed by McPherson and White (McPherson, R.F., and K.P. White Jr. (1994) Management control and the manufacturing hierarchy: Managing integrated manufacturing organizations, International Journal of Human Factors in Manufacturing 4:2, 121-144), who state that “Planning at superior levels must be consistent with control capabilities at subordinate levels, while planning at subordinate levels must be consistent with achieving the superior goals of the hierarchy”.


11 It should be realized that the effectuation lead time is not only related to the bills of materials and bills of resources, but is also a characteristic of the supply chain planning and control system. In many cases, the time buckets at higher levels of decision making are larger than at lower levels. Further, the frequency at which decisions are made, revised or processed is less at higher levels of decision making (the hierarchical structures of Gershwin (Gershwin, S.B. (1994) Manufacturing Systems Engineering, Englewood Cliffs: Prentice Hall) are based upon this premise). This means that changes in the actual (physical) process, e.g., changes in demand, may not be observed directly. Further, if they are observed, there may be a delay in processing the consequences of this observation. This processing time due to the decreased frequency of decision making at higher levels should be included in the effectuation lead time.


13 Schalla et al. (Schalla, A.-J., J.C. Fransoo, and A.G. de Kok (2004) Modeling the planning process in advanced planning systems, Information and Management 42:75-87) further analyzed the various types of anticipation that may exist.

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Colofon

Productie:
Communicatie Service Centrum TU/e

Fotografie cover:
Rob Stork, Eindhoven

Ontwerp:
Plaza ontwerpers, Eindhoven

Druk:
Drukkerij Lecturis, Eindhoven

ISBN: 90-386-1363-6

Digitale versie:
www.tue.nl/bib/