MASTER

Task valuation and resource allocation to optimize value delivered in product and process improvement projects

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Task valuation and resource allocation to optimize value delivered in product and process improvement projects

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Preface

After five years of studying at the Technology Management Department at Eindhoven University of Technology, I am pleased to end my student life in the challenging, enthusiastic and motivating environments of the Technology Management capacity group Operations, Planning, Accounting and Control and the Supply Chain Engineering department of ASML. I would like to thank prof.dr.ir. Bertrand and dr. Huang for our inspiring discussions and their commitment, and especially Mr. Bertrand for his mentoring effort during my master program. I would like to thank ASML for its support and commitment, which made it possible for me to conduct scientific research in a business environment. Especially, I would like to thank ir. Habets, who was willing to help me on a daily basis.

Summary

In many sectors, companies increasingly adhere to a project-based organization (Whittington et al., 1999). New Product Introduction (NPI) projects aim at the timely development of products with a new form, fit and/or function. Suppliers' contributions in the development stages of new products are often important. Whereas supplier involvement management can be seen as the primal responsibility of the purchasing department, the work may be divided over functional expertise groups.
This master thesis focuses on resource allocation within such functional expertise groups. Resource allocation is the allocation of available capacity to tasks. The challenges are tremendous due to e.g. interface complexity, inter project or inter activity dependency, uncertainty and performance that is hardly measurable.

Research was conducted at Advanced Semi-conductors Manufacturing Lithography (ASML), a provider of lithography systems for the semiconductor industry. Today, ASML is world leader, with customers located in over 60 locations in 14 countries in Asia, Europe and the United States. The company is headquartered in Veldhoven, the Netherlands.
The project was started in March 2007 and lasted until August 2007. It has been guided by the research model of Mitroff et al. (1974). The following steps have been taken: conceptualization, modeling and model solving. The actual implementation was out-of-scope.

The Supply Chain Engineering department identified a resource allocation problem. Since ASML has a policy of outsourcing as much as possible, it is very dependent on its suppliers. In 2005 ASML felt the need to create a new department, Supply Chain Engineering (SCe), to meet the growing demands in the semiconductor industry to produce increasingly complex systems within a strict Time-to-Market. Besides on product innovation, ASML started to focus on operational excellence. The new department became responsible for process development and continuous process improvement at suppliers. It will become possible to outsource risk management activities to suppliers, but the start-up, together with a rising number of projects and more complex products in the future, leads to an increased SCe capacity demand at least on the short term. The question remains:

Given the capacity level, how to allocate resources to tasks in order to maximize the value created by the supply chain engineer?

Current resource allocation structure

Currently, the SCe department is split permanently in three groups: the Mechanical, Electrical and the Optical group. Whereas the majority of the organizational members perceives that the work within the groups is clustered around suppliers, at the meta-level it is in fact clustered around 'product families', which is consistent with a clustering around types of production processes.

Each quarter, the Supply Chain Project Leaders and the group leaders claim capacity of individuals at the SCe department. Once agreement is reached on the quarterly allocation, work orders are released to the supply chain engineers. Guided by the formal allocation and his group leader, the supply chain engineer is free to decide which task he starts to work on.

Upon the start of the master thesis, the Work Breakdown Structure (WBS) for the department was not clear. In consultation with the supply chain engineers a WBS was made and tasks were categorized in five groups: NPI proactive, NPI reactive, Volume proactive, Volume reactive and Indirect. A further categorization is based on product families.

The SCe department consists of well educated persons, mainly male. A clear clustering, based on general competences (general skills and knowledge), has not been found.

SCe has interfaces to many other organizational entities, which are organized around either functional clusters or suppliers. This has led SCe to allocate individuals within a product family either based on product family competence or based on supplier accounts.

Conceptualization

The problems and its causes in the current situation are identified in the conceptualization step. The following measurement instruments have been used: interviews, questionnaires, claim-and-allocation sheets, critical part lists, a vacancy description on the Internet, a workshop and a newly developed method to determine the weight of tasks. The weight of a task is the value that is created if the task is completed before its due date. The basic idea behind the method 'Weight determination' is to make perceived weight that is implicitly available within organizational members explicit. Perceived weight is measured since real weight cannot be measured objectively and directly (Saaty, 1978). Experience indicates that the method triggers the decision maker to collect and apply the decision arguments. Moreover, the decision maker is guided through his own line of reasoning, which increases his consistency.

From the problem analysis, we conclude that the problem entails both a mismatch between the preferred allocation and the formal allocation and between the formal allocation and the actual allocation. A major cause of the problem is that organizational members' perception of the resource allocation system is characterized by a partial view. It is augmented by a vicious circle since more trouble shooting is required both directly and indirectly due to insufficiently used learning effects: learning by proactive work to apply this knowledge in reactive work and vice versa.

An ideal three-level resource allocation system is described qualitatively to create a consistent set of rules. At the strategic level, ‘product family teams’ act like self-steering teams with individual supply chain engineers being responsible for data aggregation per supplier, a system engineer is responsible for the early Product Generation Process Phases, and there are separate groups for indirect tasks (coaching and development of working methods). At the tactical level, product family teams are competence groups that can be claimed, up to 150%. It is recommended to resize the groups on the mid term and not to bias the work orders to certain programs, project types or suppliers. At the operational level it is recommended to assign work equally to each individual supply chain engineer up to a workload of 150%. The product family group should strive to allocate a supplier-related task to the account manager, but should not rigidly apply this rule. We also stated some side recommendations to further increase efficiency and effectivity: it is recommended to co-locate with either New Product Logistics or Procurement and to create an integral quality system.

Modeling

Based upon the analysis, we concluded that more insight is required in the actual operational resource allocation. In our formal model, both tasks and disruptions arrive to a single server, a supply chain engineer. Disruptions preempt the work of the supply chain engineer, but the work already done is not lost if a task is restarted (‘preempt-resume’). The objective is to maximize the long-run expected sum of task values, where the value of a task depends on its weight, completion time and due date.
Four algorithms are proposed to decide which task to start upon the completion of another task: two algorithms are based upon scheduling, while the other two are dispatching rules.

Model solving

The algorithms have been programmed in Matlab 6.1 and simulation was used to determine their performance. An exact algorithm for scheduling outperforms other algorithms, except in case of many tasks and many disruptions. However, it can only be applied if, at each moment in time, at most seven jobs are available (due to computer storage). The first results for a new heuristic, taking both weights and due dates into account, are promising but need to be tested more extensively.
A proper weight determination seems to be indispensable for value creation. Controlling the workload by only allowing the execution of tasks with a high performance ratio (weight per time unit) improves the performance, but also elimination of disruptions is important. It seems to be worthwhile to investigate the losses in case of delay or elimination of disruptions.

For ASML these results implicate that discussion is required to come to an agreement on the weight of tasks, to identify clear guidelines for the amount of effort that needs to be spent per task and to propagate prioritization criteria to select, delay and eliminate both task and disruptions. First steps in this direction have been taken, but refinement and pilot projects are indispensable for the future.

Introduction

In many sectors, companies increasingly adhere to a project-based organization (Whittington et al., 1999). A project can be defined as 'a one-of-a-kind effort undertaken for the purpose of achieving a specific end-objective' (Knotts, 2000). Project management entails 'a set of principles, methods and techniques applied for the purpose of being on-time, under-budget, and up to specification' (Knotts, 2000). New Product Introduction (NPI) projects aim at the timely development of products with a new form, fit and/or function. Timely means 'within the necessary time-to-market (TTM)'. The development phase ends with the Release For Volume (R4V) decision, which can be made if both the product and the process qualify.

Van Weele (2002) explains the importance of suppliers' contributions in the development stages of new products: suppliers are a major source of ideas on new products and production technologies and working together could lead to a reduction in engineering lead time and to cost benefits. Supplier involvement relates to 'the contributions (capabilities, resources, information, knowledge, ideas) that suppliers provide, the tasks they carry out and the responsibilities they assume regarding the development of a part, process or service for the benefit of a current and/or future buyer's product development projects, aside from (co-ordinating of) the manufacturing and/or delivery of the part, process or service' (Van Echtelt, 2004). Wynstra (1998) sees supplier involvement management as a responsibility of the purchasing department. However, in time-driven NPI projects for high-tech low-volume products, it makes sense to divide the work over functional expertise groups. These functional expertise groups can also be responsible for continuous improvements.

Resource allocation is the allocation of available capacity to tasks. The challenges for (human) resource allocation within these functional expertise departments are tremendous due to e.g. interface complexity, inter project or inter activity dependency and uncertainty. Moreover, the performance of such departments is not always measurable. Given the capacity level, choices need to be made regarding the work to be done and the person that will execute the activities. For this situation, insight is required in the resource allocation mechanism.

Master thesis project

This report describes a master thesis project at the Supply Chain Engineering (SCe) department at ASML, a provider of lithography systems for the semiconductor industry. The department is responsible for the production processes at ASML's suppliers. However, the capacity demand surpasses the current capacity availability of the department, as estimated for the next two years. ASML desires an efficient and effective resource allocation in a situation of limited capacity.

The project was started in March 2007 and lasted until August 2007. It has been guided by the research model of Mitroff et al. (1974). The model is depicted in figure 1.

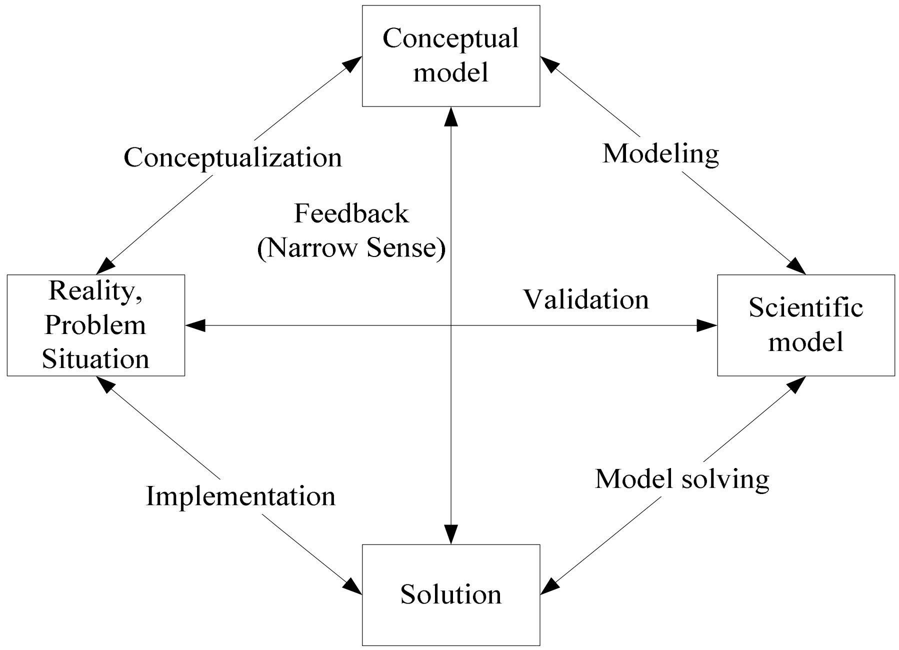


Figure 0.1 The research model by Mitroff et al. (1974)

Conceptualization

The purpose of this first phase is to get familiar with the company and its problem. By actively listening to the organization members, logically structuring their stories and embedding them into an existing body of scientific knowledge, a clear problem definition is constructed. A feasibility check is performed and agreements regarding e.g. the project plan, deliverables and the scope are established in a project proposal.

The company is described in chapter 1. The department is described in chapter 2.

The conceptualization phase is also used for analysis and diagnosis. This is required to validate the business problem, to validate the causes and consequences and to develop first insights into available directions to solve the problem. We used an empirical elaboration for these purposes. It is not based on a theoretical framework, but is guided by a question tree and entails five steps. The first step is a problem check based on factual information. The second step is an empirical and theoretical exploration of the causes and effects by open interviews, brainstorm sessions and questionnaires. After this exploration step, empirical and theoretical validation is secured by inter subjectivity checks. The fourth step is the determination of the relative importance of the causes or lines of causes by a check in different groups in the organization. It is important to note that several problem areas have

been identified in this way. In the last step we selected one problem area for which a solution is developed based on the solving of a new scientific model. Also the variables that need to be included in the model as well as the scope of the model are defined. The other problem areas are dealt with by searching the literature on existing models.
The problem and its causes are described in chapter 3.

Modeling

In the modeling phase, the quantitative model is built. A theoretical framework is developed by combining existing theoretical concepts and observed phenomena. The objective is formalized. Also, assumptions are formulated and validated by checking them with several organization members. For the other problem areas, the literature is searched for relevant findings.
The formal model is described in chapter 5.

Model solving

The third phase focuses on the design of a solution to the selected resource allocation problem area. Mathematics play an important role. For the other problem areas, the literature findings are combined to obtain a coherent set of recommendations. This phase results in the following <u>deliverables:</u>

1. Qualitative description of an *ideal resource allocation system*: The resource allocation system can be described at the strategic, tactical and operational level. At each level, multiple decisions are considered.

   Based on our analysis, the ideal resource allocation system is described in chapter 4.
2. Quantitative description of an *ideal operational resource allocation mechanism*: Decisions at the operational level concern actual work order releases to individuals and execution. We studied the execution decisions, developed four algorithms and compared them using simulation.

   The analysis and results of the decision algorithms are described in chapter 6.

Implementation

The actual implementation is out-of-scope, as is the evaluation.
In chapter 7 the conclusions can be found. Some suggestions for implementation are incorporated in these conclusions.

1. The company

This chapter contains a short description of the company[1].

1.1 ASML

In 1984, Advanced Semi-conductors Manufacturing Lithography (ASML) was founded. The company designs, develops, manufactures and services lithography systems. These systems image circuit patterns on a thin disk of silicon, the ‘wafer’: hundreds of Integrated Circuits (ICs), also called ‘chips’, per wafer.
ASML’s mission is ‘to provide leading edge imaging solutions to continuously improve our customers' global competitiveness. Ever since the company was founded, commitment has been the promise of ASML.’
To succeed in its mission, ASML believes that all its activities must stem from its core values: Quality, Integrity, Trust, Continuity, Excellence and Professionalism.

1.2 Products and markets

Today, ASML is world’s leading provider of lithography systems for the semiconductor industry with a market share by revenue of 61 percent in 2006. ASML’s main competitors are the Japanese companies Nikon and Canon. Customers are located in over 60 locations in 14 countries in Asia, Europe and the United States. The installed base is currently more than 3 000 systems: steppers and scanners. In 2006 net sales were about EUR 3.6 billion, with 266 systems shipped and 163 systems backlog.

1.3 Corporate organizational structure

Research, development and manufacturing facilities are located in Wilton, (Connecticut USA) and Veldhoven (the Netherlands). American headquarters and training facilities are located in Tempe (Arizona USA). Asian headquarters are located in Hong Kong, whereas training facilities are located across Asia. Several sales and service locations are further located in Europe, the United States and Asia. The company is headquartered in Veldhoven. It employs approximately 5,600 employees.
ASML is traded on Euronext Amsterdam and NASDAQ under the symbol ASML.

[1] Sources: Annual Report ASML 2006; www.asml.com. Last accessed: 5 July 2007.

2. The department

The Supply Chain Engineering department identified a resource allocation problem. The master thesis investigation was inspired by the business problem. In this Chapter, we describe the background of the department and its resource allocation problem, the current resource allocation system, the typology of tasks and resources and the interfaces with other departments, respectively.

2.1 Background

ASML has a policy of outsourcing as much as possible. Therefore, ASML is very dependent on its suppliers. About 92% of the product value is added in the supply chain. The supply chain consists of all production and logistic systems at all layers of suppliers through which materials, components and subassemblies flow before they enter ASML's manufacturing site.

Since the product portfolio has extended over years, the focus has shifted from 'making products as good as possible' to 'operational excellence', which means that the company is not only focusing on quality but also on time, cost and flexibility aspects.

In 2005 ASML felt the need to create a new department, responsible for the production processes at suppliers. The new department was named Supply Chain Engineering (SCe). SCe has two main responsibilities with regard to production processes at suppliers: process development and continuous process improvement. For process development, the department has to make sure that the right processes are developed when new products are introduced. For continuous improvements, the department must identify improvement areas for the suppliers and support the implementation of action plans.

At the Supply Chain engineering department it will become possible to outsource risk management activities to suppliers. This will reduce the capacity demand in the long term. However, since ASML expects more projects and more complex products in the near future, capacity demand will still continue growing. ASML forecasted a capacity demand that was 100% higher than the capacity availability for 2007. That is, SCe capacity is insufficient at least on the short term. The question remains how to allocate the scarce SCe capacity

2.2 Current resource allocation

The organizational structure is depicted in figure 2.1.

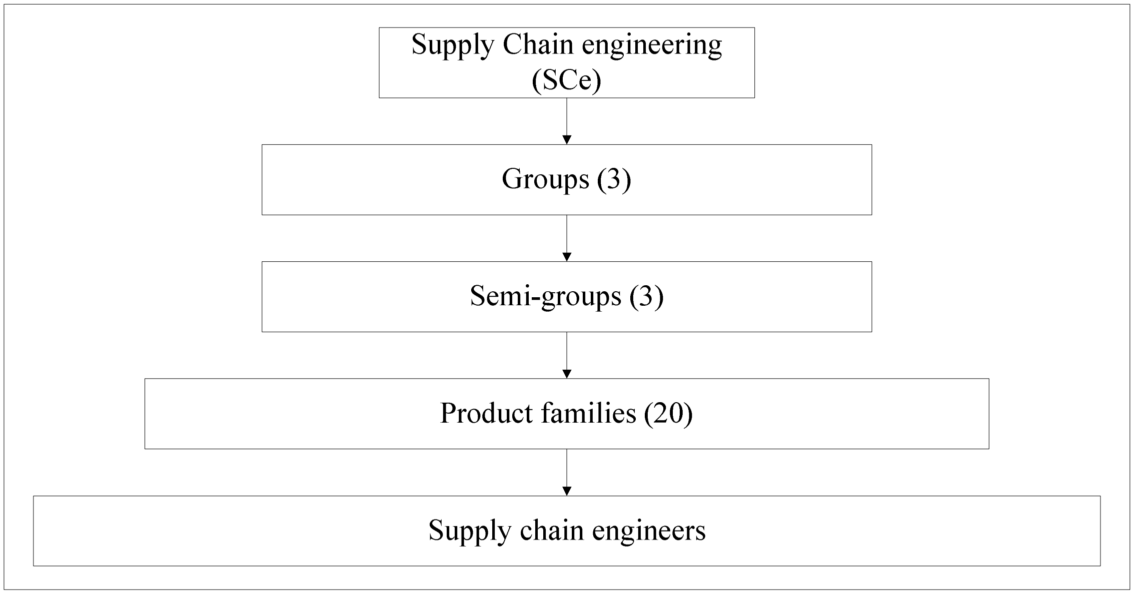


Figure 2.1 The organizational structure

The SCe department is split in three groups: SCe Mechanical (M), SCe Electrical (E) and SCe Optical (O). Historically, the development and purchasing divisions within ASML are organized according to these engineering disciplines. One of the SCe groups is split further: SCe Mechanical contains Mechanics (M), Mechatronics (Me) and Flow & Temperature (F&T). These sub groups exist since March 2007.

The groups are permanent resource groups. Their task sets are non-overlapping to a large extent: each group executes tasks that belong to its engineering discipline. Congruence between the engineering discipline (e.g. mechanical, electrical, optical), the type of production processes (e.g. drilling, milling, etc.) and suppliers makes it possible to operate almost independently.

The majority of the organizational members indicates that the work within the groups is clustered around suppliers: each member would be responsible for the work concerning a number of suppliers, e.g. supplier accounts. We call such a permanent work division a 'structure' or 'static resource allocation'. Each supply chain engineer performs tasks for a number of suppliers but the tasks relating to one supplier can be executed by different supply chain engineers[2]. In consultation with organization members it has been established that a supply chain engineer only performs activities relating to the

[2] Only in exceptional cases (5%) the supplier is involved in process development but the account manager is not. In about 20% of all cases in which the account manager is involved in process development, other supply chain engineers are involved at the same supplier as well, but in a different process development project. About half of the suppliers is involved in process development, but is not supported by an account manager.

same type of suppliers. The clustering is based on the kind of products that are produced, the 'product family'. Therefore, the organization is in fact not organized along suppliers, as perceived by the organizational members, but along the competences (knowledge and skills) required for a type of production process. It was confirmed by the supply chain engineers that the type of production processes is roughly equal for the same type of products: the 'product families'.
However, some tasks can be allocated to any available supply chain engineer of any group. These tasks are 'indirect': they do not relate to a certain supplier. Examples are the training of peers and the creation of new working methods.

Each quarter, the various Supply Chain Project Leaders and the group leaders claim capacity from the SCe department. For this purpose, a 'claim-and-allocation sheet' is used. The sheet contains the names of all supply chain engineers and some task categories. Once all the claims on individuals are collected, the leaders decide upon the allocation of the supply chain engineers for the quarter concerned. Subsequently, the leaders release work orders (tasks) to the supply chain engineers. In general, the supply chain engineer is free to decide at which task he starts to work. He is guided by the resource allocation that is communicated by the 'claim-and-allocation sheet' and his bi-yearly evaluation. Besides this guidance, he can ask his group leader to set priorities. However, sometimes the group leader sets the priorities for the supply chain engineer in advance. This is the case for significant problems (escalations): problems that block the production at the bottleneck and problems that are indicated by ASML's customers.

2.3 Tasks

For resource allocation, it is required to identify the tasks that need to be allocated.
According to the IDEF0 process modeling technique[3], a task can been defined as 'any activity that is triggered to transform inputs into outputs by means of tools and procedures'. One task and its characteristics are depicted in figure 2.2.

[3] Wikipedia article 'IDEF0', last modified: 26 May 2007, last accessed: 11 July 2007. Accessible through http://nl.wikipedia.org/wiki/IDEF0

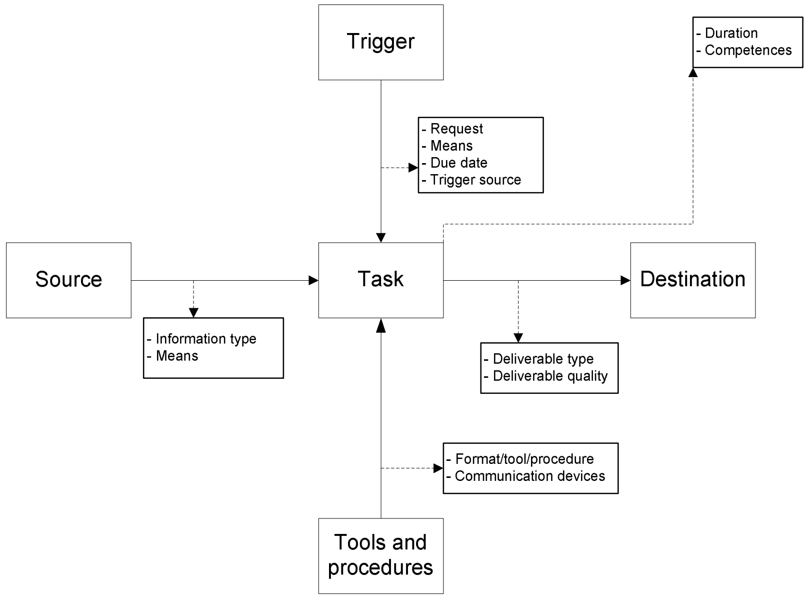


Figure 2.2 Definition of task

The execution of a task is triggered by an event or a principal, the trigger source. An action request reaches the executor by some information means. The actions must be performed before the due date. For execution of the tasks, data of any type must be gathered from information sources, via information means. Furthermore, the executor must possess competences to execute the activities, supported by tools and procedures and communication devices. Ultimately, the task will be finished after its duration and a deliverable with a certain type and quality reaches its destination.

For example, the Supply Chain Project Leader (trigger source) triggers problem solving (action request) by communicating a defect by a telephone call (information means) to the supply chain engineer (executor). The supply chain engineer needs to ensure the delivery of a qualified product (deliverable) as soon as possible (due date) and needs to report (deliverable) on the causes within a week (due date) to the Supply Chain Project Leader (destination). It will take the supply chain engineers two days (duration) to get a new product and two more days (duration) to find and report on the causes. He will need defect information on the past and process information (information type) from the supplier (source) via the Internet (means). Furthermore, he uses communication devices and the root cause tracking procedure (tools and procedures). Depending on his analysis skills (competences) he will find an appropriate solution and write a good report (quality).

In systems engineering, the Work Breakdown Structure (WBS) provides the guiding for multi-disciplinary team assignment and cost tracking and control. It is a product-oriented tree that links all system elements, products to be developed or produced. The WBS must fully correspond to the systems architecture and the specification tree (Martin, 1997). Despite the fact that the SCe is not product-oriented but process-oriented, a work breakdown structure may represent the high-level processes in which the department is involved towards the low-level tasks that need to be performed in these processes.

Upon the beginning of this master thesis project, the SCe department had a clear overview of its processes, but not of the low-level tasks. In consultation with the supply chain engineers a work breakdown structure has been made to identify these low-level tasks.

Categorization is required to identify the relevant non-overlapping task sets that will be executed by permanent resource groups. However, tasks can be categorized in different ways, e.g. according to: objectives, required competences, planability, phase of the product life cycle, communication lines, principal, type of product/process or deliverable.
Currently, management identifies four task categories: NPI projects, accounts, continuous improvement projects and escalations. The last category entails trouble shooting activities. In fact, this categorization is based upon various task characteristics. The following categorization has been made:

	Proactive	Reactive
NPI	NPI Proactive	NPI Reactive
Volume	Volume Proactive	Volume Reactive
Indirect	Indirect	

Figure 2.3 Task categorization

A further categorization is based on product families. That is, each of the task sets in figure 3.2 can be related to a product family.
The categorization was confirmed by four supply chain engineers.

2.4 Resources

In 2005, the SCe department was manned with employees of the Production Engineering (PE) department and the Quality Assurance (QA) department.
Questionnaire respondents gave an indication of the composition of the SCe department (2.4a).

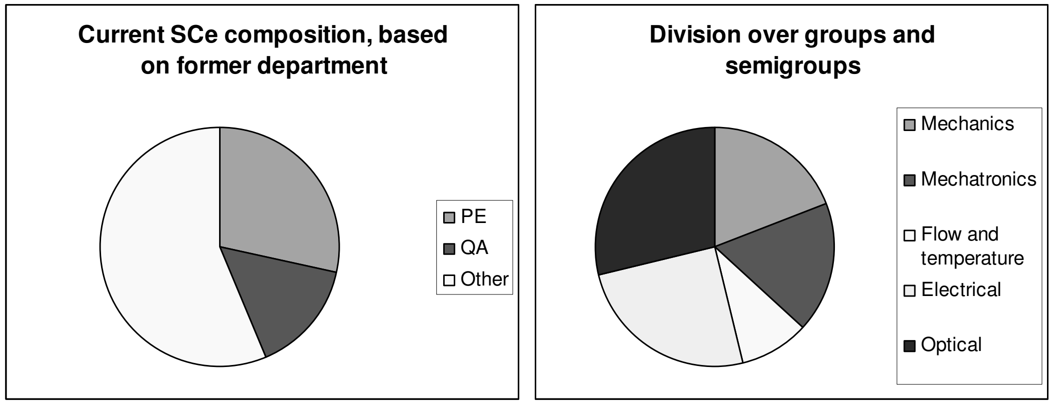


Figure 2.4 a. Current SCe composition, based on former department b. Division over groups and semigroups

On average, the relevant work experience is about 12 years, ranging between 0.5 and 31 years. The supply chain engineers are well educated: about 46% of the supply chain engineers is educated at the professional engineer level and 36% is educated at the academic engineer level. About 5% is female and 95% is male.

In the last period, many new employees have been hired.

Categorization is required to identify resource groups. We can categorize based on several resource characteristics. For competences (skills and knowledge) ultimately determine the number of tasks per time unit (efficiency) and the quality of the work per task (effectivity), a categorization based on competences (skills and knowledge) or work field (leading to skills and knowledge by experience) seems to be appropriate. We did not find a clear clustering of resources based on competences, but a clustering based on work field roughly results in the resource groups Mechanical (mechanical engineering), Electrical (electrical engineering) and Optical (applied physics).

Currently, the supply chain engineers are divided over the (semi)groups as expressed in figure 2.4b.

2.5 Interfaces

SCe has interfaces to many other organizational elements. The organizational elements are all related to the product life cycle (e.g. Brombacher, 1994), see figure 2.5.

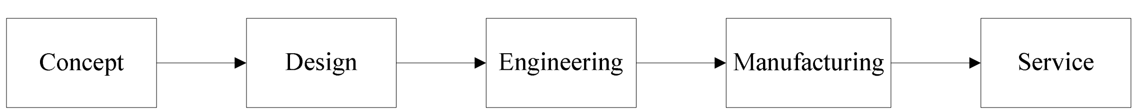


Figure 2.5 The product life cycle

The main interfaces are depicted in Figure 2.6 and described in Appendix A. It can be concluded that most other departments are organized around functional clusters. Only one other department is organized around suppliers. SCe found a compromise by being organized around product families.

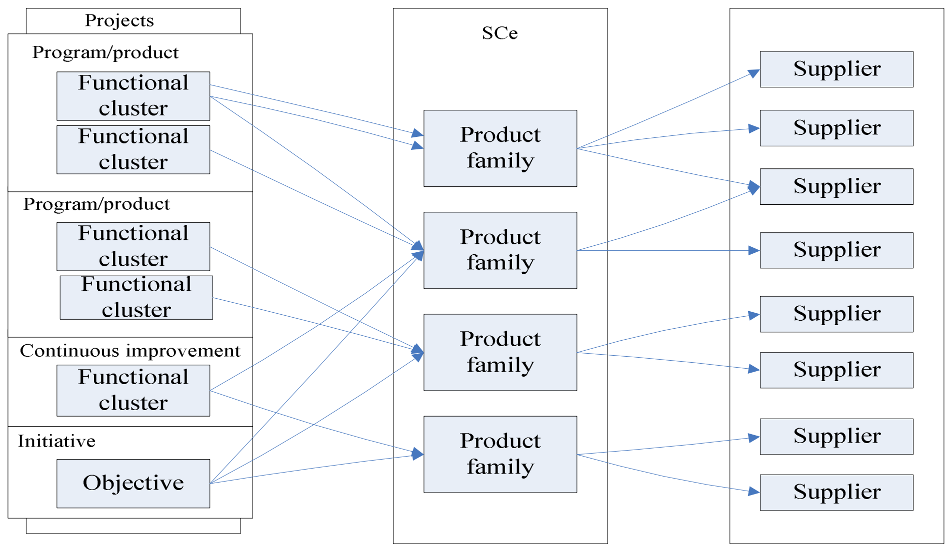
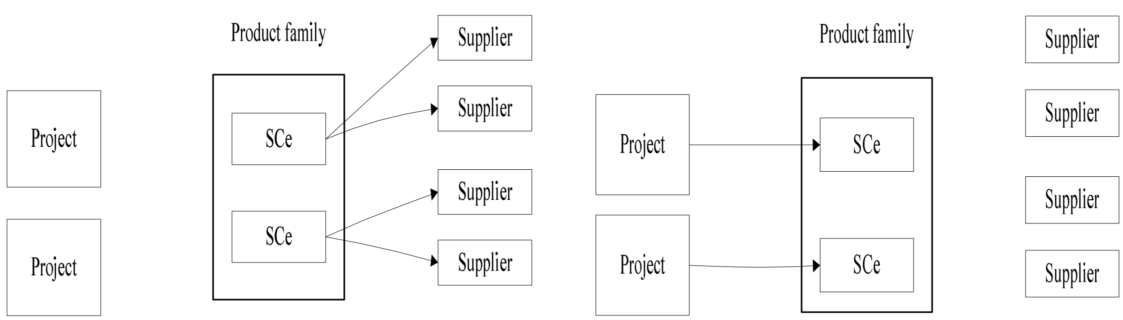


Figure 2.6 Interfaces

Within a product family, the allocation of individuals to tasks is a mixture between allocated based on product family competence and based on supplier. This is depicted in figure 2.7, together with the characteristics of each allocation structure.



- The allocation of a supply chain engineer to a project depends on the supplier selection. - Multiple supply chain engineers at one supplier only if the supplier is involved in more product families.	- The product family supply chain engineer for each project is known before supplier selection. - The number of supply chain engineers per supplier depends on the number of projects and the number of product families the supplier is involved.

Figure 2.7 Internal structure

In summary, the Supply Chain engineering (SCe) department is responsible for process development and continuous process improvement at suppliers. The department is organized around product families, although the structure is not clear to all organizational members. The task package is characterized by five task categories, to be executed for all product families. A set of well educated human resources is responsible for execution. To perform the activities, the department has interfaces towards multiple other departments.

3. The problem

In this chapter the problem is analyzed and causes are identified. The analysis methodology is described in the first part of the chapter and the analysis results are described in the second part.

The problem analysis is guided by the question tree as depicted in figure 3.1.

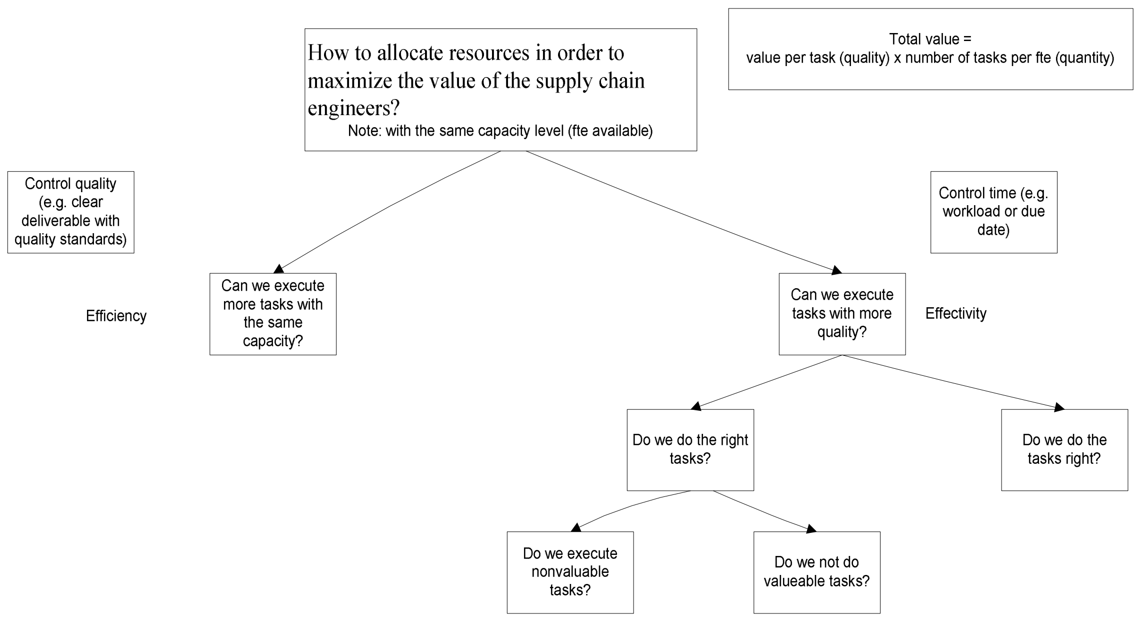


Figure 3.1 Question tree

The <u>key question</u> is:

Given the capacity level, how to allocate resources to tasks in order to maximize the value created by the supply chain engineer?

The value created by the supply chain engineer is determined by the sum of the values of all tasks he performs within the available time. The value of a task is determined by the importance of the deliverable to ASML.

To improve the value created by the supply chain engineer, there are two alternatives. Either more tasks are executed within the same capacity, or more valuable tasks are selected. These alternatives relate to efficiency and effectivity, respectively. However, one must be aware of the side effects. By executing more tasks within the same time, the quality may suffer. This negative side effect must be controlled, e.g. by defining clear deliverables with quality standards. By executing more valuable tasks, more time may be spent. Therefore, time has to be controlled in this case, e.g. by workload

control or due dates.
The effectivity question can be split in the question whether we do the right tasks and whether we do the tasks right. It may well be that non valuable tasks are executed or valuable tasks are not.

Guided by this question tree, we identify improvement areas based on actual data and theory. The performance indicator is the total value of the SCe department, whereas the resource allocation mechanism is our design variable.

3.1 The methodology

This paragraph describes the methodology. First, the operational variables will be identified. Second, the measurement instruments are described.

3.1.1 Operationalization

For analysis purposes, we need to operationalize and measure the resource allocation mechanism and its performance.

3.1.1.1 Resource allocation

For the resource allocation, the following variables have been used:

Variable	Definition	Information source
Perceived role	Perceived role of the SCe department	Interviews
Perceived organizational structure	Perceived organizational structure of the SCe department	Interviews
(Team) work dissatisfaction areas	Perceived dissatisfaction areas of ASML employees	Interviews
# fte formally allocated / task category	The number of full time equivalents that have formally been allocated to a task category in the first quarter of 2007	Overview sub group leader Mechanics Claim-and-allocation sheet Q1 2007
# fte actual / task category	The number of full time equivalents that is perceived to be spend to a task category in the first quarter of 2007	Questionnaire ‘Perceived time spent’
percentage spent – percentage allocated / supply chain engineer	The difference between the percentage of time perceived to be spend and allocated in the first quarter of 2007	Questionnaire ‘Perceived time spent’, Claim-and-allocation sheet Q1 2007
competences / supply chain engineer	The supply chain engineer’s perception of his level of knowledge and skills compared to the level of the perceived average supply chain engineer	Questionnaire ‘Competences available’

competences required / task category	The competences required per task	Questionnaire 'Competences required' Vacancy description[4]
# supply chain engineers / supplier	The number of supply chain engineers per supplier	Critical part lists, 17 April 2007
# supply chain engineers / project type	The number of supply chain engineers per project type	Critical part lists, 17 April 2007

Table 3.1 Variables resource allocation

3.1.1.2 Performance

For the performance, the following variables have been used:

Variable	Definition	Information source
# complex parts understaffed / program	The number of complex parts without supply chain engineer allocated for a program	Critical part lists, 17 April 2007
# complex parts understaffed / project type	The number of complex parts without supply chain engineer allocated for a project type	Critical part lists, 17 April 2007
# complex parts / supplier	The number of complex parts per supplier	Critical part lists, 17 April 2007
Marginal value of fte spent / proactive task category	The marginal weight of any capacity spent to a proactive task category (NPI proactive, Volume proactive)	Method 'Weight determination'
Marginal value of fte spent / task	The marginal weight of any capacity spent to a task	Method 'Weight determination', Workshop 'Prioritization criteria'

Table 3.2 Variables value

3.1.2 Measurement instruments

The key measurement instruments will be explained in this paragraph. For a description of the other measurement instruments, the reader is referred to Appendix C.

3.1.2.1 Method 'Weight determination'

The value of a task is dependent on its maximum level (called 'weight'), its completion time and its due date. The weight of a task is the value that is created if the task is completed before its due date. In order to determine the weight of task categories, we developed a new method, based upon marginal value analysis and the Analytic Hierarchical Processing (Saaty, 1978). The method is implemented in Visual Basics. The basic idea behind this method is to make perceived weight that is implicitly available within organizational explicit. Perceived weight is measured since actual weight cannot be

[4] Source: www.asml.com

measured objectively and directly (Saaty, 1978). The subsequent steps are described in Appendix H. Experience indicates that the method triggers the decision maker to collect and apply the decision arguments. In each step, the decision maker is confronted with a limited set of options. Moreover, the decision maker is guided through his own line of reasoning, which increases his consistency.

Application

The method 'Weight determination' has been applied twice.
First, the method was applied to proactive task categories. Before the method was applied, the management team indicated that reactive tasks always have priority and thus are more important than proactive tasks. However, the management could not indicate what capacity allocation was most important within the proactive categories.
Second, the method was applied to tasks. For this purpose, the method was slightly changed. In step 1, we used concrete tasks instead of capacity amounts. Each task was allowed to be selected only once.

3.1.2.2 Workshop 'Prioritization criteria'

Whereas the method 'Weight determination' is applicable to determine the weight of tasks, the underlying reasoning remains implicit. In order to make a more conscious decision and to obtain agreement on the criteria, Analytic Hierarchical Processing (Saaty, 1978) can be used. Weil & Apostolakis (2001) also applied this method for prioritization criteria.

During several workshop sessions, the following steps have been taken:

1. Identification of prioritization criteria (group brainstorm)
2. Structuring the prioritization criteria (group discussion)
3. Identification of measures for criteria (group discussion)
4. Identification of scales per measure (group discussion)
5. Identification of utility functions per scale (group discussion)
6. Weighting the objectives (individual, group discussion)
7. Validating the results[5] (individual, group discussion)

In summary, both existing data and new data are used in the analysis. New data are obtained by interviews, questionnaires, an existing and a newly developed value analysis method.

[5] This step has not yet been executed.

3.2 The analysis results

In this paragraph we report on the results of the problem analysis. First, we compare the actual capacity, the allocated capacity and the preferred capacity per product family. Second, we identify mismatches between the actual and required competencies per task category. Third, we explore the pattern of understaffing in NPI projects. Fourth, we identify other dissatisfaction areas. Fifth, we summarize our analysis.

3.2.1 Capacity per product family

Note: due to missing data points, we have been able to complete the full analysis for only a limited number of product families within the Mechanical subgroup.

Three allocations of direct task categories are compared:

- Preferred allocation: *the allocation (capacity per product family) that is obtained by rational decision making (proactive: method 'Weight determination', reactive: questionnaire)*
- Formal allocation: *the allocation that was agreed upon (claim and allocation sheet)*
- Actual allocation: *the time spent to task categories per product family as perceived by the supply chain engineers (questionnaire)*

The measurement is described in Appendix I.

This delivers the following pictures for two product families.

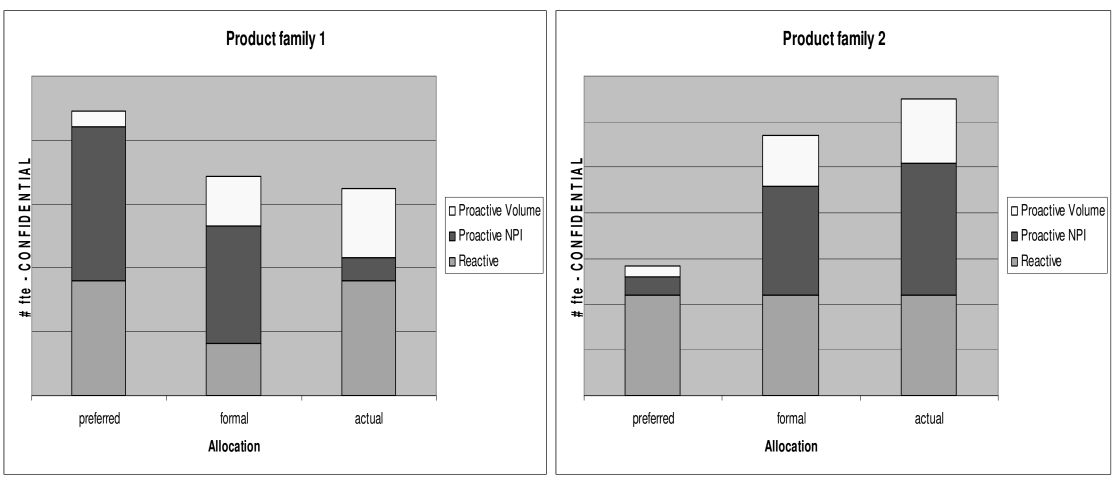


Figure 3.2 Comparison between preferred, formal and actual allocation for two product families

The preferred allocation is not in line with the formal allocation (from the claim-and-allocation sheet) and with the actual allocation (from Questionnaire 'Perceived time spent'). It should be noted that the

method ‘weight determination’ is applied to the third quarter of 2007, while both the claim-and-allocation sheet and the questionnaire ‘Perceived time spent’ apply to the first quarter of 2007. However, we may assume that the preferred time allocated for the first and the third quarter is equal. This has been confirmed by the organizational members.
This phenomenon may be caused by the unclear organizational structure. Another explanation is an unrealistic estimation of the work to be done.

There is also a difference between the formal and actual allocation. The difference between the percentage of time allocated and the percentage of time spent in the proactive NPI and proactive Volume category is depicted in figure 3.3.

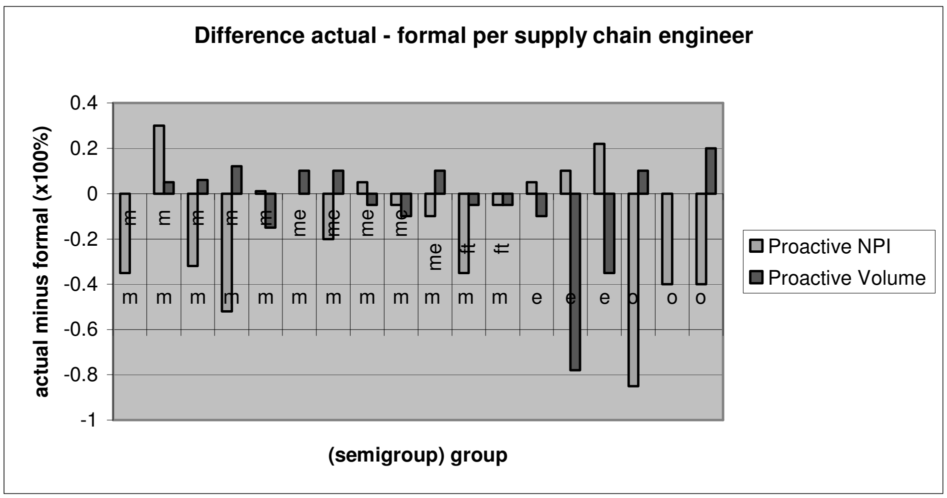


Figure 3.3 Difference between the actual and formal allocation per supply chain engineer

The most important observations with regard to the difference between the formal and actual allocation are:

- The formal allocation for Electrical to Proactive Volume is significantly higher than for other groups and to Proactive NPI significantly less.
- The actual allocation for Electrical does not differ significantly (significance level $\alpha = 0.05$) from other groups.
- In general, Proactive NPI tasks are actually allocated less than formally allocated.
- There are limited significant effects of competences (knowledge/skills) on the difference. Only ‘learning ability’ would lead to less NPI and more Volume work.

The main reason for this phenomenon seems to be a wrong estimation of the time required for tasks, which makes the formal allocation unrealistic (Van Oorschot, 2001). Supply chain engineers are forced to make choices, in which they are guided to a limited extent.

From this analysis we can conclude that:

- ***The formal allocation to product families (the size of the permanent resource groups) is not consistent with the preferred allocation. Possible causes: organizational members' partial view on the organizational structure; management estimates the work to be done wrongly.***
- ***The actual allocation to product families is not consistent with the formal allocation. Possible causes: an unrealistic formal allocation, insufficient guidance in dynamic resource decisions.***

3.2.2 Mismatch between required and actual competences per task category

From the Questionnaire 'Competences required', we obtain that the following competences are the most important competences, as perceived by two experts:

NPI Proactive	NPI Reactive	Volume Proactive	Volume Reactive	Indirect
Knowledge of design systems Knowledge of specific production processes Teamwork	Knowledge of logistic systems Knowledge of quality systems Knowledge of specific modules	Knowledge of design systems Initiative Knowledge of quality systems	Knowledge of logistic systems Knowledge of quality systems Knowledge of specific modules	Knowledge of quality systems Knowledge of logistic systems Knowledge of design systems

Table 3.3 Required competences according to first expert

NPI Proactive	NPI Reactive	Volume Proactive	Volume Reactive	Indirect
Information analysis Steering based on clear task definitions Helicopter view	Steering based on clear task definitions Knowledge of specific modules Knowledge of logistic systems	Knowledge of similar production processes Steering based on clear task definitions Knowledge of similar suppliers	Steering based on clear task definitions Teamwork Knowledge of specific modules	Convincing power Helicopter view Steering based on clear task definitions

Table 3.4 Required competences according to second expert

A first observation is that the first expert focuses upon knowledge whereas the second expert also values skills. Other observations:

- One of the knowledge areas is logistic systems. Whereas the experts indicate that knowledge of logistic systems is required, the supply chain engineers indicate that this knowledge is underrepresented. From the results of the Questionnaire 'Competences available' we can conclude that the average supply chain engineer scores himself above the average level for almost all competences required ($\alpha = 0.05$). However, the average score on knowledge of logistic systems is not significantly different from the average level (score 4).

- Another knowledge area is specific modules. The experts indicate that knowledge of specific modules is required for the reactive task categories. However, the actual resource allocation is based on parts. Therefore, it does not provide for building an experience with any specific module. From the results of the Questionnaire 'Competences available' we obtain that the average score on knowledge of similar modules is not significantly ($\alpha = 0.05$) different from the average level (score 4).

It should be noted that multiple supply chain engineers indicated that they had difficulties in filling in the questionnaire because they felt not able to make an image of the average supply chain engineer. Some of them indicated that they were new to the department and decided not to fill in the questionnaire. This may result in a bias towards higher-than-average scores. Some of them also indicated that they work completely independent and do not know what their collegues do. Also, the competence 'correcting each other' was found to be underrepresented ($\alpha = 0.05$).

Some side observations are:

- Optical perceives itself significantly ($\alpha = 0.05$) better than mechanical, mainly w.r.t.: binding leadership, operations, decisiveness, energy, initiative, innovative, adaptive, progress control, self development
- We found that former PE employees perceive themselves to be significantly ($\alpha = 0.05$) better educated than QA, where QA perceives it has significantly ($\alpha = 0.05$) more knowledge about quality systems and experience with a specific supplier.

Stepwise multiple regression has been applied to test whether the competences that explain the formal allocation match the competences that are indicated by our experts. The results indicate that the competences that are significantly related to the formal allocation, in general[6], do not match the required competences. It seems that the formal allocation is not based upon the competences required. One explanation may be that the required task set is too complex. Saaty (1978) emphasizes that a person can evaluate alternatives upon at most 9 elements. Another explanation may be that, whereas the experts are currently involved in the formal allocation, they were not involved in the formal allocation decisions in the first quarter of 2007. Moreover, the competences available within the total set of supply chain engineers have been analyzed due to missing data points, whereas actually the competences available may differ between the (sub) groups.
We also compare the results from our questionnaire to the formal job description in vacancies[7]. The

[6] Only 'Information analysis' (NPI Proactive) is significant $(\alpha = 0.05)$.

[7] Source: www.asml.com

following competences are indicated in this description:

Educational level	:	*HBO/Academic, with specialization in one of the following areas: Mechanical Engineering / Mechatronics / Electrical Engineering / Electronics / Physics / Optics*
Experience	:	*Project management, quality systems and methods, engineering towards production processes*
Personal skills	:	*Enterprising, goal oriented and flexible; analytic; team worker and able to work with different cultures; professional communication on management levels, with feeling for relations*

Table 3.5 Competences in formal job description

We observe that the formal job description focuses on both knowledge, or experience, and skills. Knowledge of logistic systems is not mentioned, but might be part of experience with 'engineering towards production processes'. Clearly, there is no search for specialists, but for generalists.

In summary, we conclude that:

- ***A diverse set of both knowledge and skills is required to execute supply chain engineering activities.***
- ***Knowledge of logistic systems is required, but seems to be underrepresented in the department.***
- ***Knowledge of specific modules is required to execute reactive tasks, but the actual resource allocation based on part processing knowledge does not provide for building an experience with any specific module.***
- ***There seems to be no knowledge sharing with regard to the way of working.***

3.2.3 The pattern of understaffing in NPI projects

For each NPI project, a critical part list is made. The list contains those parts for which significant risks are expected, the so-called 'complex parts'. A supply chain engineer should be involved for process development support for all complex parts. If no supply chain engineer is allocated to a complex part, it is 'understaffed'. We identified a pattern in the understaffing.

We observed that understaffing is concentrated in:

- new programs
- specific project types (>50% understaffed)
- suppliers delivering a small number of complex parts (>50% understaffed)

We also found that the capacity demand for proactive NPI work remains stable over time (for a detailed analysis, see Appendix J).

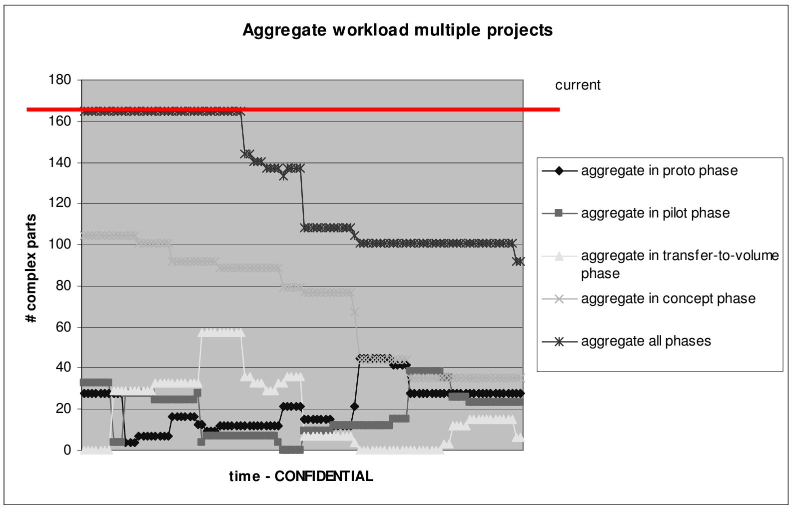


Figure 3.4 Aggregate workload for majority of projects

It should be noted that the line in figure 3.4 declines, because not all future programs are included in the analysis. Then, we conclude that the required capacity for complex parts remains stable over time.

In summary, we conclude:

- ***The understaffing has a bias towards new programs, a number of project types and suppliers that are responsible for a smaller number of critical parts.***

3.2.4 Other dissatisfaction areas

We identify some other dissatisfaction areas:

Interfaces - As described in chapter 2, many related departments are organized around projects whereas SCe is organized around product families. Project leaders indicate that they find difficulties in finding the appropriate supply chain engineer for make/buy decisions and supplier selection and in communicating Engineering Changes. An appropriate supplier selection and change review may save SCe capacity since these processes prohibit extensive control work later on. It should be noted that direct inefficiency by extra communication does not occur, since different supply chain engineers communicate with different suppliers.

Also the interface towards Procurement is not one to one: Procurement is organized around suppliers and not around product families. Procurement indicates it would like to see one supply chain engineer responsible for one supplier, because then the supply chain engineer is able to combine information on different products and processes.

Quality system - Multiple departments are related to quality issues.

We observe that:

- The Material Notification process is not defined and is not owned.
- Material Quality (MQ) and SCe both extract and analyze the same part data to identify structural problems, but Material Quality aggregates to functional cluster and SCe aggregates to suppliers.
- There is no hand-over from SCe to MQ (who is responsible and has to act first)
- There is limited communication on quality issues between Customer Support and SCe in NPI projects.
- There are differences in opinion on the position of the SCe: should the SCe look after the interests of the supplier or of ASML.

Standardization - We observe that standard procedures and deliverables are introduced, but that they are high-level, do not have clear due dates, do not have clear quality indications and are not yet communicated. The standardization work is dynamicly allocated to any supply chain engineer.

Training - There is no formal training. New employees should find information on the intranet and get a training on the job from their peers. Peers are interrupted to answer questions and non standardized working methods are passed on to new supply chain engineers.

Both the organization around product families, no concentration of standardization work and training by peers, increases the number of processes each supply chain engineer is involved in. The actual allocation over different task categories is presented in figure 3.5.

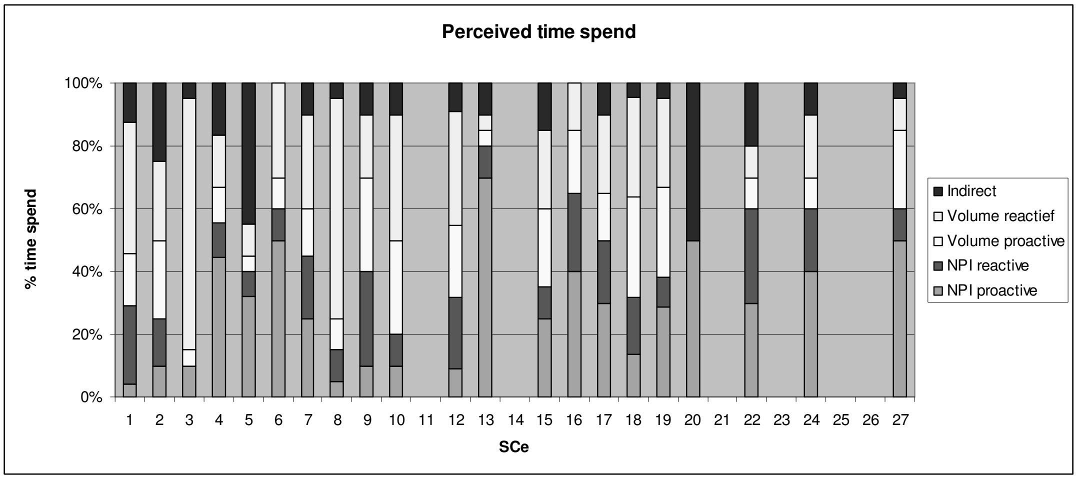


Figure 3.5 Perceived time spend per task category per supply chain engineer.

In summary, we conclude:

- ***The interfaces towards both projects and accounts lead to indirect inefficiencies.***
- ***Standardized working methods are not (well) implemented.***
- ***Training is limited to an on-the-job exercise supported by peers.***
- ***Each supply chain engineer is involved in all task categories.***

3.2.5 The cause-and-effect tree

The interplay between the current resource allocation and the problem at hand can be summarized as follows.

A partial view on the organizational structure complicates the interfaces, leading to an ineffective resource allocation (doing the right tasks). An irrational and unrealistic formal allocation (by allocation that is not based on marginal value, an unrealistic estimation of the work to be done and concentrated understaffing) in combination with limited guiding in prioritization also lead to an ineffective task selection (doing the right task). Limited competence build-up has a negative effect on both effectivity and efficiency. The resource allocation system does not always allocate supply chain engineers based on competences (with regard to the type of production processes). This may lead to less quality in defining and executing tasks (doing the tasks right) and to a lower work speed (efficiency). With limited capacity (and no outsourcing), choices are unavoidable (doing the right tasks).

A gap between the preferred, formal and actual allocation indicates that the actual prioritization choices relating to proactive versus reactive work are not in line with the preferred choices. Choices with regard to allocation to different proactive tasks seem to be inappropriate: understaffing is concentrated, which means that important parts may not be controlled at all, not even to a minimal level. Limited risk management (proactive work) and limited quality lead to more reactive work: some parts are not built to spec. The risk management actions may also have a learning effect for the supply chain engineers and the suppliers. SCe may learn from the processes and use this knowledge in problem solving activities during trouble-shooting. Furthermore, they can use their knowledge in future projects. Suppliers possibly also learn from the actions that were taken during the project. If they learn about their processes, the demand for SCe involvement may be reduced.

In case of limited learning and more problems, the supply chain engineers should spend more time on rework, which in turn increases the demand for trouble shooting capacity. If ASML decides not to 'trouble-shoot', the problems are passed on to the customer. Then, targets will not be fulfilled.

Furthermore, limited risk management support from ASML may lead to less outsourcing in the future since suppliers do not get acquainted with it.

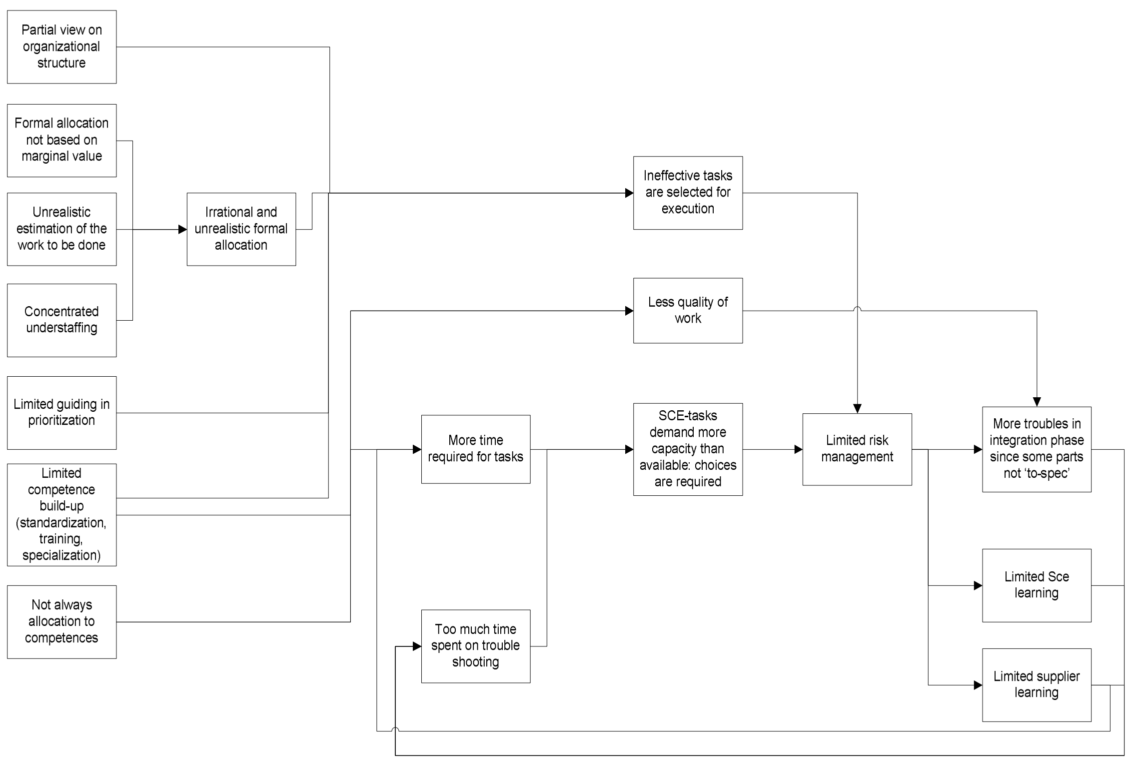


Figure 3.6 Cause-and-effect tree

The problem entails both a mismatch between the preferred allocation and the formal allocation and between the formal allocation and the actual allocation. A major cause of the problem is that organizational members' perception of the resource allocation system is characterized by a partial view. It is augmented by a vicious circle since more trouble shooting is required both directly and indirectly via insufficiently used learning effects: learning by proactive work to apply this knowledge in reactive work and vice versa.

4 The resource allocation system

In this Chapter we describe an ideal allocation system. The system is described at the strategic, tactical and operational level.

4.1 Three-level system

Resource allocation can be defined as the allocation of available capacity to tasks.
'Work' can be described at different levels, namely the levels in the Work Breakdown Structure (WBS). The work at a higher level consists of comprehensive sets of tasks (e.g. 'the R4V process'). We assume that the WBS is a tree. Therefore, different task sets do not contain shared tasks: they are 'non-overlapping'. 'Available resources' can also be described at different levels. At a higher level, single resources are grouped. We usually speak about an 'organizational structure' to denote the relations between the resources.

The mechanism of resource allocation should be a system: a set of rules that states what work is connected to what resources. The system can be described at three levels. An overview of the decisions at each level is given in table 4.1.

Level	**Element**	**Control decisions**
strategic	*work*	Definition of task sets
	capacity	Definition of resource groups
	allocation	Allocation task sets to resource groups
tactical	*work*	Order acceptance level, procedures for task selection
	capacity	Capacity and composition of resource groups
	allocation	Workload of resource groups
operational	*work*	Work order (task) release and selection
	capacity	Actual availability of individuals
	allocation	Allocation of work orders to individuals
		Allocation of individual capacity (time) to its work orders

Table 4.1 Overview of resource allocation system

At the *strategic* level, we decide about the coupling between tasks, aggregated in task sets, and resources, aggregated in resource groups. The task sets and resource groups are regarded conceptually: the individual tasks and resources are not yet specified. For example, 'the waferstage experts' are responsible for 'proactive NPI tasks for waferstage manufacturing processes'. It is important that these task sets and resource groups permanently exist, because strategic decisions are taken for a long term (e.g. yearly). The decisions at the strategic level should take into account what is reachable at the lower levels.

At the *tactical* level, we decide about the procedures for the selection of task sets that can be released in the next period (customer order acceptance level), for the selection of tasks to start (selection), for the capacity and composition of the resource groups (capacity level) and for the workload of resource groups. These decisions are taken for the mid-term (e.g. quarterly). For example, for the next quarter 40% of the available capacity is spent on NPI tasks, 40% on Volume tasks and 20% on Indirect tasks. A 5 fte capacity level is guaranteed for the group 'waferstage experts'. This group is responsible for the execution of the risk management activities. It is important that the decisions at the tactical level fit within the structure defined at the strategic level and take into account what is possible at the operational level.

At the *operational* level, concrete tasks are coupled to individual resources. Hereby, the availability of resources on the short term (capacity level) should be taken into account. In other words, a decision is made about the concrete work order releases (customer order acceptance) and their execution (selection). These decisions are taken frequently and for the short term (e.g. daily). For example, today the group leader decides that 'Pete' is responsible for 'making a Process Failure Mode and Effect Analysis' which should be executed before the end of the month. If more tasks are allocated than can be executed, a selection of the tasks is required. In the example, 'Pete' may decide to delay the execution because he decides to first 'report on the material quality of supplier X in the last month'. This example shows that the moment of work order release and execution may differ. Again, the decisions at the operational level need to be in line with the decisions taken at the tactical and strategic level.

We propose an ideal resource allocation system design for the SCe department at ASML. The system will be described at the strategic, tactical and operational level. Also some side recommendations are given to improve the efficiency and effectivity of the department. For the reasoning behind each recommendation, the reader is referred to Appendix K.

4.2 The strategic level

The following recommendations relate to the resource allocation system at the strategic level.

S1 - ***At the meta-level, redefine 'product family teams' and make them responsible for all task categories with regard to the product family (proactive and reactive NPI and Volume tasks)***

S2 - ***Within the product family team, make an individual supply chain engineer responsible for aggregating the performance data per supplier.***

S3 - ***Make one system engineer responsible for the early Product Generation Process***

phases (before supplier selection in the product families)

S4 - Assign separate groups to indirect tasks (coaching, development of working methods)

4.3 The tactical level

The following recommendations relate to the resource allocation system at the tactical level.

T1 - Resize product family teams based on the preferred allocation and a realistic amount of reactive work.

T2 - Assign supply chain engineers to product family teams based on the competences available.

T3 - Claim and allocate SCe capacity of product family teams, instead of capacity of individuals.

T4 - Control the work load per product family team at 150% of the available capacity.

T5 - Focus on the 20% most important parts of each program and do not bias work orders to certain programs, project types or suppliers.

4.4 The operational level

At the operational level, we identify two decision areas. On the one hand, daily decisions about concrete work order releases to individual supply chain engineers are required. On the other hand, it should be decided which work orders to execute at each moment in time.

4.4.1 Work order releases to individual supply chain engineers

Recommendations with regard to work order releases to individual supply chain engineers, are stated below.

O1 - Use separate work lists for different supply chain engineers and leave the scheduling decision to the supply chain engineer.

O2 - Balance the work load per supply chain engineer at 150%.

O3 - Do not concentrate the most important tasks in one work list, but spread them equally over the servers.

O4 - Strive to allocate a supplier-related task to the account manager, but use the flexibility if this server is better allocated to another job.

4.4.2 Scheduling decisions

As has been stated before, besides work order releases to individual supply chain engineers also execution decisions must be made.

From the analysis, we concluded that there is a gap between the formal allocation and the actual allocation. In order to close this gap, management should communicate priority rules, not only for the reactive tasks, but also for the proactive tasks. In the next Chapter we elaborate on the operational level, thereby leaving the allocation mechanism within resource groups external to the problem.

Note that this level is important, since it determines what task is ultimately selected from a larger set of possible tasks.

4.5 Side recommendations

Beside recommendations with regard to resource allocation, some other improvement areas have been identified.

Side1 - Co-locate with either New Product Logistics or Procurement.

Side2 - Create an integral quality system.

Table 4.2 gives a summary of the recommendations.

Level	Number	Recommendation	Positive effect on		
			Efficiency	*Doing the right tasks*	*Doing the tasks right*
Strategic	S1	Product family structure	■	■	■
	S2	Account managers	■		■
	S3	System engineer in PGP0-2		■	
	S4	Indirect task groups	■	■	■
Tactical	T1	Size product families		■	
	T2	Competence-oriented assignment			■
	T3	Claim-and-allocation to product families		■	
	T4	Work load control at 150%	■		
	T5	Focus on 20%, no bias		■	
Operational	O1	Decentralized scheduling	■		■
	O2	Work load control at 150%	■		
	O3	Spread important tasks		■	
	O4	Account managers allocation	■		■
Side	Side1	Co-location	■	■	■
	Side2	Integral quality system	■	■	■

Table 4.2 Summary of recommendations and impact areas

5 The formal model

Based upon the former analysis, we conclude that more insight is required in the actual operational resource allocation.
In this chapter we will describe the formal model. First, we structure the work situation. Second, we enlist our definitions. Third, assumptions are made explicit and substantiated. Fourth, the problem is formalized.

5.1 The work situation

The work situation is depicted in figure 5.1.

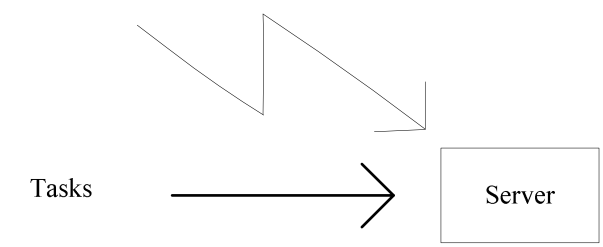


Figure 5.1 Work situation

We consider a situation in which tasks (or 'jobs') arrive to a single server, a supply chain engineer. The tasks $j = 1,...,n$ can have either a stochastic or deterministic arrival time (or 'ready date'), r_j, and has a deterministic processing time, p_j. Disruptions occur according to a Poisson process (λ). If a disruption occurs, the server is not available for processing tasks during the solving time of the disruption, which is assumed to be independently exponentially distributed (μ). No disruption can arrive at the supply chain engineer while he is solving a disruption.
A task can be preempted, but we assume the 'preempt-resume' model, as opposed to the 'preempt-repeat' model: the work already done is not lost and if the task is restarted the server can go on with the remaining work, whereas in the preempt-repeat model the work that has been done is lost and the server has to restart from scratch after preemption.
The objective is to maximize the long-run expected sum of task values $value_j$ (or 'average task value per time unit'). The value of a task depends on its maximal value, or weight w_j, completion time z_j and its due date d_j, as is depicted in figure 5.2.

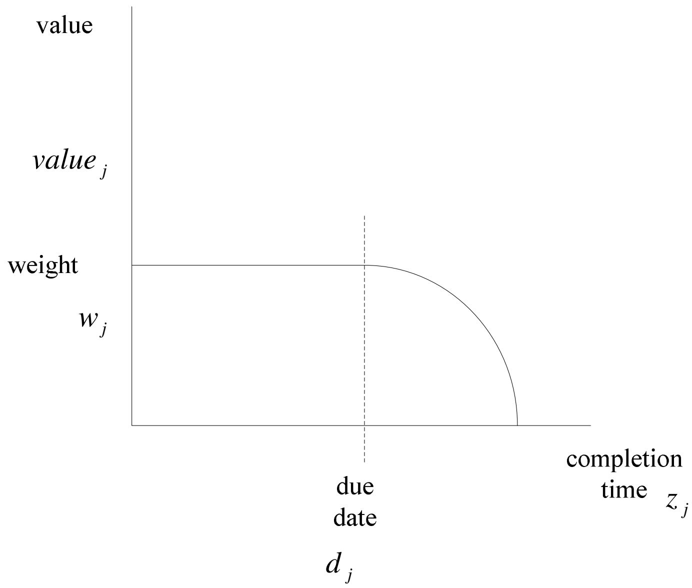


Figure 5.2 Value per task as a function of the completion time

This form has been indicated by the organizational members to best represent the value function.

The duration of the time between the starting time s_j and the completion time z_j is the sum of the processing time and the total disruption time before or during the execution of the job, x_j. If a task is completed before its due date, the maximal value w_j is obtained; if it is completed after its due date, the task value is increasingly declined by a discounting rate c_j, but can never be negative.

At each moment in time, we need to decide which task to work on in order to ultimately achieve the maximum long-run expected sum of task values. All tasks that may be started are on a 'worklist'. Tasks disappear from the work list if they will not result in any value once they would be started immediately. In fact, this is an online and stochastic scheduling problem: we reconsider our decisions if new information comes available (online) and the completion times are uncertain (stochastic).

5.2 Definitions

A list of definitions is presented below.

j	task	:	proactive NPI or Volume task
r_j	ready date	:	first possible moment of execution of task j

d_j	due date	:	moment at which task j must be completed
p_j	processing time	:	processing time of task j
$value_j$	value	:	value of task j
w_j	weight	:	value of task j if completed before d_j (maximal value)
c_j	discounting rate	:	rate at which w_j decreases after d_j
s_j	starting time	:	the actual starting time of task j, $s_j \geq r_j$
z_j	completion time	:	the completion time of task j
N_j	task length	:	the total duration of tasks until z_j
x_j	disruption length	:	the total duration of disruptions before or during the execution of task j
$duration_j$	duration	:	the sum of task length and disruption length
a_j	required capacity per time unit	:	the capacity that task j requires per time unit
λ	arrival rate of disruptions	:	the number of disruptions arriving per time unit
μ	solving rate of disruptions	:	the number of disruptions solved per time unit

5.3 Assumptions

The following assumptions are made regarding the work situation. These assumptions have been confirmed by the organizational members. For a critical reflection upon the assumptions, as a validation of the model, see Appendix L.

1. r_j is stochastic for some tasks and deterministic for other tasks
2. A task j can be scheduled and rescheduled at any moment in time after r_j.
3. d_j is deterministic for all tasks
4. p_j is deterministic (negligible variation)
5. $a_j = 1$ for all tasks
6. Preemption of tasks is allowed at each moment in time. No preemption is allowed for disruptions.

7. The value of tasks is determined by:

$$value_j = \begin{cases} w_j & if \quad z_j \le d_j \\ w_j + 1 - e^{c_j(z_j - d_j)} & if \quad d_j < z_j \le d_j + \dfrac{\ln(w_j + 1)}{c_j} \\ 0 & else \end{cases} \tag{5.1}$$

For $c_j > 0$, the plot in figure 5.2 represents the value per task for various completion times.

Some tasks are mini projects: they consist of sub tasks that must be executed sequentially. The value of such a task can be partly obtained after any sub task.

An example is presented in figure 5.3.

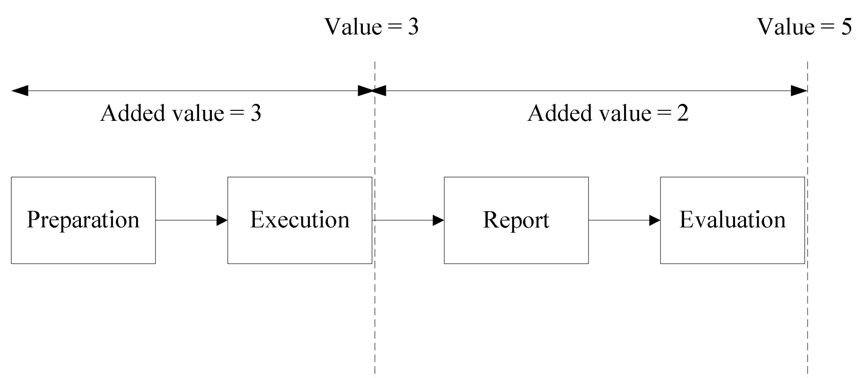


Figure 5.3 Sequence of subtasks

It is assumed that the processing time of mini projects is optimized externally.

8. Disruptions arrive according to a Poisson process (λ); if a disruption arrives while the server is solving another disruption, the new disruption is passed on to another server.

9. The solving time of disruptions is exponentially distributed (μ).

10. Resource availability is constant over time (single server).

11. There is no setup time.

5.4 Formal problem

The problem is formalized as

$$\max \sum_{\forall i: z_i = (0,T]} \frac{E[value_i]}{T} \tag{5.2}$$

s.t.

$$\begin{aligned} & s_j \geq r_j && \forall j \\ & u_t = [0,1] && t \in (0,T] \\ & T \to \infty && \end{aligned} \tag{5.3}$$

Our aim is to maximize the long-run average task value obtained per time unit Δt, which is the sum of the value of all tasks completed during $(0,T]$ divided by $T = \text{constant} \cdot \Delta \text{t}$. The first constraint indicates that each task can only start after its ready date. The second constraint indicates that the utilization must be equal to zero or one at each moment during $(0,T]$.

It has to be decided which tasks will be executed at each moment in time during $(0,T]$.

A formal model has been introduced to investigate the operational resource allocation. The objective is to maximize the sum of the value of all tasks completed during a time interval.

6 The operational resource allocation mechanism

In this chapter we model the decision making process. First, we identify the information we need for decision making and the decision moments. Several decision algorithms are proposed as a base for decision making. Then, we identify side performance measures and research questions. At the end of this chapter we present the results.

6.1 The decision making process

The work situation is stochastic and dynamic. At each moment in time we do not know which tasks and disruptions will arrive in the future. For disruptions, we can estimate the number and solving time based on the characteristics of a Poisson process. Because of the online character, we must determine at which moments in time we will make new decisions and what information will be taken into account at those decision moments.

6.1.1 Decision information

Suppose we start our decision making process at time $t_{now} = 0$. Let us define G_t as the set of all tasks that can be executed at time t. G_t is stochastic for all $t > t_{now}$ due to stochastic r_j, but is deterministic at t_{now}. If the tasks are not too tight and the uncertainty regarding r_j is significant, it is reasonable to base our decision solely upon $G_{t_{now}}$: adapting the current schedule for (forecasted) tasks with a future release date does not make sense if we do not have sufficient knowledge on future releases.

6.1.2 Decision moments

We need to determine our decision moments: the moments at which we determine what task to work on. Completion times of tasks will be taken as decision moments. For an explanation of this choice, see Appendix M. It should be noted that the arrival of a disruption always changes the schedule: we start solving the disruption immediately.

6.1.3 Decision algorithms

At $t_{now} = z_j$ we only need to decide which task to start. This decision can be based upon several decision algorithms. We compare the following four decision algorithms.

The first two algorithms are based upon finding a schedule for multiple tasks. Thereby, we take into account that we need to schedule a reasonable period of time to prevent the server from starving. It should be noted that the first part of the schedule is more robust (a smaller difference between the current schedule and the optimal schedule at each moment in time): a smaller number of disruptions and task arrivals occur between t_{now} and the completion time. The importance of the first jobs was recognized by Jang (2002). Note that upon each decision moment, we only decide that we start the job at the first position in the schedule.

The other two algorithms are based upon scheduling, or dispatching, rules. A decision heuristic is used to select the first job to work on.

The four algorithms can be found in Appendix N and are described below.

6.1.3.1 The Exact algorithm for scheduling

Upon the completion of a task k, we select all tasks that can be started immediately and can lead to value creation. For each possible sequence of the selected tasks, we determine the expected sum of all values if all tasks in G_t are executed sequentially without preemption. The expected sum of one task j is given by

$$E\left[value_j\right] = \int_{x_j=0}^{-t+d_j-N_j} w_j f\left(x_j\right) dx_j + \int_{x_j=\max\left(0,-t+d_j-N_j\right)}^{\max\left(\max\left(0,-t+d_j-N_j\right),\left(\frac{\ln\left(w_j+1\right)}{c_j}-\left(t+N_j\right)+d_j\right)\right)} \left(w_j + 1 - e^{c_j\left(t+N_j+x_j-d_j\right)}\right) f\left(x_j\right) dx_j \tag{6.1}$$

where

$$f\left(x_j\right) = \sum_{n=0}^{\infty} \frac{x_j^{n-1}\mu^n e^{-\mu x_j}}{(n-1)!} e^{-\lambda N_j} \frac{\left(\lambda N_j\right)^n}{n!} \tag{6.2}$$

Finally, we select the sequence with the highest expected sum of all values and start executing the first task.

6.1.3.2 The Heuristic algorithm for scheduling

The Heuristic algorithm for scheduling tries to simplify the objective function and to eliminate the stochastic elements of the system by adapting the due dates. A solution method for the Weighted

Number of Tardy Jobs Problem (Lawler & Moore (1969), possibly added with the reduction mechanism of Potts & Van Wassenhove (1988)), can be applied to the problem with the adapted due dates to obtain a schedule for our problem. The first task of the schedule will be started.

Two adaptation steps are required to obtain new due dates.

First, we can approximate the value function by assuming that the value is dropping immediately at a certain moment in time, instead of declining increasingly to zero during $\left[d_j, d_j + \frac{\ln(w_j+1)}{c_j}\right]$. Let us assume that this point lies at $d_j^{avg} = d_j + \frac{1}{2}\frac{\ln(w_j+1)}{c_j}$. This seems to be reasonable because the loss of value before this point is much smaller than the loss after this point. Second, the time between the decision moment and a future due date will be used for task handling and disruption solving. We can estimate the expected ratio of time spent to tasks and time spent to disruptions during this period. We adapt the due date d_j^{avg} by reducing it with the expected time spent on disruptions.

An explanation of this method is provided in Appendix O.

6.1.3.3 The Return on Effort heuristic

Again, upon the completion of a task k, we select all tasks that can be started immediately and can lead to value creation. Instead of calculating the expected value of the total value for each sequence, we calculate the expected value for each task, given that the task is started immediately. The expected task length is given by

$$E\left[duration_j\right] = p_j + \frac{\lambda p_j}{\mu} \tag{6.3}$$

Finally we calculate the ratio $\frac{E\left[value_j\right]}{E\left[duration_j\right]}$ and start the task with the highest ratio (based on the results of prior research in stochastic and dynamic settings, summarized by Silver et al., 1998, pp. 689).

As a simpler alternative, the ratio $\frac{w_j}{p_j}$ is analyzed instead of $\frac{E\left[value_j\right]}{E\left[duration_j\right]}$.

6.1.3.4 The Modified Due Date heuristic

The Modified Due Date heuristic also tries to simplify the objective function and to eliminate the stochastic elements of the system by adapting the due dates. Again, upon the completion of a task k, we select all tasks that can be started immediately and can lead to value creation. For each selected task, we can adapt the due date like in the Heuristic algorithm for scheduling and approximate the processing time by the duration like in (6.3). Next, we can apply the Modified Due Date heuristic of Baker & Bertrand (1982) to the new problem to obtain a solution for our problem. The Modified Due Date of a task j then becomes

$$d_j^{\text{mod}} = \max\left(d_j^*, t + E\left[duration_j\right]\right) \tag{6.4}$$

6.1.3.5 Side performance measures

The objective is to maximize the sum of the values of all tasks completed during $\left(0,T\right]$. However, the following performance measures will also be calculated:

- the sum of the values of all tasks completed during $\left(0,T\right]$ if the decision maker is not aware of the actual weights of tasks, but assumes that all tasks are equal – *to show the importance of communication on weights*
- the long-run sum of the values of all tasks completed during $\left(0,T\right]$ if the decision maker is not confronted with the total set of tasks but his workload is controlled – *to show the influence of incorporating idle time*
- the long-run sum of the values of all tasks completed during $\left(0,T\right]$ if the decision maker is not confronted with the total set of tasks and disruptions, but the work is divided over two servers (a resource group) – *to show what value is obtained if proactive and reactive work is allocated to different servers*

6.1.4 Research questions

We state the following research questions:

Research question R1 - Which algorithm performs best?

The Exact algorithm for scheduling takes both due dates and weights, disruptions and the total set of already arrived tasks into account and is therefore based on the most complete set of information (although lacking information on tasks arriving in the future). For this reason we expect it to perform best.

Research question R2 - What is the impact of wrongly estimated weights on the performance of the Exact algorithm for scheduling?

We expect that the weights are essential for decision making, since maximizing the value created per time unit is our ultimate objective.

Research question R3 - What is the impact of Work Load Control (WLC) on the performance of the decision algorithms?

Although WLC may result in idle time, considerable gain is expected from reducing the risk on elimination or delay of highly valuable tasks.

Research question R4 - What is the impact of a reduction of disruptions on the performance of the decision algorithms?

Planning becomes easier and risks of not obtaining the expected value are reduced. Therefore, it is expected that the performance is significantly improved.

6.2 The results

The algorithms have been programmed in Matlab 6.1 and have been run on a Intel ® Pentium ® computer (Micro processor 1400 MHz, 587 MHz, 504 MB of RAM). For a discussion on verification, the reader is referred to Appendix P. The program code is provided in Appendix Q.

The four algorithms have been compared in several cases[8]. A case is characterized by the setting of four design parameters: the number of jobs arriving per time unit, the disruption characteristics λ and μ, the discounting rate c_j and the tightness $d_j - r_j$. The setting of the other parameters is presented in the table below. Some general insights are presented in Appendix R.

Symbol	*Parameter*	*Setting*
-	Number of events (arrival disruption, arrival first task, completion task)	500
p_j	Processing time	$U[0,10]$
w_j	Weight	$U[0,10]$

Table 6.1 Setting standard parameters

Test parameters are case parameters and the number of cases per experiment, the number of instances

[8] The significance level in all tests is $\alpha = 0.05$

per case and the number of simulations per instance. The setting of the test parameters[9] is presented in Appendix S.

6.2.1 Comparison between simple and adapted version of heuristics

To determine whether the simple Return on Effort heuristic based on the ratio $\frac{w_j}{p_j}$ is significantly different from the more complex ratio $\frac{E\left[value_j\right]}{E\left[duration_j\right]}$, we carry out a paired-sample t-test[10] (based upon the results of experiment 10[11]).

$$H_0: \left(E\left[\sum_{\forall i: z_i=(0,T]} \frac{E\left[value_i\right]}{T}\right]\right)_{simple} = \left(E\left[\sum_{\forall i: z_i=(0,T]} \frac{E\left[value_i\right]}{T}\right]\right)_{complex}$$
$$H_1: \left(E\left[\sum_{\forall i: z_i=(0,T]} \frac{E\left[value_i\right]}{T}\right]\right)_{simple} \neq \left(E\left[\sum_{\forall i: z_i=(0,T]} \frac{E\left[value_i\right]}{T}\right]\right)_{complex} \quad (6.9)$$

The same kind of test is carried out for the simple $d_j^{\text{mod}} = \max\left(d_j^*, t + p_j\right)$ and the more complex $d_j^{\text{mod}} = \max\left(d_j^*, t + E\left[duration_j\right]\right)$ for the Modified Due Date heuristic.

The results are presented in the table below.

Method	*t-statistic*	*P-value*	*Conclusion*
Return on Effort heuristic	-0,354	0.704	Do not reject
Modified Due Date heuristic	-4.198	0.000	Reject

Table 6.2 t-test for simple and complex version of heuristics

We conclude that the complex Modified Due Date heuristic outperforms its simple counterpart, but the simple and complex Return on Effort heuristics do not significantly differ from each other. Therefore, in the next paragraphs we will only represent the simple Return on Effort heuristic and the complex Modified Due Date heuristic.

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[9] If multiple levels are presented, these are the levels that are used in the design.

[10] Paired-sample t-tests have been used throughout the thesis: the disruptions occurring per simulation were identical for testing the performance of different algorithms.

[11] The outcome did not contradict the results of other experiments.

6.2.2 Comparison of algorithms

The performance of the four algorithms, added with the random decision maker, is presented in figure 6.1.

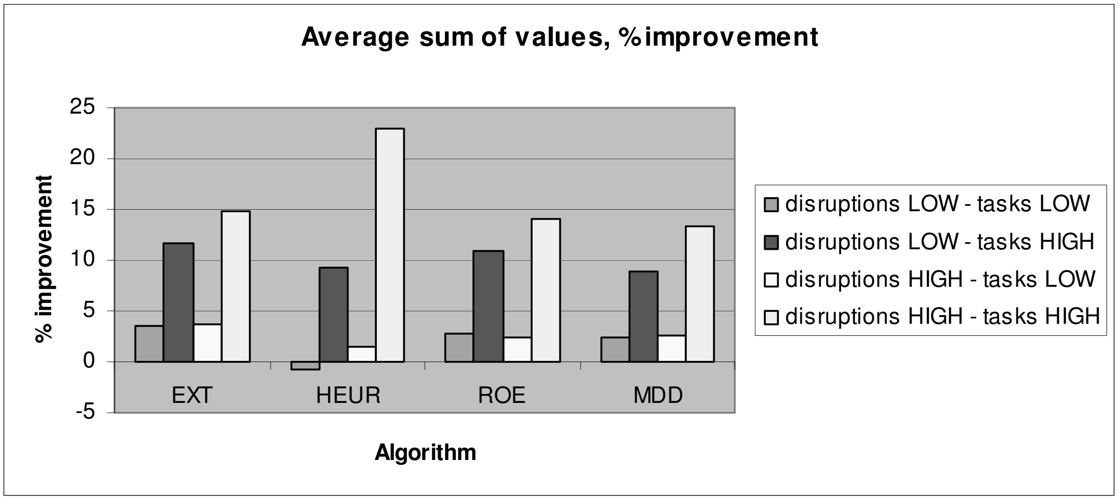

Figure 6.1 Percentage: (algorithm performance – performance random decision maker)/performance decision maker * 100; EXT: Exact algorithm for scheduling, HEUR: Heuristic algorithm for scheduling, ROE: Return on Effort heuristic, MDD: Modified Due Date heuristic, disruptions LOW $\lambda = 0.2, \mu = 0.5$ or $\lambda = 0.4, \mu = 0.5$, disruptions HIGH: $\lambda = 0.6, \mu = 0.5$ or $\lambda = 3, \mu = 2$, tasks LOW: 50 tasks/500 time units, tasks HIGH: 100 tasks/500 time units

The Exact algorithm for scheduling significantly outperforms the Heuristic algorithm for scheduling $(P-value\ 0.004)$, the Return on Effort heuristic $(P-value\ 0.005)$ and the Modified Due Date heuristic $(P-value\ 0.000)$ for the smaller disruption arrival rates. The Return on Effort heuristic significantly outperforms the Heuristic algorithm for scheduling $(P-value\ 0.025)$ and the Modified Due Date heuristic $(P-value\ 0.000)$ for the smaller disruption arrival rates[12].

For the larger disruption rates, the Heuristic algorithm for scheduling outperforms the Exact algorithm for scheduling $(P-value\ 0.001)$, the Return on Effort heuristic $(P-value\ 0.000)$ and the Modified Due Date heuristic $(P-value\ 0.000)$ for the larger number of tasks. However, for the smaller number of tasks the Exact algorithm for scheduling significantly outperforms the Return on

[12] A more extensive case (Appendix S, experiment 6) showed that the Heuristic algorithm for scheduling may significantly outperform the Modified Due Date heuristic for smaller disruption arrival rates $(P-value\ 0.000)$, mainly in case of higher tightness $(d_j = r_j + U[0,20]$ vs. $\mathrm{d_j} = r_j + U[0,50])$.

Effort heuristic $(P - value\ 0.008)$, while the other methods do not significantly differ.

The relatively better performance of the heuristic algorithm in case of larger disruption rates may be due to an (over)protection against disruptions. The mechanism can be compared to applying resource buffers, defined as 'warning systems or reminders that make sure the resources are ready when it is time to work on a critical task' (Tükel et al., 2006).

There is a difference between the performance of the Exact and Heuristic algorithm for scheduling. From a comparison of the decisions made by both algorithms for scheduling, we obtain that the heuristic version performs worse if it fails to select a high-valued task that is too tight to be scheduled if the due dates are adapted. In reality, value is still obtained upon the completion of such a task if the completion time turns out to be smaller than $d_j + \frac{\ln(w_j + 1)}{c_j}$.

6.2.3 Consequences of erroneous weight determination

Whereas processing times and due dates can often be estimated with sufficient accuracy, the determination of the weight parameters is more difficult. Subjectivity can play a role. However, our results show that a correct weight determination is important.

Suppose that the decision maker suspects that the performance ratio $\frac{w_j}{p_j}$ for all tasks are equal $(w_j = p_j)$. However, in reality, the weights differ. Furthermore, he applies the Exact algorithm for scheduling, which was identified as performing best. For experiment 9, its performance will be reduced to a level that is significantly worse than deciding randomly. This result indicates the importance of a proper weight determination. Communication and discussion about what organizational members perceive to be important, seems to be indispensable.

6.2.4 Influence of Work Load Control (WLC)

In our algorithms we select a task based on the knowledge we have on the set of tasks that have already arrived. The Exact and Heuristic algorithm for scheduling and the Modified Due Date heuristic also take into account that disruptions can be expected in the future. However, also new tasks will arrive in the future. If we would take this into account, it may better to wait for a task with a high performance ratio $\frac{w_j}{p_j}$ instead of always starting a task if there is at least one that can be started. Then, we would not hinder the valuable task to be started immediately upon its arrival, resulting in a higher expected value[13]. Instead of considering each task for selection, one might preselect the tasks available based upon the performance ratio $\frac{w_j}{p_j}$. If, for example, the workload is 150%, one might decide to start only those tasks that have a ratio that is above a certain threshold value (e.g. 0.7). The decision maker is then prevented from working on less valuable tasks: he could better wait (or still try to finish it in time) and start a future job immediately upon its arrival.

For smaller disruption arrival rates, in general, WLC significantly improves the performance in case of

- a larger number of tasks arriving (100 tasks/500 time units vs. 50 tasks/500 time units[14])
- a larger disruption arrival rate $\left(\lambda = 0.2, \mu = 0.5 \text{ vs. } \lambda{=}0.4, \mu{=}0.5^{14}\right)$
- a smaller discounting rate $\left(c_j = U[0,1] \text{ vs. } c_j = U[0,5]\right)$

There is also a difference for different algorithms, if WLC (threshold value 0.7) is applied

- the Heuristic algorithm for scheduling performs significantly worse $\left(P-value\ 0.000\right)$
- the Exact algorithm for scheduling and the Return on Effort heuristic do not perform not significantly different $\left(P-value\ 0.203;0.160\right)$
- the Modified Due Date heuristic and the random decision maker perform significantly better $\left(P-value\ 0.005;0.000\right)$

For larger disruption rates, in general WLC significantly improves the performance in case of

- a larger number of tasks arriving (100 tasks/500 time units vs. 50 tasks/500 time units[14])
- a smaller tightness (larger due date) $\left(d_j = r_j + U[0,10] \text{ vs. } \mathrm{d_j} = r_j + U[0,20]^{14}\right)$

If WLC (threshold value 0.7) is applied,

- the Heuristic algorithm for scheduling does not perform significantly different for the smaller number of tasks arriving $\left(P-value\ 0.077\right)$
- the Heuristic algorithm for scheduling performs significantly better for the larger number of tasks arriving $\left(P-value\ 0.024\right)$
- the Exact algorithm for scheduling, the Return on Effort heuristic, the Modified Due Date heuristic and the random decision maker perform significantly better $\left(P-value\ 0.000;0.000;0.000;0.000\right)$

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[13] Another option would be to start a less valuable task, but preempt it when a high valuable task arrives.

[14] Scenarios significantly $\left(\alpha = 0.05\right)$ differ.

Figure 6.2 represents the performances relative to the random decision maker without WLC applied. In general, applying the Exact algorithm for scheduling and Work Load Control leads to the best improvement.

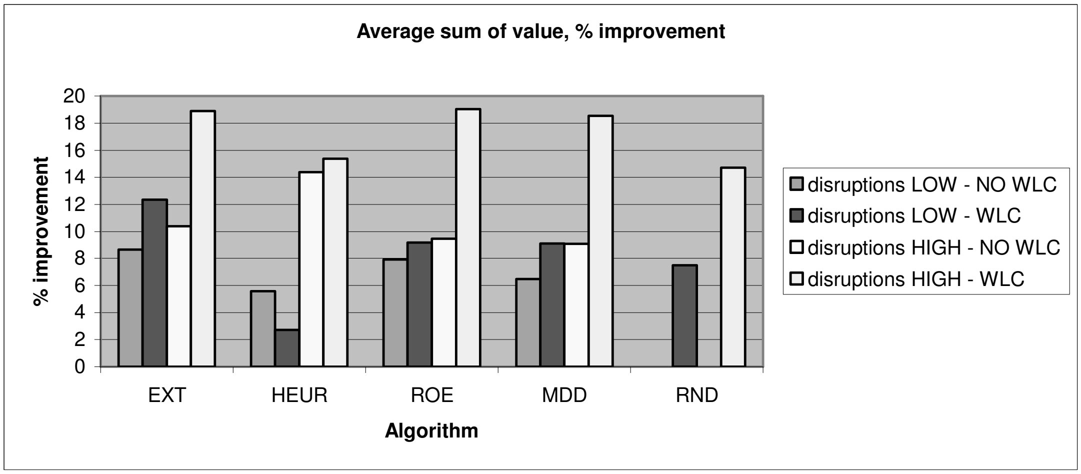

Figure 6.2 Percentage: (algorithm performance – performance random decision maker)/performance decision maker * 100 with and without WLC; EXT: Exact algorithm for scheduling, HEUR: Heuristic algorithm for scheduling, ROE: Return on Effort heuristic, MDD: Modified Due Date heuristic, disruptions LOW $\lambda = 0.2, \mu = 0.5$ or $\lambda = 0.4, \mu = 0.5$, disruptions HIGH: $\lambda = 0.6, \mu = 0.5$ or $\lambda = 3, \mu = 2$

6.2.5 Reduction of disruptions

Disruptions have a negative impact on the value that can be obtained. First, they complicate the planning. Second, even if the best schedule is chosen, the maximum value may still not be obtained due to stochastics. It would be better if disruptions could be reduced. We consider two options for two servers:

- the work for two servers is merged; one server becomes responsible for disruption solving, while the other server becomes responsible for task handling
- the disruptions for both servers are reduced

Note that in both situations not all disruptions can be handled immediately any more: in the first option, the server needs to delay some disruptions (or disruptions are discarded and the server may get idle) due to a loss of flexibility, while in the second option disruptions are totally eliminated. In reality more options exist (for example, reallocation in case of overload) and more factors play a role (for example, some disruptions cannot be eliminated or can only be handled by one server). However, these two options have some advantages: in the first option, the capacity spent on disruptions is strictly limited, thereby preventing an over reactive system; in the second option, flexibility is fully used to be able to handle disruptions in parallel (fire car effect). Note also that both options are not comparable.

Their relative performances depend upon the possibility to delay reactive tasks and the loss for discarded disruptions. It should also be remarked that knowledge-sharing is indispensable for ensuring sufficient learning effects if the first option is implemented.

Let us first evaluate the first option. We compare the sum of the performances of the two servers for the old situation to the performance of the server responsible for tasks if the work is merged. It turns out that the performance in case of a split between disruptions and tasks outperforms significantly (95.0% confidence interval for mean percentage of difference: $\left[-109.340;-82.003\right]$[15]). The difference becomes significantly larger for scenarios with

- more tasks arriving (200 tasks/500 time units vs. 100 tasks/500 time units for two servers)
- a higher tightness $\left(d_j = r_j + U\left[0,10\right]; d_j = r_j + U\left[0,20\right]; d_j = r_j + U\left[0,50\right]; d_j = r_j + U\left[0,100\right]\right)$
- a larger disruption arrival rate $\left(\lambda = 0.4, \mu = 0.5; \lambda = 0.6, \mu = 0.5\right)$.

The performance improvement may be due to the fact that at each moment in time more jobs are present that lead to a high value per time unit and to the fact that the value of a task is maximally obtained once it is chosen (and the decision algorithm works well) due to the deterministic setting.
For the second option we compare the sum of the performances of the two servers for the smaller disruption arrival rate $\left(\lambda = 0.4, \mu = 0.5\right)$ and the larger disruption arrival rate $\left(\lambda = 0.6, \mu = 0.5\right)$. By eliminating one third of the disruptions, a performance improvement of about 28 % $\left(\pm 3.905; \alpha = 0.05\right)$ can be reached.

[15] $\lambda = 0.6, \mu = 0.5$

6.3 Improvement of the heuristic

From our results, we identify a significant gap between the performance of the Exact algorithm for scheduling and the Heuristic algorithm for scheduling. Whereas the Exact algorithm seems to perform well, the Heuristic algorithm lags behind. Based on the insights obtained, a new heuristic algorithm is proposed: the Average Value Opportunity heuristic (see Appendix N).

Again, upon the completion of a task k, we select all tasks that can be started immediately and can lead to value creation. Then, for each possible combination of two tasks ($l(l-1)$ where l is the number of selected tasks,) we determine the expected sum of values if these two tasks are executed sequentially without preemption, like in (6.1) and (6.2). For each task, we determine the average of all expected sum of values in sequences of two tasks where this task is started first. Finally, we select the starting task with the highest average of all expected sum of all values and start this task.

This heuristic is based upon the findings that:

- the first tasks are most important if tasks arrive dynamicly over time
- starting the first task should leave enough room for other tasks to be executed before their due date
- taking the expected sum of values into account seems to be beneficial in disruptive situations.

This new heuristic is tested in one of the experiments and results are promising (Appendix T).

6.4 Implications for ASML

ASML's task and disruption characteristics are within the range that has been studied. Therefore, the conclusions drawn from the experiments seem to be applicable. Company specific case data and implications in this area are presented in Appendix U.

We identified four algorithms. In conclusion,

- ***The Exact algorithm for scheduling outperforms other algorithms, except in case of many tasks and many disruptions. However, it can only be applied if, at each moment in time, at most seven jobs are available (due to storage limitations). There is room for improvement by obtaining a better approximation of the Exact algorithm for scheduling. The first results for a new heuristic, the Average Value Opportunity heuristic, taking both weights and due dates into account, are promising but need to be tested more extensively.***
- ***A proper weight determination is indispensable for value creation. Work Load Control in combination with the Exact algorithm for scheduling leads to the highest improvement. The performance improvement by elimination of disruptions is significant. It seems to be worthwhile to investigate the losses in case of delay or elimination of disruptions.***

7 Conclusions

In this chapter we summarize our main findings. Furthermore, we identify limitations and directions for future research.

7.1 Main findings

We recommend a consistent three-level allocation system.

- At the strategic level, 'product family teams' can act like self-steering teams with individual supply chain engineers responsible for data aggregation per supplier; a system engineer gets responsible for the early Product Generation Process Phases and there are separate groups for indirect tasks (coaching and development of working methods).
- At the tactical level, product family teams are competence groups that can be claimed, up to 150%. It is recommended to resize the groups on the mid term and not to bias the work orders to certain programs, project types or suppliers.
- At the operational level it is recommended to equally assign work to each individual supply chain engineer up to a workload of 150%. The product family team should strive to allocate a supplier-related task to the account manager, but should not rigidly apply this rule. The scheduling decision should be left to the supply chain engineer. Preferably, he should use the Exact algorithm for scheduling, but if this rule is not applicable, a Work Load Control rule may be applied. That is, a task with a performance ratio (weight-per-time-unit) above a certain threshold value should always preempt a task with a ratio below this threshold value. The weight of tasks can be determined by the method 'Weight determination' or by the model created in the workshop 'Prioritization criteria'.

We also stated some side recommendations.

- It is recommended to limit the reactive work. Again, the result of the workshop 'Prioritization criteria' can be applied.
- To further increase efficiency and effectivity, it is recommended to co-locate with either New Product Logistics or Procurement and to create an integral quality system.

7.2 Limitations

Our research has been limited by the following factors:

- Data on the Work Breakdown Structure, competences and task durations were not yet available. Therefore, we needed to use perceptions instead of objective measurement data. We also tried to analyze the complex parts per product family, but did not receive enough data.

Due to limited and anonymous responses, we have not been able to compare the preferred, formal and actual allocation for each product family.

- The task categorization used in the preferred and actual allocation is not completely identical to the categorization in the actual allocation. A translation was required.
- The exact algorithm takes significant time. For complex problems, Matlab 6.1 is even unable to solve the problem. Therefore, we only tested the performance of the exact algorithm for a limited number of cases, instances and simulations.
- Data gathering took a long time. Therefore, the quantitative results are based on an experimental design. Unfortunately, the same type of tests has not been run for the ASML case data.
- Inspired by the disappointing performance of the Heuristic algorithm for scheduling, a new heuristic is proposed. However, this new heuristic has not been extensively tested yet.

7.3 Future research and management actions

Further research is suggested in the following areas:

- It is recommended to simulate the ASML situation with business specific case data to obtain better estimates of the effects of various measures.
- More specific, and possibly quantitative, decision support is required at the strategic and tactical level. Thereby one should take into account the resource and task characteristics at the operational level. Also the work order releases to individuals could be analyzed with a scientific model.
- Further insights may be obtained if not the long-run average task value obtained per time unit Δt is considered as an objective, but also the variance of the value is taken into account.
- It is recommended to find better approximation methods for the Exact algorithm for scheduling, since we identified that there is much room for improvement. The first results of a newly proposed heuristic seem to be promising.
- In our analysis and design we assumed a given capacity level. Further research is required to trade-off the costs of hiring and firing new employees and the costs of limited capacity. It should be noted that it can be reasonably assumed that the first capacity spent delivers the highest value, as was identified by the method Weight Determination which showed indifference points. The sum of the capacity indicated before the indifference point does not differ that much from the current capacity. However, the task sets may differ over time and so do the task and resource characteristics.
- It is proposed to analyze the resource allocation model from a human resource perspective. In this problem we identified the multiple bosses problem and learning (and forgetting) effects.

It may also be interesting to study the influence of control power at supply chain engineers. Furthermore, an investigation of the learning curve might bring interesting results.

- The communication structure at the department is also an issue that deserves attention. Thereby, both the communication and relationships of the department with externals (the supplier, other ASML departments) and internally (knowledge sharing between supply chain engineers) could be studied.
- It is proposed to build new application areas and extensions of the algorithms presented in this report. For example, how do they perform in a static and/or deterministic environment; what is the influence of setup times; what is the influence of stochastic processing times; how can precedence constraints be built in? It is recommended to study the scheduling method that takes general precedence relations into account. Also ‘nondisruptable’ tasks can be identified and analyzed.

Further management actions are suggested on the following topics:

- For ASML, we recommend to plan discussion meetings with management on the short term. Discussion areas have been identified in Appendix U.
- For implementation, we suggest ASML to use the decision tool that was designed during the workshop ‘Prioritization Criteria’ during some pilots. Furthermore, we suggest ASML to evaluate the resulting decisions and user satisfaction after a certain period of time. A threshold value for the performance ratio also needs to be established.

ABBREVIATIONS

ANOVA	Analysis of Variance
ASML	Advanced Semi-conductors Manufacturing Lithography
CCB	Change Control Board
CE	Cost Engineering
DFMEA	Design Failure Mode and Effect Analysis
EC	Engineering Change
EDD	Earliest Due Date
EXT	Exact algorithm for scheduling
FMEA	Failure Mode and Effect Analysis
F&T	Flow and Temperature
fte	full time equivalent
HEUR	Heuristic algorithm for scheduling
HEUR2	Average Value Opportunity heuristic (new heuristic)
LDD	Latest Due Date
LPT	Longest Processing Time
M	Mechanics
MDD	Modified Due Date heuristic
Me	Mechatronics
MQ	Material Quality
MQP	Material Quality Performance
NPI	New Product Introduction
NPL	New Product Logistics
OSC	Operational Supplier Contact
PE	Production Engineering
PFMEA	Process Failure Mode and Effect Analysis
PFT	Product Family Team
PGP	Product Generation Process
PLC	Product Life Cycle
QA	Quality Assurance
QLTC	Quality, Logistics, Technology, Costs
R4V	Release For Volume
RND	Random
ROE	Return On Effort heuristic
SAT	Supplier Account Team
SCe	Supply Chain Engineering Mechanical, Electrical and Optical

SCE	Supply Chain Engineering
SCPM	Supply Chain Project Management
SPT	Shortest Processing Time
TACR	Tasks, Accountability, Contributing, Responsibility
TPD	Technical Product Documentation
TTM	Time-To-Market
WBS	Work Breakdown Structure
WETC	Weighted Earliness/Tardiness Costs
WLC	Work Load Control
WNTJ	Weighted Number of Tardy Jobs

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Task valuation and resource allocation to optimize value delivered in product and process improvement projects

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Introduction

The rapidly growing semiconductor industry generates a strong demand for lithography manufacturers to produce increasingly complex systems within a strict Time-to-Market. Besides on innovative technology, the market creates a pressure on operational excellence. In challenging New Product Introduction (NPI) projects, suppliers are often a major source of ideas on new products and production technologies and cooperation could lead to a reduction in engineering lead time and to cost benefits [1]. This may result in a growing demand for scarce Supply Chain Engineering capacity.
The challenges for resource allocation at Supply Chain Engineering departments are tremendous due to interface complexity, interproject or interactivity dependency, uncertainty and a hardly measurable performance criterion. Given the capacity level, choices need to be made regarding the work to be done. For this situation, the resource allocation mechanism should be optimized.

Objective

The aim of this Master Thesis is to develop an ideal resource allocation system, defined by a consistent set of decision mechanisms at the strategic, tactical and operational level, to maximize the value created by the Supply Chain Engineering department. The contribution is threefold:

1. Comprehensive framework for resource allocation systems
2. Methodology for determining the value of tasks
3. Prioritization rules at the operational level

Methodology

Guided by the research model of [2] research was conducted at the Supply Chain Engineering department of Advanced Semi-conductors Manufacturing Lithography (ASML). The business problem entails a mismatch between the preferred, formal and actual allocation. Insufficient learning effects result both directly and indirectly in capacity-intensive trouble shooting activities. Methodologies for design:

1. A literature search provided the basis for the framework.
2. Two methods have been applied to obtain measures of 'value'. First, a new method is developed, based on marginal value analysis and Analytic Hierarchical Processing [3]. Second, a combination of Failure Mode and Effect Analysis and Analytic Hierarchical Processing is applied to abstract the reasoning behind prioritization decisions, leading to a business-specific decision model.
3. A formal model has been developed from the highly dynamic and stochastic business environment and algorithms have been implemented in a tool to compare their performance in simulation runs.

Experimental Results

Scheduling algorithms

- *EXT*: Exact algorithm (based on expected value)
- *HEUR*: Heuristic algorithm (based on translation to Weighted Number of Tardy Jobs problem)

Dispatching rules

- *ROE*: Return on Effort heuristic (based on weight-per-time-unit)
- *MDD*: Modified Due Date heuristic (based on adapted version of modified due date [4])

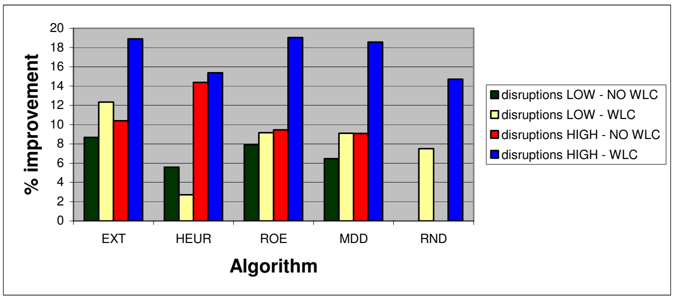

Figure 1 *Improvement w.r.t. random decision making* (RND)

Conclusions

1. Decisions at the strategic, tactical and operational level should be made explicit and communicated to the servers.
2. A correct value determination is indispensable for decision making. Two appropriate methods are proposed.
3. Combining the principle of selection (Work Load Control) with a consideration of the effect on the total set of tasks, turns out to be effective. Furthermore, the elimination and delay of disruptions will benefit the system due to a simplification of the online and stochastic scheduling problem and limited risks during execution.

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