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MASTER

Manpower capacity planning in the semiconductor industry

a case study : ASML process lab

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Manpower Capacity Planning
in the Semiconductor Industry
A Case Study: ASML Process lab

by

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ABSTRACT

During this master thesis a manpower capacity planning tool for the semiconductor industry was developed. Methods for workload and manpower calculations were designed as a result of a case study conducted in ASML Process lab, where the environment is mainly characterized by stochastic demand and make to order production. In addition, the research environment was modeled with System Dynamics and the suitability of System Dynamics simulation for manpower capacity planning in the semiconductor sector was discussed.

ACKNOWLEDGEMENTS

EXECUTIVE SUMMARY

Semiconductor sector is an example of the manufacturing sectors in which the volatility of demand is high. In addition to the high volatile demand, the semiconductor sector is also characterized by rapid advances in technology, which is another factor hampering the optimization of workforce because of the potential inequalities it causes in the knowledge level of different workers. Due to these characteristics of the sector, matching the production capacity with demand by the use of good manpower capacity planning strategies becomes one of the major concerns of the semiconductor companies.

This master thesis is as study of manpower capacity planning in the semiconductor industry, conducted with the help of the industrial partner ASML. A case study was conducted in ASML Process lab to develop a distinct manpower capacity planning tool.

The issues related with manpower capacity planning in ASML Process lab led to the following research assignment:

Design a tool that predicts the workload in a make-to-order production environment with stochastic demand, reworks and learning effects and that determines the necessary manpower capacity. Extend the tool with a suitable simulation approach for better insight on the problem and possible solutions.

The following research questions were formulated and answered during this research

1) What are the main factors that affect the workload in the manufacturing environment that is investigated during the research?
2) How to quantify the relationships between the workload and the influential factors?
3) How to design a tool that will convert the workload into manhours and that is easily adaptable to changing situations?
4) Is System Dynamics a suitable simulation approach to model the manpower capacity planning problem in such production environments?

Firstly, the factors affecting the manpower need of Process lab are investigated and a complex relationship structure, depicted in the following figure was observed.
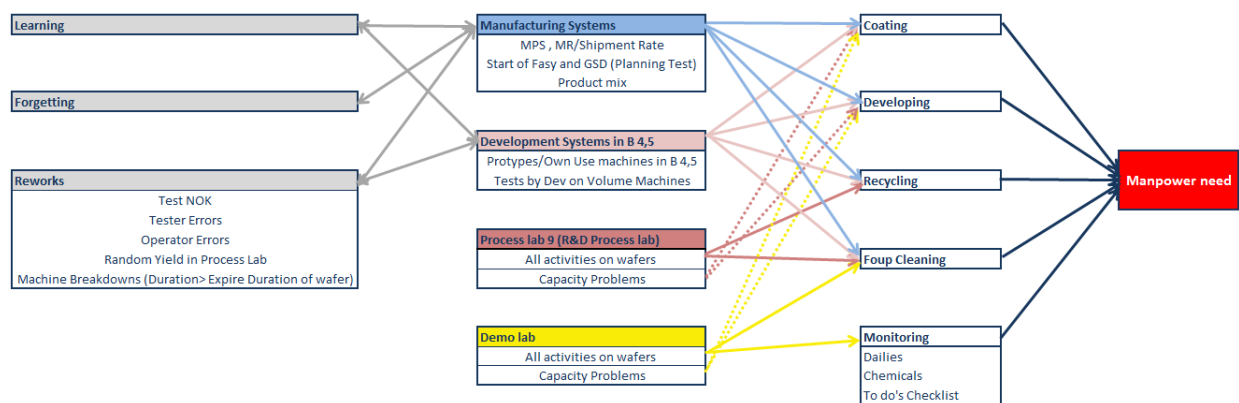
During the thesis a new method was formulated to calculate the coating and developing workload in the Process lab. This method uses Gantt-chart of wafers and the wafer usage parameters to calculate the expected wafer usage of the machines seen in the Gantt-Chart. Regarding the wafer usage of the machines no studies had been conducted before. This gap was closed with this thesis for each machine type, by using the historical records for the wafer usage of the machines. Following Figure summarizes the workload calculation method proposed in this chapter and displays the issues increasing the unpredictability of the wafer usage of machines.
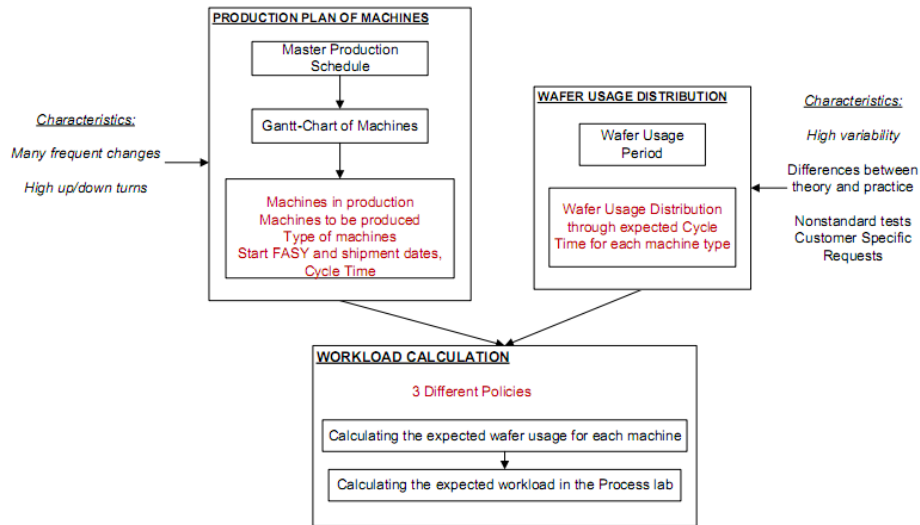
About the workload calculation in the Process lab it was concluded that the ***Move Rate cannot solely be a parameter in estimating the wafer usage of machines and the required manpower to process these wafers.*** The wafer usage distribution through the cycle time of the machine is not constant and it changes between the machine types. According to the different algorithms developed in this thesis investigating the relationship between the MR and the shipment rate, ***the wafer usage distribution is more affected by the shipments, since a big portion of the wafer demand is realized close to the shipment of machines.***

The manpower calculation method proposed in this thesis calculates the manpower need in terms of manhours. According to the observations in the Process lab *it was concluded that* **the manpower decisions in the Process lab should be based on the number of foups to be processed, not only on the number of wafers.** Therefore during this thesis a new method was developed to estimate the manpower need that uses the number of foups and the average order size as two important inputs. The time needed to process each foup with the required order size is calculated during the case studies in the Process lab.

Following the manpower calculations based on the estimated workload it was concluded that *the manhours need follow the same pattern as the workload on monthly level.* This is because the changes in duration of the work steps due to different order size are in terms of minutes, much smaller than months, and the effect of changes in the duration of these worksteps are negligible when aggregated to months

Our last research interest was seeking additional tools to more accurately represent the cause-effect relations between the important factors for manpower capacity planning in the problem environment. For this purpose a System Dynamics model was developed and the manpower planning problem in the Process lab was simulated. Three important feedback loops were identified in the system affecting the manpower capacity planning decisions, which can be called as Hiring, Firing and Training Lopps. The variables and the feedback structure are shown in the following figure.
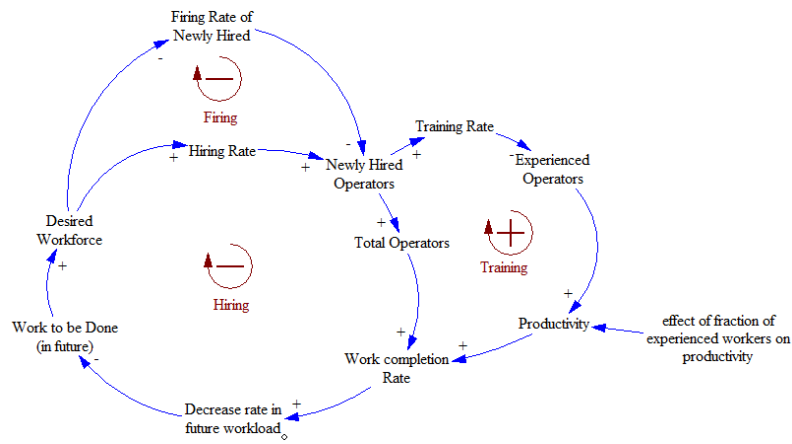
The validity of the system dynamics model was checked by comparing the simulated behavior of the workload with real historical data. It was concluded that the model the model successfully models the real system and it could be used for scenario analysis to understand the effect of changes in important variables on the manpower capacity decisions.

Considering this comprehensiveness of the system dynamics model and the interest of the managers at ASML in System Dynamics, it can be concluded that *more attention should be paid to employ System Dynamics simulation approaches in the semiconductor sector for manpower planning problems.* With this thesis we aimed to provide a basis for System Dynamic approach as a solution of the manpower planning problem in the semiconductor industry as an attempt to fill the gaps both in the literature and the industry about the application of System Dynamics simulation in the semiconductor sector. Therefore, this thesis provides a fundamental basis for future research on this subject.

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1. INTRODUCTION

Due to the high pace of change and economic instabilities in some markets, the optimization of the workforce level possesses a crucial role in many businesses today. This is especially true in the manufacturing sector since the "human component of production" is the most important and costly part of the supply chain (Gresh et al., 2007). The volatility of demand that is prevalent in some sectors increases the importance of having a good manpower planning strategy. Semiconductor sector is an example of the manufacturing sectors in which the volatility of demand is high. In addition to the high volatile demand, the semiconductor sector is also characterized by rapid advances in technology, which is another factor hampering the optimization of workforce because of the potential inequalities it causes in the knowledge level of different workers. Due to these characteristics of the sector, matching the production capacity with demand by the use of good manpower capacity planning strategies becomes one of the major concerns of the semiconductor companies.

The semiconductor sector consists of the integrated circuit (IC) fabrication and all related activities. As Çatay et al. (2003) pointed out, semiconductor manufacturing is one of the most complicated manufacturing processes. Production of a single wafer requires over 400 processes in different work centers, with more than one visit to some of the centers since the same operations are needed in order to build multiple layers on top of the wafer (Çatay et al., 2003). A flow chart illustrating a typical production sequence of wafer can be found in Figure 1. The number of arcs represents the number of revisits a wafer does to the work center during production.
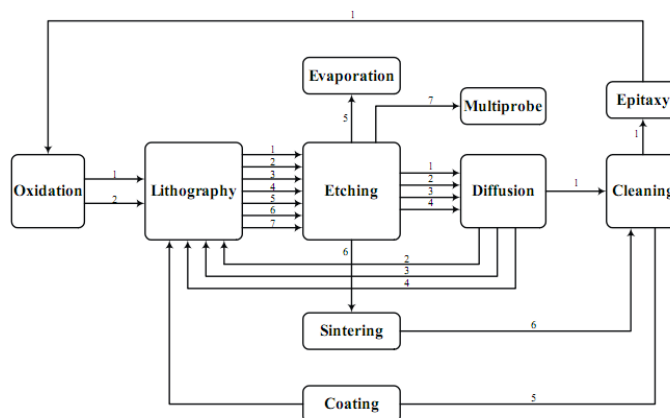
Figure 1: Simple silicon TTL integrated circuit process flowchart (Source: Çatay et al., 2003)

While the production processes in the semiconductor sector are so complex, requiring good production planning strategies, the rate of change in products and technology makes it difficult to have a good estimate of demand to use as an input for production planning (Swaminathan, 2000). Moreover, the random yield and reworks that by nature exist in the semiconductor manufacturing processes reinforce the unpredictability of the workload in a semiconductor company. All of these factors show the need for a good strategy to plan future capacity requirements and the difficulty of satisfying that.

The capacity of a manufacturing firm is composed of two different groups: **machinery** and **manpower.** The machinery used in the semiconductor industry is generally expensive, special purpose, designed and made to order equipments which require high investments in terms of finance and time (Sterman, 2000; Swaminathan, 2000). Hence in most cases the tendency is to invest in the manpower to cope with the need to make capacity adjustments, which has comparably shorter lead time of acquisition and operational costs compared to machinery.

This master thesis is as study of manpower capacity planning in the semiconductor industry, conducted with the help of the industrial partner ASML, the world's leading provider of lithography for the semiconductor industry (http://www.asml.com/). It aims at helping the semiconductor sector by providing new insights on manpower planning and by designing a manpower capacity planning tool. The effectiveness of this tool has been tested in real environment by a practical case study on a semiconductor manufacturing department.

The remainder of this chapter is organized as follows: Section 1.1 explains the motivation of this study by pointing out the gaps identified in the current literature. Section 1.2 introduces the research approach that is adopted during this master thesis. Section 1.3 clarifies the aim of the study and finally Section 1.4 presents how the remainder of this report is organized.

1.1. Motivation of the Research

The first task in this master thesis was to conduct an extensive literature review about manpower capacity planning in the semiconductor industry. During this literature review three different research areas, namely flexible manpower planning, learning and semiconductor industry, were investigated for relevant contibutions (Candar, 2010).

The review of current literature for manpower capacity planning revealed that the area of manpower planning in manufacturing is still an immature field of research. There are important gaps identified during the literature review for this master thesis, which point out new research possibilities related to manpower planning, learning and semiconductor industry. This section presents these gaps and explains the motivation behind this research.

From the literature review we have concluded that **the current state of art lacks studies that combine flexible manpower planning with make-to-order production and stochastic demand.** When we focus specifically on manpower planning in the semiconductor industry, which is highly characterized by stochastic demand, the notion of learning and forgetting also becomes important. The semiconductor sector is a high-tech, innovative sector. Hence the random yields, reworks, product and worker mixes are both expected to jointly result in learning and forgetting cycle. This situation directly

influences the cycle time, which is the most challenging factor in the competition between different semiconductor companies. Although the importance of learning is acknowledged by both the practitioners in the sector and the researchers, **there is no study yet that combines the flexible manpower planning problem with learning effects in the semiconductor industry.**

Existing studies about manpower planning in manufacturing are mostly conducted on request by specific firms and thus the model settings reflect the environment in which the problem is studied. However, **the literature still needs more case studies conducted in a semiconductor company.** Supporting this research with a practical case study contributes to reducing this gap and investigating the effects of demand uncertainty and high technology requirements in terms of their relation with manpower capacity needs of the semiconductor sector.

The literature review also revealed that the solution methods differ among the studies conducted so far about the manpower capacity planning problems. Mathematical modeling is by far the most preferred solution approach by the researchers to tackle with the problem of flexible manpower capacity planning in manufacturing. However, there are also opponents to the mathematical modeling method who emphasize the difficulty to apply it and to measure its performance in practical settings. They propose heuristics or simulation methods instead of mathematical modeling to deal with the problem. System Dynamics approach stands out as a new solution method that has high potential "to build computer simulations of complex systems, and to use these simulations to understand the structure and behavior of systems and to design more effective policies" (Sterman, 2000). It is also described as "a method to enhance learning in complex systems" (Sterman, 2000). Being a relatively new simulation approach, System Dynamics is a promising tool to bring a new angle of sight to dynamic problems. During this master thesis we aim at utilizing it to model manpower planning dynamics in semiconductor(-like) sectors. This way we contribute both to the System Dynamics and manpower planning literatures, since **there is no study yet modeling the manpower planning problem in the semiconductor industry with System Dynamics approach.**

Another gap identified in the current state of art on manpower planning area is that the flexible manpower planning in a manufacturing setting regards the workload in the problem environment as a direct function of demand for end products. However, in the semiconductor sector the workload is most likely to be affected by other factors. These might be either production related factors such as the different types of processes and associated rework rates and/or learning rates, as well as production unrelated factors such as cleaning the production environment, monitoring the equipment, etc. **The literature needs more studies that give recommendations on how to predict the workload of a semiconductor production unit by taking into account both the production related and unrelated factors and their combined effects on workload**.

With the new directions that the above mentioned gaps in manpower planning literature point out, the motivation for this master thesis has emerged: There is still room for further research in the literature on flexible manpower planning in the semiconductor industry, which takes into account both production related and production unrelated factors for a reliable workload estimation and for long term flexible manpower planning under stochastic demand, make to order production with random

yields, rework and learning effects. We intend to reduce this gap by the help of a practical study in the field.

The following section explains further the research approach followed during this master thesis and clarifies the reason to work with a partner from the semiconductor industry for the research.

1.2. Research Approach

As the literature survey pointed out, the manpower planning literature still provides interesting research opportunities. The semiconductor sector in particular offers a challenging research environment thanks to its fluctuating demand and long lead time characteristics, which require good planning tools and flexible capacity arrangements to be dealt with. Considering the limited number of studies conducted so far about manpower planning in the semiconductor industry, it can be asserted that in order to apply the relevant theories developed so far in the current state of art in manpower planning, a more thorough understanding of the semiconductor sector and the current state of practice is necessary.

This thesis aims at serving for the need of close cooperation between the academia and the industry to address the questions that arise in practice and to validate the theories of the academy on manpower planning in real life.

The case study during this master thesis has been conducted in cooperation with the semiconductor equipment company ASML. ASML is suitable for and quite interested in flexible manpower planning research since it is situated upstream in the supply chain of semiconductor production, which makes it obligatory to take measures against the so-called upturn and downturn demand situations. Focusing on a special production unit within ASML, called the Process lab, has made it possible to capture the effects of demand fluctuations better during the research with its unique characteristics. At the start of this master thesis, there were no tools used in ASML Process lab for manpower planning. Therefore, an academic research for a flexible manpower planning tool was supported also by the managers at ASML.

The following section explains the initial aim of the research and clarifies what is intended to reach as an outcome of this research.

1.3. Aim of the Research

The aim of this research is to provide a tool that can support the manpower planning decisions in the companies that operate in the semiconductor sector. After a thorough analysis of gaps in the current literature, discussions with the industrial partner ASML and first observations ASML Process lab, the initial goal of the research has been agreed as follows:

Design a tool for flexible manpower planning in an environment which is characterized by
- stochastic demand for multiple end products, which are mostly produced make-to-order
- unpredictability in the workload, caused by the unpredictability in demand and other factors not directly related to the demand

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- effects of learning and forgetting, where both the activities creating the demand and the processes to meet the demand are knowledge-intensive

The tool is not intended to be perfectly automated to work under all manufacturing scenarios and make the manpower decisions by itself, but rather to support management to see many of the relevant aspects to take into account when making the manpower decisions. In other words, during this thesis we seek to design an approach for flexible manpower capacity planning in the semiconductor industry and support this approach with the right tools. The planning tool is for long-term planning; day-to-day plans and decisions are not part of the purpose of this tool.

1.4. Thesis Outline

The remainder of this report is organized as follows: Chapter 2 presents the semiconductor industry, the company ASML and its role in the industry. It also gives introductory information about ASML Process lab, where the research settings for this master study were provided. Chapter 3 explains the research design by presenting the problem, the research questions and the scope together with the project deliverables and research steps. Chapter 4 presents the research environment, ASML Process lab, by mentioning important factors that were taken into account during the design of the Manpower Capacity Planning tool during this thesis. Chapter 5 explains the method used for estimating the workload in the Process lab. Chapter 6 presents the method proposed for converting the workload estimation in to the manpower capacity requirement. Chapter 7 discusses the suitability of the System Dynamics approach for manpower capacity planning in the semiconductor industry and provides the System Dynamics model for the manpower capacity planning model in ASML Process lab. Finally, Chapter 8 summarizes the conclusions of this research, gives recommendations and provides future research options.

2. INDUSTRIAL PARTNER OF THE RESEARCH: ASML

In this chapter we aim to provide information about the semiconductor industry, the company ASML and the specific production unit ASML Process lab which constitutes the research settings of this master thesis study. We first describe in Section 2.1 the company ASML and explain the challenge of manpower capacity planning in ASML, that results form the characteristics of the sector. Section 2.1.4 aims to list the important challenges that the Process lab faces in terms of manpower capacity planning and justifies our motivation to design a tool for manpower capacity planning in the Process lab during this project.

2.1. Company Description: ASML

2.1.1. Semiconductor Industry

The semiconductor sector is the sector consisting of the integrated circuit (IC, chip) fabrication and all related activities. Formed firstly around 1960s with the first fabrications of semiconductors, the semiconductor industry today represents the aggregate collection of companies engaged in the design and fabrication of semiconductor devices.

The most important features of the semiconductor industry can be listed as[1]:
- Very high intensity of research and development
- The role as technology enabler
- Maximal exposure to international competition
- Continuous growth
- Cyclical demand pattern with high volatility
- The need for high degrees of flexibility and innovation in order to constantly adjust to the rapid pace of change in the market

It is possible to make a distinction between the players in the semiconductor industry as the IC manufacturers and the supportive industries such as the semiconductor equipment manufacturing

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[1] Adapted from Karabash (2008)

industry where ASML has a significant role. The following subsection aims at introducing semiconductor equipment manufacturing and ASML's role in the industry.

2.1.2. Semiconductor Equipment Manufacturing and ASML

Semiconductor equipment manufacturing can be defined as a supportive industry for semiconductor manufacturing since it provides necessary machinery to produce ICs. As one of the world's leading manufacturers of semiconductor equipment, ASML designs, develops, manufactures, markets and services advanced systems used by the semiconductor industry to fabricate ICs.

ASML was founded in year 1984 and in 25 years it has made its way to global leadership in the semiconductor manufacturing sector. The charts displayed in Figure 2 show the major semiconductor equipment manufacturers and their relative market shares in years 1984 and 2009, followed by Figure 3 which depicts the steady increase of ASML's market share through years.

Figure 2: Major players in semiconductor equipment manufacturing in years 1984 and 2009
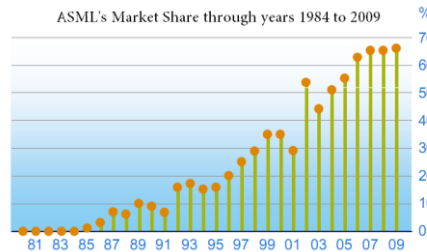
Figure 3: ASML'S market share through years 1984 to 2009

2.1.3. Customers of ASML and Their Use of ASML Products

ASML's customers consist of many of the major global IC manufacturers, among which Intel, Toshiba and Samsung are the most well-known ones, that provide the chips used in a wide array of electronic, communications and information technology products such as computers, mobile phones, MP3 players.

ICs are manufactured on silicon wafers. The structure of the transistors is imaged multiple times (20-30) on the wafer. ASML's customers use ASML machines during this "imaging" step. After various manufacturing steps, the projected images of lines are converted to real network of lines that are able to store electricity and information, completing the manufacturing of the chip. Appendix I gives detailed information about the manufacturing steps of chips and the use of ASML machines during chip manufacturing.

The three most important characteristics of a wafer scanner, like the machines produced at ASML, are: throughput, overlay and imaging (de Jong, 2008). Throughput determines how fast the wafer scanner can process wafers. Overlay determines how precise the alignment is between the layers of the lines exposed onto the wafers. The imaging capability is the minimal line width that can be imaged using the wafer scanner. The overlay and the imaging performance also affect the number of ICs that can be produced from a single wafer, by allowing more lines to be imaged with accurate and smaller images. The size of the wafer that is loaded into the machine, changing between 150mm, 200mm or 300mm in diameter, also determines the maximum number of ICs to be produced from a single wafer.

2.1.4. The Challenge of Capacity Planning at ASML

A major challenge that ASML faces comes together with the features of the semiconductor industry described in Section 2.1 and the technological requirements mentioned in Section 2.1.3.

The characteristics of the semiconductor sector, i.e. being shaped by the effects of high volatile demand, high-technology interaction subject to learning effect, random yields and rework, require the companies to have good capacity planning strategies operating in this sector. Being one of these companies, ASML mainly aims at flexible manpower strategies.

Having a large customer base of IC manufacturers makes ASML highly vulnerable to economic cycles and the up and down turns in the semiconductor sector. Besides, the goal of enhancing the throughput, overlay and imaging qualities and reducing the cycle time of production, require increasing complexity and new technologies to be developed. Nowadays, several new types of machines are developed, integrated and tested concurrently (de Jong, 2008). So, a big challenge for ASML is matching the production capacity with demand, which is difficult to predict, while trying to comply with the technological requirements and remain competitive in terms of cycle times.

This unsteady nature of the sector emphasizes the need of flexible management of capacity resources among which manpower could be named as one of the most important ones when the knowledge-intensiveness of the operations and the high level design requirements in manufacturing is considered. Hence, the production environment of ASML provides a suitable research setting during this master thesis project. The following section describes ASML Process lab, the manufacturing unit in which the research was conducted, by explaining its responsibility in the organization and by justifying the need to develop a distinct manpower capacity planning tool for it.

2.2. ASML Process Lab

2.2.1. Place of ASML Process lab in ASML Organization

ASML Processing and Metrology Unit contains the Process lab which provided the practical research settings during this master thesis. During this report, Process lab, Process lab 4 (because of its location in Building 4 of the ASML Veldhoven campus) and ASML Process lab will be used interchangeably.

Appendix II explains the organizational breakdown of ASML and shows the place of the Processing and Metrology Unit in the organizational chart.

ASML Process lab supports manufacturing of machines by providing wafers for the tests done on the machines during manufacturing. Detailed information about the operations in the Process lab will be given in Chapter 4.

2.2.2. The Need for a Distinct Manpower Capacity Planning Tool in ASML Process lab

In this section we present the reasons why a distinct manpower capacity planning tool is necessary in ASML Process lab. These reasons can be listed as follows, each of which will be explained in detail later on.

- Workload of the Process lab is not proportional to the number of machines.
- Technological improvements increase the unpredictability of the workload in the Process lab.
- Process lab's position in the semiconductor supply chain increases the effects of demand variability.
- Reworks and random yields increase the workload variability in the Process lab.

Workload of the Process lab is not proportional to the number of machines

The workload of the Process lab depends on how many wafers the machines on the production floor use for the tests and how this wafer use is distributed through the manufacturing cycle time of the machine. Therefore it is difficult to calculate the manpower need as a direct function of the number of machines to be produced.

Contrary to the situation described above, a common practice in the other manufacturing departments of ASML is calculating the manpower need by using the production start rate of the machines. This production start rate is referred with the term Move Rate (MR). MR is an important parameter for the manpower calculations of many manufacturing departments at ASML because the workload is directly related to the number of machines on the production floor, unlike the workload of the Process lab. For example in the test departments a ratio which shows how many workers should be present for each machine in the production (MMV: Abbreviation for Man to Machine Ratio in Dutch) is used and multiplied by the WIP to assess the manpower need. However, in the Process lab to come up with such a ratio based on the number of machines is more difficult.

The start of machines and the start rate (MR) are expected to have an impact on the wafer demand as well since the machines demand wafers after the modules are built and assembled. The effect of MR is acknowledged by the managers of ASML Process lab but whether there is a direct relationship between the Move Rate and the workload of the Process lab had not been analyzed before. It has been one of the interests during this research to investigate this relationship.

Technological improvements increase the unpredictability of workload in the Process lab

The responsibility of the Process lab is providing wafers whenever a test needs to be done on the machines with wafers during manufacturing. With the continuous R&D studies, ASML products are getting more and more complex with each new product launched. These design changes also have an impact on testing; changing the test sequences and making the test phase a stochastic process because it is unknown beforehand what faults are present in the system. Moreover, the actual duration of tests and in turn the cycle time of machines vary depending on the test strategies used (de Jong, 2008). Since Process lab is the material supplier for tests; this stochasticity results in the forecast difficulties in the demand and workload in the Process lab.

Process lab's position in the semiconductor supply chain increases the effects of demand variability

ASML Process lab may be considered as a supplier of the semiconductor equipment manufacturing firm (ASML, departments for machine production), which is a supplier of the semiconductor manufacturing firms. Considering the position of the Process lab on this chain, it is expected that the effects of demand change will be really dramatic in the Process lab since it is close to the upstream of the flow, which is supported by the term "Bullwhip Effect" in the supply chain theory. Figure 4 depicts this phenomenon graphically.
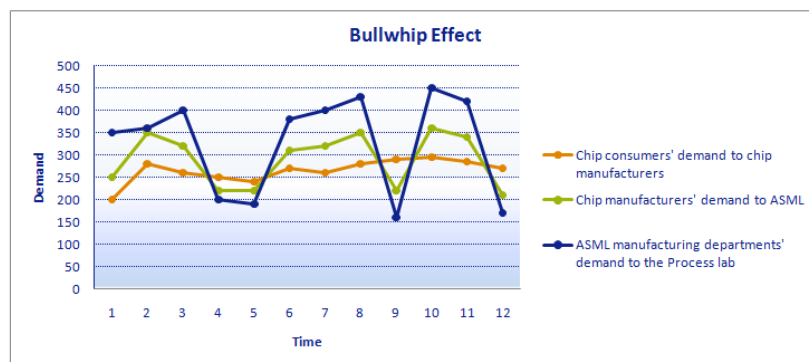
Figure 4: Bullwhip Effect on the Process lab

Reworks and random yields increase the workload variability in the Process lab

ASML operates in a high-tech sector, manufacturing complex machines. This results in reworks and repetitions in many operations during the manufacturing of the machines. For the Process lab the reason of the repetitions are two-fold either stemming from the Process lab itself or the manufacturing departments (the reasons due to worker errors in the Process lab or in the test departments, equipment problems in the Process lab or in the modules/machines produced in the production floor, etc). More explicitly, in the test departments the tests may result on rework, when the wafers needed for the test should be processed once again in the Process lab. Unfortunately, interviews with several departments at ASML showed that no data has been kept till now about the rework rate of separate tests in the sequence. This in turn adds to the unpredictability of demand in the Process lab, because it is unknown

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how many times a definite test will be repeated and how many times the wafer associated with that test will be requested. Similarly, in the Process lab itself also random yields and reworks are present, with the rework rates being unknown.

Taking into account all of the factors described above (disproportion between the workload and the number of machines, unpredictability of workload due to technological advancements, Process lab's position as a supplier, reworks and random yields) it can be asserted that the Process lab needs to have a distinct tool that takes into account the effects of other factors affecting the workload, which are specific to the Process lab and wafer production. The manpower planning tools that are used in the other manufacturing departments at ASML are not directly applicable to the Process lab since the factors affecting the workload and the manpower capacity needs are different in the Process lab than the other manufacturing departments.

These reasonings strengthened our motivation to design a distinct manpower planning tool for the Process lab during this master thesis research.

2.3. Conclusions

In this chapter we provided a background information about the company ASML and ASML Process lab, where the practical part of this master thesis was conducted. We explained the challenge of manpower capacity planning in the semiconductor sector and justified our reasons to conduct a case study in ASML Process lab.

The following chapter explains the research design, repeating the problem investigated during this research and indicating the research questions, scope and deliverables of this research.

3. RESEARCH DESIGN

In this chapter we explain the design of our research. In Section 3.1 we state the problem that we investigated and the solution that we aimed to attain as a result of this research. The problem definition is based on the literature survey results and the information and discussions provided in Chapters 1 and 2. In Section 3.2 we state the final research assignment and the research questions which we will answer in the later chapters of this report. In Section 3.3 we explain the scope of the research and justify our choice of the scope boundaries. In Section 3.4 we give a list of the deliverables of this master thesis study and in Section 3.5 we explain the steps that we followed to obtain these deliverables.

3.1. Problem definition

In Chapter 1 we have presented the gaps in manpower planning literature and our motivation for this research. After carrying on an intensive literature research and identifying the gaps in manpower planning literature, we have defined our purpose during this research as follows:

"There is still room for further research in the area of flexible manpower planning in the semiconductor industry, which takes into account both production related and unrelated factors for a reliable workload estimation and for long term flexible manpower planning under stochastic demand, make-to-order production with random yields, rework and learning effects. We intend to reduce this gap by the help of a practical study in the field, which is supported by simulation tools that have not been used in this area before."

With this research purpose in mind, the first weeks of the research was spent observing the work environment of the Process lab and sharing information with the operators there during the operations, by examining the demand databases of ASML Process lab and by making interviews with key personnel.

Following this initial research inside the organization and seeing the need for a distinct manpower planning tool, it was decided that ASML Process lab provides required settings for our research (See Chapters 2 and 4). The issues related with manpower capacity planning in ASML Process lab can be stated as follows, which leads to our problem definition for this research:

> *"Stochasticity is an inherent feature of the demand in the Process lab. This situation leads to the unpredictability of future workload, which results in the unpredictability of future manpower need. Due to the high volatile demand affecting the workload, ASML mainly aims at flexible worker recruitments. ASML Process lab has unique characteristics compared to the other manufacturing departments at ASML. Thus, the manpower capacity requirement plans applied in the other departments are not directly applicable to the Process lab.*
>
> *The lack of a systematic approach to identify the causes of changing the workload of the Process lab, to estimate the change in the workload and to convert this estimate into a flexible manpower recruitment plan was visible at the beginning of this research. This constituted the main research problem of this master thesis and a need for a special tool for manpower capacity planning was acknowledged. The tool is expected to forecast the wafer demand of the machines with a good accuracy and to convert this demand information into the manpower capacity need in terms of worker hours. In addition to the design of the tool, suitable simulation approaches should be investigated to model the problem and to extend the features and results of the tool."*

3.2. Research Questions

According to the research problem, the research assignment and the related research questions were formulated as follows:

Research Assignment: Design a tool that predicts the workload in a make-to-order production environment with stochastic demand, reworks and learning effects and that determines the necessary manpower capacity. Extend the tool with a suitable simulation approach for better insight on the problem and possible solutions.

Research Questions:

1) What are the main factors that affect the workload in the manufacturing environment that is investigated during the research?
    a) What is the definition of the overall workload?
    b) What are the factors affecting the workload?
    c) What is the relationship between the workload and the MR (Move Rate, number of machines started to be produced per week), Master Production Schedule (MPS), and production unrelated factors?
2) How to quantify the relationships between the workload and the influential factors?
    a) What is the effect of the production plan on the workload?
        i) How does the demand of wafers vary over cycle time of a machine?
        ii) What is the effect of the product mix on the workload?
    b) What should be the formulas expressing the relationships between the factors, MPS and the workload?
    c) Which performance measures should be considered for the successful design of the tool?
3) How to design a tool that will convert the workload into manhours and that is easily adaptable to

changing situations?

4) Is System Dynamics a suitable simulation approach to model the manpower capacity planning problem in such production environments?

It is noteworthy to state here once again that this research assignment was carried in ASML Process lab, employing a case study approach. Thus, the research questions reflect the specific problem and solution steps for ASML Process lab manpower capacity planning. In this respect, these questions were answered during this research specifically for ASML Process lab, with general recommendations when possible that can be utilized by other researchers working in similar research environments. Interested readers can refer to Appendix III to see the similarities and differences between ASML Process lab and ordinary semiconductor companies. Similarly, Appendix IV provides a comparison of the Process lab with other manufacturing departments at ASML.

3.3. Research Scope

During the research only the demand formed by four types of machine families were considered as main product families. These machine families are the XT19x0, NXT19x0, XT14x0 and XT8x0. Appendix V explains the naming system for the ASML products and provides the breakdown of ASML products into machine family categories. These machine types are chosen because they recently form the majority of the machines produced and expected to form the majority in near future also. Appendix VI shows that the share of these machines among the machines shipped since year 2008 changes between 87.5% and 100% and that it is not expected to drop below 88% in the near future.

The shift design in the Process lab is not included in the research scope. The reason for not directly including the shift design was twofold. Firstly, during the literature review it was seen that work scheduling and roostering is an area as large as the ones that were chosen to be examined during this research, namely Workforce Planning, Learning and Semiconductor Industry areas (Candar, 2010). In order to narrow down the project scope, the shift design and work scheduling literature were not reviewed during the literature survey and left out of scope during the master thesis as well. Secondly, the main goal of this thesis is to design a tool for long term planning. Working on a shift structure would require assessing the distribution of the requests during a day, which implies an operational planning. The manpower needs that will be given as output of the tool designed for this project can be used as an input to the scheduling decisions, but we leave this concept for a future research.

3.4. Research Deliverables

The deliverables of this master thesis will be:

- An extensive literature review for Manpower Capacity Planning in Semiconductor Industry, which combines the areas of Workforce Capacity Planning, Learning and Semiconductor Industry (Candar, 2010)
- An overview of the factors changing the workload in the problem environment
- Recommendations on measurement of the effect of factors important in manpower capacity need calculation (data management and formulation)

- o Algorithms and source codes written in Visual Basic to get the average wafer usage information for each machine type
- o Detailed analysis of demand databases, pointing out issues and enhancement options to keep more reliable data
- A Capacity Requirements Planning (CRP) tool for flexible manpower capacity planning, adaptable to changing situations
  - o Different approaches for converting the Master plan of machines into the wafer use with comparison of results
  - o Algorithms and source codes written in Visual basic to get the manpower need
  - o A manpower capacity planning tool to use with different type of machines and demand mix
- Performance analysis of the tool (based on the agreed performance measures, adaptability and continuity)
- System Dynamics simulation model for manpower capacity planning in the semiconductor industry (based on the case study conducted in ASML Process lab)
- Master Thesis report

3.5. Research Steps

During this research, the regulative and reflective cycles defined by van Strien (1997) and van Aken et al. (2005) have been used as a roadmap for design steps. The research plan was created independently and revised continuously according to the results of interviews, demand data analysis and brainstorm sessions with the thesis supervisors to create a successful design of a manpower planning tool. Figure 5 shows the steps followed during the research.

The Design Part, which is the focus of this master thesis study is shown by the dashed box, in which the problem mess and problem definition phases are shown in grey because they have already been explained in the previous sections of this report. The analysis and diagnosis step is the part where the relevant quantitative and qualitative research methods are used. The plan of action steps contains the design of the possible solutions to the problem, i.e. the design of a manpower capacity planning tool in our case. The intervention phase is the implementation of the solution tool and the following steps are associated with the results of this implementation. Due to time restrictions, only insights about the implementation will be given during this master thesis and evaluation of planned improvements will remain out of scope.

Figure 5: Design steps followed during the research

4. CASE STUDY ENVIRONMENT: ASML PROCESS LAB AND IMPORTANT FACTORS FOR MANPOWER PLANNING

This chapter gives more detailed information about our case study environment: ASML Process lab. In this chapter we aim to provide the necessary background to understand the logic behind the manpower capacity planning tool designed during this thesis. Therefore we first provide information about the machinery equipments and the workforce in the Process lab in Section 4.1, since they are the two sources of capacity affecting our manpower planning tool. Section 4.2 gives introductory information about the operations in the Process lab. During this research we only focus on the coating and developing operations, during which the wafers are processed and made ready to be used in the tests. In Section 4.2 we provide further reasoning for excluding the other operations from the scope of the research. Section 4.3 mentions the different customers of the Process lab and their effects on the workload. Following all these information we summarize the important factors and relationships affecting the workload of the Process lab in Section 4.4. Section 4.5 evaluates the current way of manpower capacity planning in the Process lab according to the findings of Section 4.4. Lastly, Section 4.6 provides the concluding remarks for this chapter.

4.1. Machinery, Equipment and Workforce in the Process lab

ASML Process lab is responsible for providing wafers for the manufacturing of machines within ASML. A **wafer** is a thin slice of semiconductor material, such as a silicon crystal, used in the fabrication of integrated circuits and other micro devices. Figure 6 shows a pile of silicon wafers.

Figure 6: Silicon wafers

As mentioned in Section 2.1.3, the size of the wafers can change between 150mm, 200mm and 300mm in diameters. The use of 150mm wafers and 200 mm wafers has been gradually decreasing in the semiconductor industry during the last years, while the use of 300 mm wafers has been increased. Table 1 shows the distribution of the wafer sizes used by ASML machines during manufacturing, through years 2008 to 2010. It is seen that the use of 300mm wafers is increasing with shares higher than 95%. This is a direct reason of the fact that the increasing throughput requirements mentioned in Section 2.1.3 favor the use of larger wafers.

Table 1: Percentage of wafer sizes requested to ASML Process lab 4 in years 2008, 2009, 2010

size	Years 2008 Count of size	2009 Count of size	2010 Count of size	Grand Total Count of size
150	0,13%	0,16%	0,07%	0,12%
200	4,08%	3,54%	2,43%	3,46%
300	95,78%	96,30%	97,50%	96,42%
Grand Total	100,00%	100,00%	100,00%	100,00%

Stocking, handling, processing, testing and measuring of wafers are always done while the wafers are placed within special plastic boxes. These boxes are called foup (Front Opening Unified Pod), which are boxes that can contain at most 25 wafers. The wafers continue their journey within ASML in the same foup. So it can be said that no wafer travels on the production floor outside the foup. Figure 8 shows a foup with wafers placed in it. The machines that are used in the Process lab for coating and developing the wafers are called **track**s. Figure 7 shows a track with foups loaded on it.
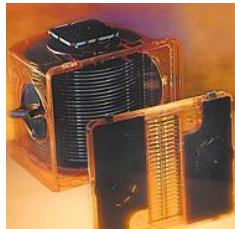
Figure 8: Foup with wafers

Figure 7: Track with foups

Within ASML the term "**operator**" is used to refer to the workers who conduct the daily operations in the Process lab. We also chose to use the same term in this report to refer to the workers inside the Process lab. It is possible to distinguish two types of workers in the process lab as new hires and senior operators. Throughout this report we use the terms "newly hired operators", "new operators" and "inexperienced operators" interchangeably to refer to the new hires. Similarly we sometimes use "experienced operators"" to refer to the senior operators.

The difference between the two types of operators is that new hires need to go through a training period to get the necessary knowledge and skills. The training period is about 3 months, during which the new hires are trained under the supervision of a senior operator on different type of operations. At the end of the training period the new hires have to pass both a theoretical and a practical exam in order to work without direct supervision of a senior operator. **During this master thesis we assume that all new hires become experienced workers as soon as their training period is completed.**

4.2. Description of the Operations Creating the Workload in the Process lab

This section aims to present the main operations creating the workload in the Process lab. These operations can be listed as: Coating, Developing, Recycling, Foup Cleaning and Monitoring. During this thesis we are mainly interested in the Coating and Developing operations since these are the operations during which the wafers are "processed" and the other operations are conducted mainly to continue the

flow of wafers inside the organization. Section 4.2.1 and Section 4.2.2 provide brief information on coating and developing operations, respectively. Recycling, Foup Cleaning and Monitoring operations are introduced in Section 4.2.3 with our reasons for not directly including these operations in the manpower capacity planning tool designed during this research. The detailed descriptions for all of the operations can be found in Appendix VII.

4.2.1. Coating

The process of covering the wafer with layers of chemicals is called **coating**. Coating enables the wafers to be exposed in the lithographic process. During the lithographic exposure the patterns of the chip are formed by removing some parts of the chemicals on the wafer thanks to the reactiveness of the chemicals to light. The wafers on which chemicals are applied are called **coated wafers**. Sometimes the tests do not require the wafers to have any chemicals on it. Wafers without chemicals are called **bare wafers**. Bare wafers are generally used for cleaning or measurement purposes inside the machines during the tests.

Because of the chemical sensitivity of the coating materials, the coated wafers have very short expiry durations, usually a couple of hours, and they must be used in the tests before they expire. During ordering the wafers the testers specify what time they will use the wafers in the tests and the wafers are prepared in the Process lab such that they will be ready just before the specified test time. The coating orders are made with very short lead times by the test departments (less than half an hour 42% of the time, See Appendix VIII). This is because of the fact that the test sequences and number of repetitions of the tests vary during manufacturing and also that there are many possible combinations of chemical layers to be applied on the wafers. These complicate the estimation of the wafer demand, changing the timing of the need for specific tests and combination of coating materials. In short, coating is a make-to-order process.

4.2.2. Developing

After exposing to light during the tests, the coated wafers are brought back to the Process lab for developing (Bare wafers are not developed after the tests). Developing is a baking process after which the patterns on the wafer become visible and further reactions of the chemicals against light are prevented, protecting the shape of the images on the wafer. After developing the wafers are not vulnerable to light anymore. So, developing should be done as soon as possible after the tests are completed in order to prevent the chemicals on the wafer from getting distorted.

Sometimes the tests require that after developing, the wafer is used for another step of the test in the machine and after this step is completed the wafer is developed again. In other words some wafers can be developed multiple times. The test may result negative in any of these steps. In this case the whole test is repeated from the beginning, by requesting new wafers to be coated for the same test. This situation also increases the complexity of estimating the workload since the number of repetitions, both in the tests and in the number of developing steps required, is not completely known beforehand.

4.2.3. Recycling, Foup Cleaning and Monitoring Operations

Recycling is the process during which the chemicals on the wafers are removed and the wafers are made ready to be used in other tests. The foups also need to be cleaned occasionally to remove any particles that may harm the processes. We collect all the other operations in the Process lab under the name of Monitoring. Monitoring include operations like checking if the tracks work accordingly, checking the level of the chemicals in the tracks, general cleaning activities, etc.

In our tool we decided not to include the Recycling and Foup cleaning operations directly due to lack of time for observing all aspects of the workload in the Process lab. The workload of the monitoring activities is somewhat fix per time period and the necessary manpower need for monitoring activities has already been estimated by the Processing group. Therefore, during this thesis the Monitoring operations are also left out of the research scope.

4.3. Customers of the Process lab and Their Effect on the Workload of the Process lab

As we have mentioned before, Process lab's responsibility is supplying wafers during the test phases of the machines. So the machine manufacturing departments are the main customers of the Process lab. During this thesis we will distinguish two types of machines (systems), namely Manufacturing Systems and Development Systems.

Manufacturing Systems are the machines that are produced after the proto type machines are completed. Manufacturing Systems include the following types of machines:

- pilot machines
- the machines produced after the machine type is released for volume (volume machines)
- the machines that were previously inside ASML for own use (R&D or training purposes) but later handed in to the production departments to enter the same process as volume machines

We can say that Manufacturing Systems are generally produced to be shipped to an end customer. Since the machines have a definite test sequence during manufacturing, the tests to be conducted on the same machine types are expected to be similar. What differs is:

- the cycle time of production (due to learning curve and upturn/downturn situations)
- the repetition of tests (due to reworks)
- test sequences because of customer specifications (tests to be conducted on the machine specifically requested by the customers before the shipment)
- way of working among the testers (changing tests sequences or ordering different amount of wafers for the same tests)

All of these differences among the Manufacturing Systems increase the variability in timing and the amount of wafer requests for the tests.

We refer to the prototypes and other own use machines that are used for research and development or training purposes inside ASML as Development Systems. Development Systems have higher cycle time of production compared to the Manufacturing Systems and their test planning and wafer use are even less predictable than the Manufacturing Systems. The reason for the higher unpredictability of wafer usage for the Development Systems is that there is not a definite sequence of tests for these machines. The tests to be conducted on the Development Systems are determined and announced in weekly meetings and the wafer need estimation of these machines are done following these meetings.

It has also been observed that even when a machine is being produced for volume, sometimes the machine can stay idle in the production because the testers do not start a test that might not finish until their working sift is completed. In this case, the personnel from the R&D departments may conduct some tests on the Manufacturing Systems for their own studies. This practice influences the unpredictability of wafer use of Manufacturing Systems as well.

The numbers in Table 2 show the relative amount of coating requests for development and volume production purposes. We can interpret these numbers as follows: In a downturn the relative amount of research and development activities increases compared to the volume production activities, which decreases because of the decrease in the end customers. Year 2009 was a downturn in the semiconductor industry because of the economic crisis. The effects of this downturn can be seen in the decrease in the number of machines shipped in that year (See Appendix IX) and also in the relative increase in the research and development activities (Table 2). In the upturn periods however, this distribution seems to be more stable with around 23% research and development activities and 77% volume production activities. Due to lack of historical data it is not possible to trace back more upturn and downturn periods to see if this pattern is true in longer time span.

Table 2: Relative amount of coating requests for development and volume production purposes

Department	Years			
	2008	2009	2010	Grand Total
	Count of order	Count of order	Count of order	Count of order
DEVELOPMENT	23,49%	35,76%	23,21%	27,15%
VOLUME	76,51%	64,24%	76,79%	72,85%
Grand Total	100,00%	100,00%	100,00%	100,00%

Process lab 4 provides wafers both to the Manufacturing Systems and to the Development Systems that are built in Building 4 and 5 of the Veldhoven campus of ASML. In addition to these machines, ASML Process lab has two other customers, namely Development Process lab and Demo lab. Development Process lab is responsible for satisfying the wafer demand of the research and development machines in other buildings. Demo lab is responsible for demonstration of how the machine works to the customers. These two labs have their own tracks for wafer processing but in case they run out of capacity they use the tracks in Process lab 4 for their coating and developing activities.

In addition to developing and coating, Process lab 4 is responsible for the recycling of wafers and the cleaning of the foups inside whole ASML production facilities since it is the only location in ASML that has the recycling and foup cleaning machinery.

4.4. Factors to be considered in Manpower Capacity Planning for ASML Process lab

In the previous sections we explained the workload of the Process lab consists of different operations and we can distinguish them as coating, developing, recycling, foup cleaning and monitoring. We also mentioned that this workload is affected by the activities of different customers. In addition, we emphasized the importance of learning/forgetting and reworks in a semiconductor industry, which also applies to the activities of the customers of Process lab affecting the workload in the Process lab.

In this chapter we aim to summarize these relations by the help of a visual diagram. By this, we provide answers for our first research question: We define the workload of the Process lab in terms of different operations and explain the relationships between the factors affecting the workload and these different operations.

To depict these relations visually we first formed a table representing these relations (Table 3). Table 3 provides a neat representation of the complex relations affecting the workload of the Process lab[2]. This complexity is clearly seen in Figure 9 that represents the same relations schematically.

In Figure 9, if there is a solid line between an operation in the Process lab and the customer, this means that the workload for that operation is directly affected by the activities regarding that customer. The dotted lines however, depicts that there is occasionally a relation between the two. These two different relation types are shown by "continuous direct relation" and "discontinuous direct relation" in Table 3. To limit the complexity in Figure 9 we only show the relations that directly affects the workload of the Process lab. Other factors which may indirectly affect the workload in the Process lab are present but not included in our representation. For example, learning effects influence duration of the research and development tests on a development machine. If the machine is in Building 4 or 5 this effect is directly included. However if this machine is in Building 9, the tests on it influence the activities of the Development Process lab, which affects the workload of Process lab 4. In Figure 9 we do not directly show the relation between the learning effects and the machines in Building 9. However we include the relations between the Development Process lab and the Process lab 4. A similar example can be given for the relations regarding the reworks on the development machines.

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[2] In this table, on the upper right corner of the cells, we assigned a number to each relation. The explanation of each relation shown in the table (and in the schema) can be found in Appendix X.

Legend:

√	Continuous direct relation
◊	Discontinuous direct relation
☐	No direct relation

Numbers in the upper right corner of cells are used as reference for the explanations of the relations

Manpower need		Manufacturing Systems in B 4,5	Development Systems in B 4,5	R&D Process lab (Process lab 9)	Demo lab	
		√ [1]	√ [2]			Learning
		√ [3]				Forgetting
		√ [4]	√ [5]			Reworks
	Coating	√ [6]	√ [7]	◊ [8]	◊ [9]	
	Developing	√ [10]	√ [11]	◊ [12]	◊ [13]	
	Recycling	√ [14]	√ [15]	√ [16]	√ [17]	
	Foup Cleaning	√ [18]	√ [19]	√ [20]	√ [21]	
	Monitoring					

Learning

Forgetting

Reworks
Test NOK
Tester Errors
Operator Errors
Random Yield in Process Lab
Machine Breakdowns (Duration> Expire Duration of wafer)

Manufacturing Systems
MPS , MR/Shipment Rate
Start of Fasy and GSD (Planning Test)
Product mix

Development Systems in B 4,5
Protypes/Own Use machines in B 4,5
Tests by Dev on Volume Machines

Process lab 9 (R&D Process lab)
All activities on wafers
Capacity Problems

Demo lab
All activities on wafers
Capacity Problems

Coating

Developing

Recycling

Foup Cleaning

Monitoring
Dailies
Chemicals
To do's Checklist

Manpower need

Figure 9: Schematic representation of the relations between the factors affecting the workload of the Process lab

4.5. Evaluation of Current Way of Manpower Capacity Planning in the Process lab according to Important Factors for Manpower Planning

It has been mentioned before that there is no systematic tool used for Manpower Planning in the Process lab. According to the increase/decrease in the Move Rate (number of machine starts per week), the Processing Group determines to increase/decrease the number of Operators in the Process lab. Detailed information about the current way of manpower capacity planning in the Process lab can be found in Appendix XI.

When this current practice is evaluated in terms of the relations identified between the factors affecting the workload in the Process lab (Table 3 and Figure 9), it is seen that some important factors and relations identified are not taken into account. More specifically, with the current strategy, the planning of manpower is done only based on the information about the number of machines on the production floor. However, it has been identified that the timing and amount of the wafer usage is more important to calculate the workload and the manpower need in the Process lab. Learning/forgetting and reworks in the tests all affect the timing and the amount of wafer demand. These in turn affect the cycle time and distribution of the tests during the cycle time of the machine, which are not reflected by the Move Rate alone. What is more, Move Rate cannot provide information about the machine types and the product mix, which is another important consideration for the manpower planning in the Process lab, since the wafer usage of the machines are expected to be different between different machine types. Therefore, a more systematic design of a tool is necessary which can capture more relations affecting the workload in the Process lab. During this research, we aimed to include as many influential factors and relations as possible, which are represented by Table 3 and Figure 9 in the previous section.

4.6. Conclusions

In this chapter we presented the Process lab and identified the important factors that should be taken into account in manpower capacity planning. Thereby we found answers for our first research question, which was about definition of the workload in the Process lab, identification of the important factors for manpower planning and their relations.

The overall structure of the relations identified between the important factors (depicted in Figure 9) exhibits the complexity of the workload estimation and calculating the manpower capacity needs in the Process lab. While identifying these relations we benefited from the findings in literature, the interviews in ASML, both in the Process lab and the customers, and the wafer demand databases. This first step of the research is important in the sense that there were no studies done before in the Process lab that displays explicitly such a comprehensive relationship structure to be considered in the manpower decisions. Additionally, it provides a solid base during this research for the design of a new manpower planning tool for the Process lab.

5. WORKLOAD CALCULATION METHOD

In the previous chapter we have provided a schema showing the relationship structure between the influential factors for manpower capacity planning in the Process lab. With that schema, we have found answers for our first research question. Our second research question was about the calculation of the coating and developing workload in the Process lab. The following information is necessary in order to calculate the total workload of the Process lab during a specific time period:

- The number and the type of machines on the production floor in that specific time period
- Start and finish time of the period during which these machines are expected to demand coated or developed wafers from the Process lab.
- Distribution of the wafer demand during this period both for coating and developing

This information can be acquired by combining the production plan of the ASML machines and the expected wafer usage distribution of each machine. In Figure 10, which explain the method of workload calculation proposed in this thesis, these two are shown as two inputs for the workload calculation, together with the causes that increase unpredictability of workload.
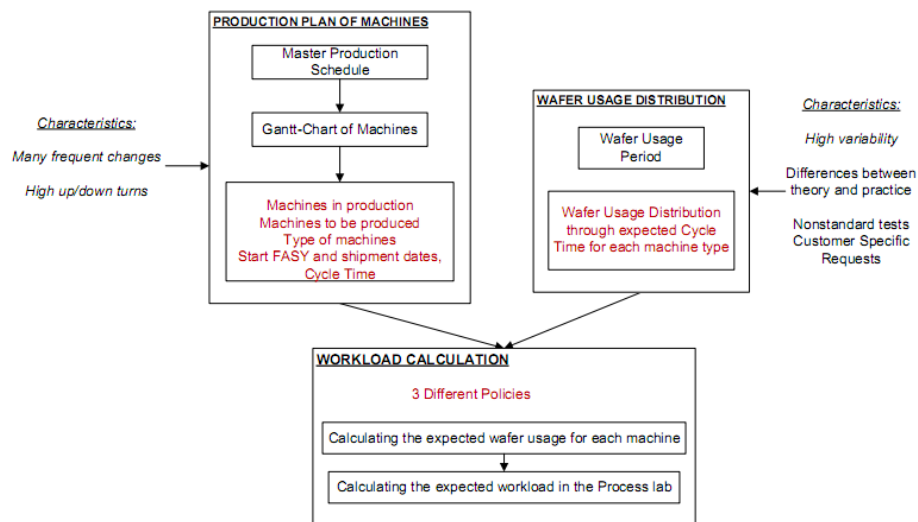
Figure 10: Flow of the Proposed Workload Calculation Method

The remainder of this chapter aims to describe the workload calculation method by following the flow shown in Figure 10. Firstly in 5.1, production planning of the ASML machines is described and the reasons to use the production plan as an input for workload calculation of the Process lab are explained. In Section 5.2 the method to obtain the expected wafer usage distribution is explained. In Section 5.3 the method of estimating the total workload by combining the Gantt-Chart and the wafer usage distribution of the machines is explained.[3]

5.1. Production Plan of Machines at ASML

It was explained that the responsibility of the Process lab is providing wafers for the tests done on the machines. Therefore in this thesis it was decided to use the Production Plan of the machines to get information about the expected time in the future that each machine will order wafers from the Process lab (first input in Figure 10). Therefore in this section we first explain the manufacturing phases (Section 5.1.1), then we explain the production plan and Gantt-Chart of machines that is used to see the timing of the manufacturing phases (Section 5.1.2). Lastly we provide the reasons to use the Gantt-Chart of machines as an input to the workload calculation of the Process lab (Section 5.1.3).

5.1.1. Manufacturing Phases of ASML machines

In general the manufacturing phases of the ASML products follow the sequence shown in Figure 11. First different modules of the machine such as lens and wafer stage are assembled (Assembly (ASSY) Phase). Then these modules are brought together and assembled into the whole machine (Final Assembly (FASY) Phase). The day that the Final Assembly phase starts is referred using the terms "Start (of) FASY". The machines then undergo different tests to determine if they work as required (TEST Phase). After the tests are completed with Final Acceptance Test (FAT) and the customer agrees on shipment of the machines, the machines are disassembled, packed and shipped to the customers. (PREPACK and SHIPMENT). The Goods flow Shipment Date (GSD) shows the date that the shipment starts.
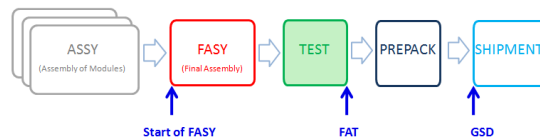
Figure 11: Manufacturing Phases of ASML machines

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[3] The Manpower Capacity Planning Tool developed during this thesis uses the methods that are described in Sections 5.2 and 5.3. The structure of this tool is designed specifically for ASML Process lab. During the remainder of this chapter, interested readers are referred to the relevant Appendices for more details about the tool developed for Manpower Capacity Planning in ASML Process lab.

5.1.2. Master Production Schedule (MPS) and Gantt-Chart of machines

We refer to the production plan at ASML as the masterplan or Master Production Schedule (MPS) in this report.

The masterplan shows all information available about the machines, such as the machine number, machine type, customer and Planned/Actual dates of Start FASY, GSD etc. ASML TEST department forms a Gantt-Chart by using MPS as an input to determine the planning of the tests. Since Process lab's main responsibility is supporting the machine production during the tests, it was decided to use the same Gantt-Chart to obtain information about the timing of tests during this research as well. The detailed explanation of using Gantt-Chart as an input for manpower planning in ASML TEST department can be found in Appendix XII. This Appendix also compares the purpose of using the Gantt-Chart to calculate the workload and manpower need of the Process lab with that of the TEST department. The main difference is that for calculating the workload of the Process lab, Gantt-Chart itself is not enough and it should be combined with the wafer usage distribution.

Gantt-Chart of Tests is a separate table formed by extracting the required data for manpower calculations from the masterplan. It shows the machine number, machine type, customer, Start of FASY, FAT and GSD dates, together with the planned cycle time of the machines. One by one for each machine in the masterplan these information are extracted and a Gantt-chart for production is formed. A representative display of the Gantt chart is given in the following figure.

Figure 12: Gantt-Chart of Machines

In the Gantt-Chart weeks highlighted with red show the FASY weeks, weeks highlighted with green show the TEST weeks, turquoise shows the Prepack and the light blue shows the GSD week. Dates are represented by using the ASML date representation, where last two numbers show the week number and the first numbers show the year (e.g. 1027 means the 27th week of 2010). The timeline of the Gantt-Chart encompasses two planning years, starting with the first week of the current year and ending with the last week of the coming year (first row in Figure 12).

The following subsection justifies further our choice of using this Gantt-chart for manpower capacity planning for ASML Process lab.

5.1.3. Reasons for using Gantt-Chart of Tests for Process lab Manpower Capacity Planning

- In the Gantt-Chart, the type of the machine, the Start Date of FASY and GSD are available for each machine in a planning horizon of 2 years. Cycle time information is visible for each machine and the algorithms about the calculation of cycle times, by which the Gantt-Chart is formed, already enable the learning curves to be included in the planning.
- It is possible to see week by week which machines will be on the production floor. Hence, regarding a specific week in the planning horizon, it is possible to calculate how many weeks it has been since the machine is started to be produced and how many weeks have left for it to be shipped to the customer. This way, it is possible to introduce the wafer use information through the cycle time of the machine after this information is calculated using the demand databases in the Process lab.
- The Gantt-chart of Tests is regularly updated with each update of the MPS. Consequently it ensures that the manpower planning tool for the Process lab can be easily updated when this plan is introduced as a basis to the tool.

One drawback of this planning information for the test departments is that, it lacks information about the prototype machines which also affects the workload in the Process lab. As it was mentioned in Section 4.3, in addition to the wafer demand of the Manufacturing Systems, Process lab 4 is also responsible for meeting the wafer demand of some Development Systems, including the prototype machines produced in Buildings 4 and 5. The interviews at ASML revealed that the timing of tests for the prototype of machines is not available on long term. The planning of these tests is done on weekly basis and there is no tool that conveys this information to Process lab 4. Similarly for the coating and developing requests that are created by the Development Process lab and Demo lab, there were no resources to estimate them. However, compared to the demand from the manufacturing systems the demand from these machines is regarded negligible. Due to the tradeoff between time and added value of additional data about the wafer demand of prototype machines, Development Process lab and Demo lab, it was decided not to include estimation of their demand in our scope and it was left for future research.

The following section explains the wafer demand distribution, the second input for the workload calculation method.

5.2. Wafer Demand Distribution of Machines through Cycle Time

In the Gantt-Chart of the machines only the start and finish of production of the machines can be seen. In order to calculate the workload of the Process lab, we need to know how the wafer usage of the machines will be during this cycle time of each machine seen in the Gantt-chart. This was a challenging task during the thesis because the variability of the wafer usage is high between each machine. This is because of the high technology requirements of the machines which result in high variability in the number of tests conducted on the tests, the cycle time of machines and

different requirements from the end customers for additional tests. Even though there is high variability in the wafer usage of each machine, it is still necessary to come up with a standard wafer usage distribution that can forecast the wafer usage of machines with good accuracy in order to calculate the total workload of the Process lab in future.

The interviews at ASML about the wafer usage of machines revealed that the wafer usage of a machine generally varies over its cycle time. The general idea was that the number of wafers used for a machines increases when the machine is close to shipment, because of the specific requests of customers and the complexity of tests requiring more wafers and resulting in more reworks. However, these comments were based on experience of the individuals, not on a thorough analysis with wafer demand data of the machines. During this research we aimed to satisfy the need for a comprehensive analysis about the wafer usage of machines. Therefore we sought answers for the following questions:

1) In which portion of the cycle time do the machines expected to use wafers? (When do the machines start (finish) ordering wafers compared to the Start of FASY (GSD)? (Section 5.2.1)
2) Is the monthly/weekly wafer usage of a specific machine constant or does it change from the day of first wafer usage till the day of last wafer usage? (Section 5.2.2)
3) How does the wafer usage vary over the cycle time of a specific machine type? (Section 5.2.3)
4) Does the wafer usage vary between the machines from the same machine type (Section 5.2.3)
5) Does the wafer usage vary between different machine types? (Section 5.2.3)

The wafer demand databases of Process lab were used as the information source for answering these questions.[4] Historical records for the wafer needs of each machine since June 2007 were examined. Since most of these databases are kept in Microsoft Access or Excel files it was decided that the Visual Basic Programming would be the most efficient means for obtaining relevant information from these databases. The results presented in this chapter were obtained by running the codes written in Visual Basic on the demand databases of the Process lab. In the following subsections, we only explain the methods and algorithms which we used to extract relevant information from the databases to answer the questions presented above. The source codes are given in the Appendices.

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[4] There are two databases used in the Process lab. One of these databases shows all the coating orders made since summer 2007 and their specifications (time of the order, wafer amount ordered, chemicals to be applied, the information of the machines for which the order is made, etc.). The other database shows all the coating and developing orders processed and the time at which the processing started. More detailed information about these databases is given in Appendix XIII.

5.2.1. The Wafer Usage Period (WUP)

We call the period between the first day of wafer use and last day of wafer use as the Wafer Usage Period (WUP). WUP is an important element in the wafer demand information of machines because it determines during which portion of the cycle time the machines are expected to use wafers. WUP provides answers for the first question presented in the beginning of Section 5.2.

Since we are interested both in the workload of coating and developing activities, separate WUP calculations were done to see the WUP for coated and developed wafers.

Before explaining the results for the WUP, it is important to differentiate between three types of wafers: bare wafers, coated wafers and developed wafers. In ASML Process lab the term coating request is used both for bare wafers and coated wafers request. During this the same term was adopted. However there is an important distinction between the bare wafers and coated wafers which may influence the results of WUP: Bare wafers mostly do not require any developing after they are used in the machines for tests. However, coated wafers need to be developed after they are exposed in the machines and since the wafers are vulnerable to light before developing, the wafers should be developed as soon as possible after the tests. According to these facts, the expected results from the demand data analysis for the period in which machines make coating or developing requests are:

$$WUP_{coating} \geq WUP_{developing} \qquad \text{for all machines}$$
$$\text{First coating date} \leq \text{First developing date} \qquad \text{for all machines}$$
$$\text{Last coating date} \geq \text{Last developing date} \qquad \text{for all machines}$$

When the $WUP_{coating}$ and $WUP_{developing}$ for each machine were calculated by using the data in the Process lab databases and when they are compared to the Start FASY and shipment date of machines, unexpected results were observed which deviated from the real practice. To tackle with this unreliability issues regarding the databases, following assumptions were made and adopted throughout the thesis.

- **We will only refer to one WUP assuming that**

$$WUP_{coating} = WUP_{developing} = WUP \qquad \textit{for all machines}$$

- **We assume that the machines may require wafers any day between the start of the TEST phases till the GSD (GSD not included). 5**

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[5] In the cycle time norms already defined in ASML, the TEST phases start on average 1 week after the Start of FASY.

The calculation method for WUP is explained in Appendix XIV and Appendix XV, specifically for the Process lab databases, together with the issues resulted in the aforementioned assumptions.

5.2.2. The Wafer Usage through the WUP for a Single Machine

In order to come up with a standard distribution for machine types, first the historical wafer usage of each single machine were investigated as it will be explained in this subsection. Then by combining the information about the wafer usage of each machine, an expected wafer usage distribution was calculated for each machine type (Section 5.2.3)

Choice of Time Unit for Calculation of Wafer Usage during the WUP

The main approach to calculate the wafer demand during the WUP of a single machine was to divide the WUP into smaller periods and to calculate the wafers ordered by each machine in each of these small time units.

In the production plan of the machines there are no specific rules regarding the day the production can start or the shipments can be done, such as "the machines are started to be produced in the first week of each month" or "the shipments are done on the last day of each month", etc. Therefore the choice of the length of the time unit becomes important in the design of the tool for workload calculation. For example, the 2nd week before the GSD might be in the same calendar month as or one month before the GSD according to the week of the shipment, changing the workload of different months in practice. To be able to reflect this situation in the tool, it was decided to divide the WUP into weeks rather than months.

Moreover, the Gantt-chart of machines also uses weeks as the planning unit. Since our main method is to combine the information on the Gantt-Chart with the wafer usage information, keeping the same planning unit was more beneficial. After the workload for each week is calculated, by simply adding up the workload of the weeks of each month, monthly results can be calculated more accurately with this approach.

Taking into account all these discussions, it was chosen to use **weeks** as the time unit for calculating the wafer usage distribution of the machines. MS Excel Visual Basic codes were developed during this thesis in order to calculate week by week the wafer usage of each machine between their first day of WUP and last day of WUP, both for coated wafers and developed wafers. By the help of the code, for each week in the WUP of a machine, the total number of wafers ordered by that machine, the total number of orders (i.e. total number of foups coated since each coating order is processed in separate foups) and the average lot size (the average number of wafers per order) is calculated. Appendix XVI describes the algorithm in detail used for this calculation and gives the source codes, with a representative output.

Difference in Calculating the Demand for Coating and Developing

The only information we could see in the Process lab databases about the developing requests is the number of orders made for developing and the time of these orders (See Appendix XIII for the databases used in the Process lab). Since there is no data available about the amount of wafers developed but only the number of developing orders is available, we base the method of calculating the demand for developed wafers on the number of foups.

Recall that the wafers are first coated and used in the tests, then brought back to the Process lab to be developed. The wafers are always processed in the same foup. The interviews with the testers revealed that there might be cases where the testers order more coated wafers than needed, which might result in different number of wafers in the foup coated and the foup developed for the same test. During this research **it was assumed that the lot size of the foup do not change between the coating and developing steps.**

However, the number of wafers to be developed can be changed by the repetitive developing processes for the same foup. Some tests require multiple developing of the same wafers. Therefore in order to calculate the demand for developing during the WUP of machine the number of repetitions for the developing process should be known. We call this "Developing to Coating Ratio (Dev/Coat)" in this report. The method for calculating the Dev/Coat Ratio is explained in the second part of Appendix XVI.

5.2.3. The Wafer Usage Distribution of Machine Types

In order to estimate the wafer usage of the machines for the upcoming periods, it is necessary to define a standard wafer usage distribution for each machine type. This way, once the type of the machine is seen on the Gantt-Chart, the associated wafer usage can be calculated for the cycle time of the machine that is defined on the Gantt-Chart.

Previous subsections explained how the wafer usage distribution and related parameters (number of wafers/foups to be coated, average lot size, Dev/Coat), is obtained for each machine. In order to calculate wafer usage parameters for each machine type, the results of these historical wafer usage distributions for each machine are grouped with respect to the machine type. For each machine type, the average value approach was used to come up with a representative distribution of the wafer usage through the WUP.

The average value approach takes the average of the calculated wafer usages of each machine week by week. More specifically, for the first week wafer usage of the machine type it takes the average of all machines' wafer usage from that type in their first week, for the second week wafer usage of the machine type it takes the average of all machines' wafer usage in their second week and so on. The following figure explains schematically how the wafer usage distribution for a machine type was obtained from the wafer usage distribution of single machines.
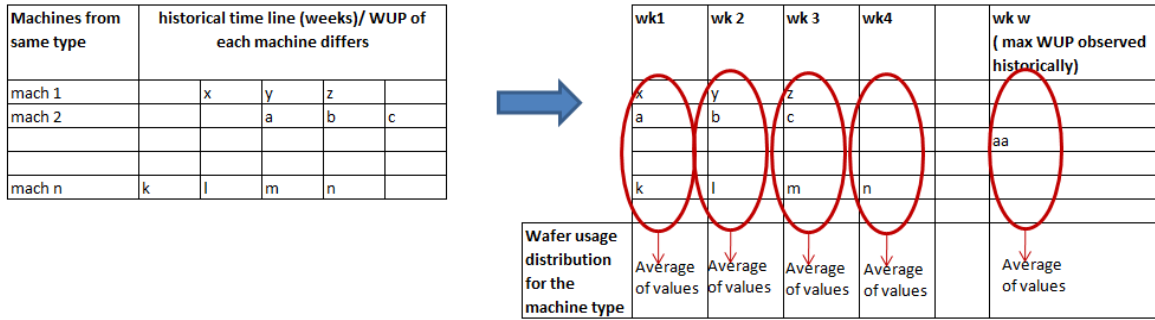
Figure 13: Calculation logic for Wafer Usage Distribution for machine types

Note that, this approach decreases the sample size, especially for the higher weeks, since each machine can contribute to the wafer usage distribution up to the week of its total cycle time. One measure against this was using the average of all machine types for these weeks, which will be explained more in detail in the next subsection.

Results for the Wafer Usage Distribution for Coating

Appendix XVII presents the coating information for some machines from the same machine type with similar WUPs. The results displaying the demand for coating during the WUP of individual machines show that the number of orders and the number of wafers is higher in the last weeks of the WUP, as expected. Hence it could be concluded that the wafer usage is not constant per time unit through the cycle time of machine; it increases when the machine is close to shipment. This answers questions 2 and 3, presented in the beginning of Section 5.2.

It was observed that the pattern of increased wafer need was generally true for different machines. However, the results also showed that there is no specific, standard point in WUP where this increase is observed. This is because of the fact that the last part of the cycle time is the part where the tests are more intensive, resulting in more random yields. This situation sometimes obliges the testers to make some sequence changes to meet the cycle time requirements while still completing the tests (including the specific tests required by the customers). Figure 14 shows the results for the calculated wafer usage of XTII19x0 and XTIV19x0 machine types, together with the overall average wafer usage of all machines, during the first 30 weeks of the WUP.[6]

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[6] 30 weeks was used to provide standard weekly wafer usage information for each machine type, considering that the production of a volume machine takes around 3-4 months and putting some excess weeks to include the wafer demand information of the pilot machines which have higher cycle times.
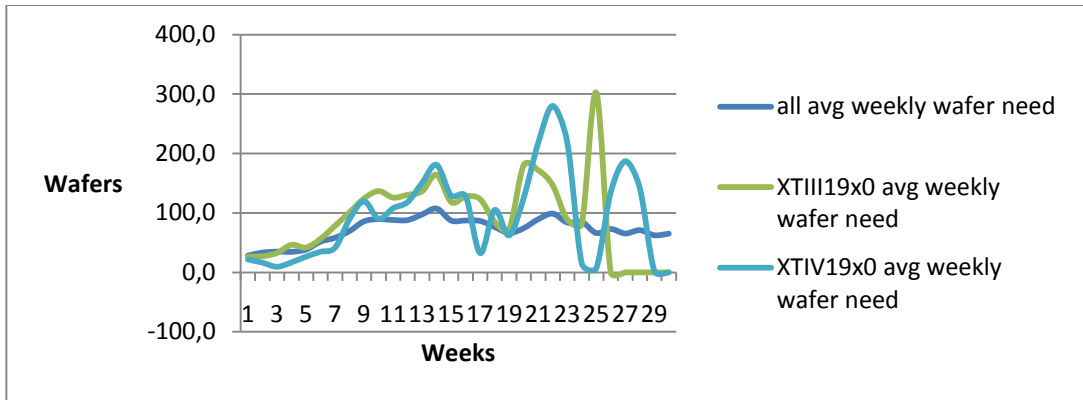
Figure 14: Distribution of Wafer Usage through the WUP

In Figure 14 it is seen that for the first 16 weeks the average values for the wafer usage smoothly follows the same pattern (low in the beginning, increasing later). It is not surprising to see that the patterns are close to each other because most of the machines have a cycle time of 4 months, providing a reliable sample size. The differences in the later months are more easily visible because as cycle time increases, the number of sample size used to take the average decreases, decreasing the reliability of the average value approach. Thus in the tool designed for Manpower Planning in the Process lab, the machines that have a planned cycle time greater than 30 weeks are all regarded as the same group of machines, whose wafer usage is taken by using the overall average for better reliability of results. Seeing the differences in the wafer usage of different machine types, it can be concluded that the distribution of wafer usage tends to vary between machine types. This answers our 5th and 6th questions, presented in the beginning of Section 5.2.

This conclusion is further supported by the difference between the average wafer usage of all machines (regardless of the machine type) and the average wafer usage of the machines from a specific machine type. If all the machine types had similar wafer usage the values for different machine types would not differ from the overall average. This situation leads us to the conclusion that MR, which represents the machine start rate per week with no differentiation between machine types, cannot be solely a parameter to calculate the workload of the Process lab since the product mix also has an effect in the wafer usage through the cycle time of different machine types.

Results for the Wafer Usage Distribution for Developing

We have mentioned that the bare wafers do not require developing. During the analysis for the coating requests it was seen that on average 20% of all the coating orders per month are for bare wafers and 80% of them are for coated wafers. This ratio is calculated regarding the overall workload of the Process lab, not for specifically the individual machines. The ratio of the need for wafers vs. the need for coated wafers need may change through different periods during the production of a single machine. However, since the main aim of the tool designed during this

research was to calculate the overall workload, it was decided to use this ratio as a constant when calculating the developing orders.

Regarding the Dev/Coat ratio, representing the repetitive developing requests on the same foup, it was decided not to separate the developing information per machine type and use the overall average of all machines for the same week of WUP, due to the issues with the database. At ASML Process lab, a general Dev/Coat ratio of 1.2 is used currently. During the analysis the values smaller than 1.2 were corrected to 1.2 while the values greater than 1.2 are kept as they are. If the machine has not made any coating requests during a specific time unit, this means that it has not used any developed wafers in that time unit. So, for these time units the Dev/Coat ratio is taken is zero. [7] Taking into account these discussions, the developing workload for a specific planning period t can be calculated by using the formula:

$$Number\ of\ foups\ to\ be\ developed\ (t)$$
$$= Number\ of\ foups\ ordered\ with\ coating\ requests\ (t) * 0.8\ (bare\ vs. coated) * \frac{Dev}{Coat}\ (t)$$

5.3. Calculating the Overall Workload of the Process lab

In the previous sections, two inputs that are used for calculating the overall workload of the Process lab were explained. The main approach is combining the information about machines in the Gantt-Chart with the wafer usage distribution parameters.
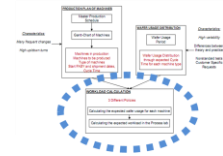
For combining the Gantt-chart information with the wafer usage parameters, firstly five separate tables were formed that have the same structure as the Gantt-chart. These tables each are to be filled with a different aspect of wafer usage distribution week by week. After the fill in process is completed , Number of wafers to be coated, Number of wafers to be developed, Number of foups to be coated, Number of foups to be developed, Average lot size (number of wafers per foup) for each machine are shown on one of the tables. We call these tables as the "Process lab tables". We call the charts formed by this method as the "Gantt-Chart of wafers".

The following subsections explain how the Gantt-chart of machines is converted into Gantt-chart of wafers. The general sequence consists of the steps: Checking the type of the machine (Section 5.3.1), finding the right wafer usage distribution according to the type of the machine (Section 5.3.2), filling in the Process lab tables with the wafer usage parameters week by week (Section 5.3.3). Figure 15 displays an example of how the Gantt-Chart of machines and the wafer usage information is combined to form the Gantt-Chart of wafers:

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[7] Due to the issues with the database showing the developing requests, Dev/Coat ratio resulted mostly in the 1.2 value. Hence the shape of the distribution for developed wafers generally follow the shape of the graph for coating wafers and not shown in the report.

Gantt-chart of machine

1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127
	U	c	M	m	m	m	m	m	m	S	s	s	s	s	s	F	P	G		

Wafer distribution defined for that machine type:

Week after st of fasy											
	1	2	3	4	5	6	7	8	9	10	11
Avg number of wafers coated	21,90	16,50	9,66	16,97	26,78	34,87	41,77	89,87	119,59	90,23	107,97

Gantt-chart of wafers to be coated for the same machine

1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127
	U	22	17	10	17	27	35	42	90	120	90	108	118	151	181	129	128	G		

Figure 15: Converting the Gantt-chart to wafer usage, an example

5.3.1. Machine Groups

In the Gantt-Chart of the machines each machine belongs to a group which shows the type of that machine. Currently there are 20 machine groups defined in the Gantt-chart of machines. During the design of the workload calculation feature of the tool, it was chosen to use the same grouping. One difference is that an additional group is added in order to account for the wafer norms of the machines that use wafers in a period of more than 30 weeks. This choice of grouping was explained in Section 5.2.3 , saying that as the cycle time is increased, the number of sample size used to take the average decreases, decreasing the reliability of the average value approach. Hence, the machines that have WUP greater than 30 weeks are regarded as a new group, whose wafer usage after the 30th week is taken by using the overall average of all machine types. The machine groups used in the Manpower Capacity Planning Tool is shown in Appendix XIX.

5.3.2. Wafer Usage Parameters for the Machine groups

The workload calculations are done by using the group number of machines stated in the Gantt-Chart. An MS Excel VBA code links the machine type to the wafer usage parameters that are defined for that machine. This link is done based on the group number that the machine belongs to (1 to 20, 21 if the WUP>30). Table 4 shows the wafer norms defined for the XTIV19x0 type machines. As explained before, different parameters seen in separate rows of this table are used to fill in the associated Process lab tables.

Table 4: Wafer usage parameters defined for XTIV19x0 type machines (first 11 weeks shown)

Group:	9	XTIV19x0

Week after st of fasy											
	1	2	3	4	5	6	7	8	9	10	11
Avg number of wafers coated	21,90	16,50	9,66	16,97	26,78	34,87	41,77	89,87	119,59	90,23	107,97
Avg number of foups coated	3,06	2,39	2,09	3,16	5,00	6,26	7,43	14,37	15,86	12,00	14,76
Average order size	7,97	6,84	4,47	5,59	5,39	5,22	6,20	5,78	7,11	7,76	8,28
Developing/Coating Ratio	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2

5.3.3. Policies for Calculating the Workload

The challenge for combining the cycle time information of the machines with the wafer usage distribution is that there is high variability both in the cycle time and the number of wafers needed during the cycle time, which increases the unpredictability of the future workload. When the Gantt-Chart from different periods are examined, it can be seen that machines sometimes can stay idle in the production cabin and no tests are applied on the machine during this period, or there can be shifts in the start and shipment dates of the machine in the long run. In addition, the number and frequency of the tests applied on a machine may change depending on the cycle time and machine type. These all cause difficulties in developing a standard method for calculating the wafer workload to be created by each machine.

The above mentioned challenge requires assessing the relative reliability of Start FASY and shipment date to be used as a basis to calculate the expected wafer usage of machines on a specific date in their cycle time. One of these points should be chosen in order to combine the Gantt-Chart (showing the Start FASY and shipment dates of the machines) with the wafer usage distributions calculated in Section 5.2 (showing the expected wafer usage week by week, either in a forward fashion starting from Start FASY or backwards fashion starting from the shipment date). To understand which approach gives more reliable forecast, three different policies were developed during this thesis in order to convert the Gantt-chart of machines to a Gantt-Chart of wafers and their reliability were measured (Section 5.4). The policies can be listed as follows:

- Policy 1: Based on Start FASY
- Policy 2: Based on Shipment Date
- Policy 3: Combination of Policy1 and Policy 2

These policies all serve for the same purpose: Check the type of the machine, find the start and end date of the TEST phase, calculate week by week the expected wafer usage during the TEST phase. What differs between these policies is that for each week in the cycle time of the machine they either check the total time already completed since Start FASY of the machine or the time left until the shipment of the machine. The remainder of this subsection explains the policies in more detail and provides representative figures for the execution of the policies.

The algorithms of each policy and the Visual Basic codes to apply them in the manpower planning tool developed during the thesis are provided in the Appendices (Appendix XX to Appendix XXII) in detail. The example executions of the policies are shown for a single machine in this subsection. Calculating the total workload of the Process lab requires repeating the same steps for each machine seen on the Gantt-chart according to the chosen policy (the performances of the policies are compared in the next section. This way the Gantt-chart of machines is converted to Gantt-Chart of wafers (separate Gantt-charts for number of wafers to be coated/developed, number of foups to be coated and average order size). Gantt-chart of wafers

provide the expected workload of the Process lab for each week in the planning timeline (2 years), which is basically the summation of the workload created by each machine in the same week.

Policy 1: Based on Start FASY for all weeks of the cycle time

This policy uses the week of the Start FASY as a reference. It fills in the Gantt-chart of machine with the wafer usage parameters using a forward calculation, starting from checking the Start FASY, finding the first TEST week in the timeline of the Gantt- Chart and filling in the upcoming weeks. Figure 16 shows the first two steps and the last step of the execution of Policy 1 for an example machine.
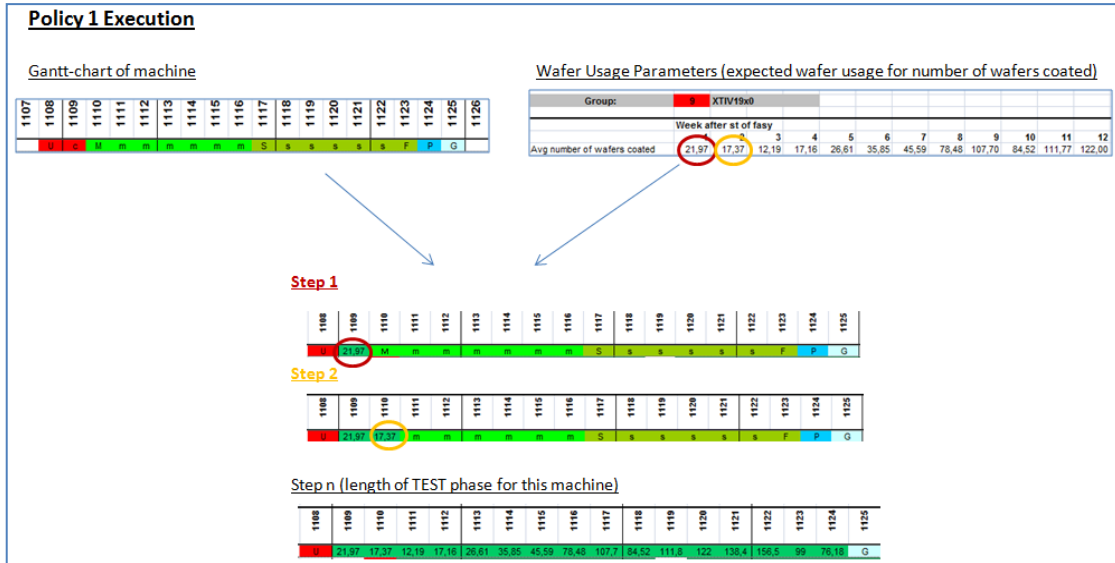
Figure 16: Execution of Policy 1

Considering that the wafer usage increases before the shipment of machines, it was decided to check how the results change when shipment date is used as a reference. Hence, a second policy is defined in order to introduce wafer norms with a backwards calculation, starting from the GSD week and filling in the preceding weeks.

Policy 2: Based on the Shipment Date for all weeks of the cycle time

This policy is basically the opposite of Policy 1. It uses the shipment date (GSD) as reference and fills in the wafer usage information backwards starting from the last week of TEST. Figure 17 shows the first two steps and the last step of the execution of Policy 1 for the same example machine used in explaining Policy 1.

Note that since the reference points are different in the two policies the wafer usages calculated for the same week differ.
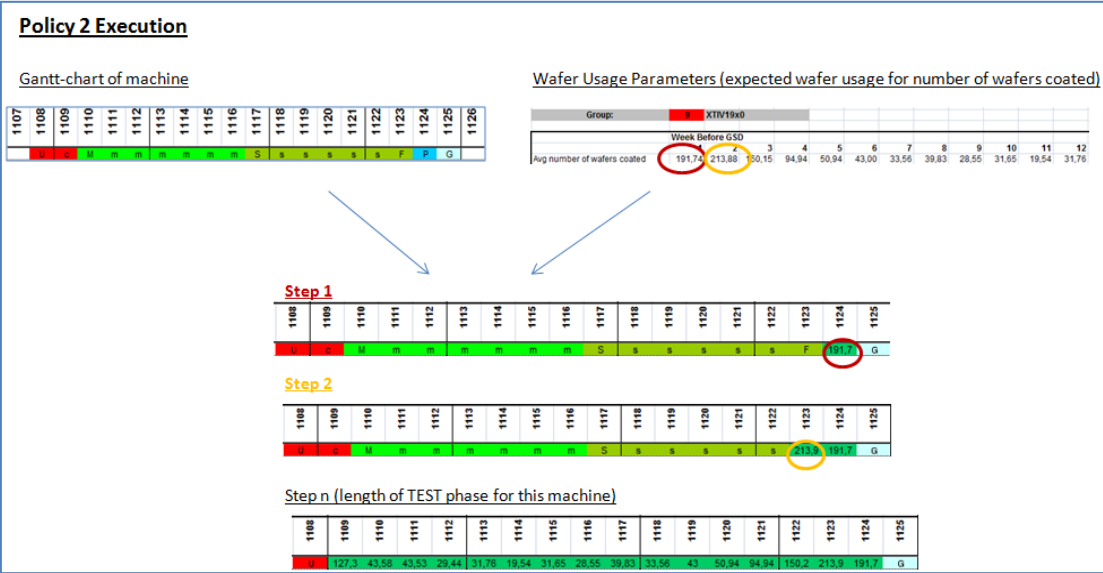
Figure 17: Execution of Policy 2

As it will be explained in 5.4 Policy 1 gave better results than Policy 2 in the first runs of the tool. However this result might depend on the machine type chosen, the upturn/downturn situations and similar factors that might affect the cycle time and wafer usage of the machines. What we know as a general fact valid under most scenarios is that the wafer usage is expected to be higher when the machine is close to the shipment while we cannot tell a pattern for the tests and wafer usage for the first part of the cycle time. This fact is expected to be more influential with the machines that have long cycle times because in this case the wafer usage of the machine gets even less predictable but the increase in the wafer usage when the machine is close to the shipment still remains valid. What is more, the reliability of the averaging method for calculating the wafer norms is expected to be better since the number of machines that use wafers in the last weeks of the cycle time is higher, providing a larger sample size. Therefore, a third policy was developed in an attempt to both keep the relatively better performance of Policy 1 and to decrease the variability of the wafer usage resulting from the long cycle time of the machines, a third policy was developed to form the wafer Gantt-Charts.

Policy 3: Based on Start FASY for the first 30 weeks and GSD for the other weeks

Policy 3 starts filling in the wafer norms forward, based on Start FASY like in Policy 1. This continues for the first 30 weeks. However, the wafer norms of the 21st group are defined with respect to the GSD (like in Policy 2). Hence, when the group of the machine is changed to group 21, the week to be filled in is compared to the relative position with respect to the GSD now, rather than Start of FASY.

The following section explains the method used for validation check and compares the workload estimations resulting from each policy.

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5.4. Validation of Workload Estimation Results Calculated with the Proposed Method

Validation means determining whether the results presented by the model/tool are an accurate representation of the real system.

During this thesis, because of the lack of data, only the coating information could be validated with real historical results. The validation is done by applying all three policies described in Section 5.3.3 separately on the Gantt-Charts issued in December 2008 and June 2010. As a performance measure the Mean Absolute Error (MAE) is used. For the validation of the results regarding any time period t, MAE is defined as

$$MAE\ (t) = \frac{|Estimated\ coating\ workload\ (t) - Actual\ coating\ workload\ (t)|}{Actual\ coating\ workload\ (t)}$$

where, the Estimated coating workload is determined by using the methods described in Section **Error! Reference source not found.** and the Actual coating workload is determined by sing the demand database in the Process lab. When the results are examined, it was seen that the methods mostly provided satisfactory forecast values within the requested range by ASML Process lab (-+30%). The results are given Table 5 for the XT19x0 machine family.

Table 5: MAE Results for XT19x0 machine family

		2008 (12 months)	2010 (9 months)
	MAE (wafers)	7%	22%
Policy 1	MAE (foups)	9%	19%
	MAE (wafers)	12%	21%
Policy 2	MAE (foups)	14%	15%
	MAE (wafers)	36%	22%
Policy 3	MAE (foups)	31%	19%

Figure 18: Policy1 results XT19x0 machine family, 2008 Dec Gantt-Chart

When the results were examined for the XT19x0 machine family for years 2008 and 2010, it can be seen that the relative performance of the three policies change compared to each other. In year 2008 the performance of the policies can be listed as Policy 1, Policy 2, Policy 3 from the most successful to the least successful one, whereas for year 2010, Policy 2 provides the best performance. The graphical representation of actual and forecasted number of foups can be seen in Figure 18: Policy1 results XT19x0 machine family, 2008 Dec Gantt-Chart year 2008 resulting from Policy 1. Number of wafers follows similar results as the number of foups, thus not shown in the figures.[8]

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[8] Detailed results can be found in Appendix XXIII.

The reason for the change between the accuracy of policies through years was investigated in the relationship of the wafer usage between the Start Rate and Shipment Rate of the machines. The shape of the wafer usage distribution is compared with the shape of the change in MR and shipment rate of XT19x0 family type machines in years 2008 and 2010 for Policy 1 and Policy 2 respectively, since they provide the best results. The figures for this comparison are given in the second part of Appendix XXIII.

Comparing the real wafer usage values with the MR and shipment rates, it was concluded that the wafer usage is expected to follow more closely the shipment rate rather that the MR (start rate). Another comparison was made to compare the wafer usage with the start rate of machines with one quarter delay (i.e. comparing the wafer usage of the 2nd quarter of 2008 with the MR of 1st quarter of 2008 rather and so forth), to take into account the average cycle time of 4 months. When the forecasted wafer usage for the same periods were compared with the MR, shipment rate and MR with a quarter delay, it can be concluded that the choice of algorithms result in a deviation from the real numbers in favor of the reference points. This can be seen in the results of 2008, where the shape forecasted numbers result in an intermediary form between the shapes of the shipment and start rates.

5.5. Conclusions

In this chapter we developed a method to forecast the workload in the Process lab. This method uses Gantt-chart of wafers and the wafer usage parameters to calculate the expected wafer usage of the machines seen in the Gantt-Chart. The Gantt-Chart of machines was readily available at ASML during the research, therefore the reasons to use this Gantt-chart was emphasized in this chapter. Regarding the wafer usage of the machines no studies had been conducted before, therefore this chapter provided the method to calculate the wafer usage parameters for each machine type as well. 3 different policies were developed to combine the two inputs and to calculate the total workload in the Process lab.

The workload calculation methods and the discussion provided in this chapter regarding the average wafer usage distribution of machines and the comparisons between the wafer usage and the start and shipment rate of machines give answers for our second research question, where we sought answers for the effect of product mix on the wafer usage and the quantification methods of workload. Next chapter provides the methods designed to answer our third research question, which is about the conversion of the estimated workload to manpower needs.

6. MANPOWER NEED CALCULATION METHOD

In the previous chapter we have described the factors affecting the workload of the Process lab and we have provided methods to estimate the workload of the Process lab in a long term by taking into account these factors. The workload estimation provides the basis for the manpower need calculations, which we explain in this chapter. The method proposed in this thesis for calculating the manpower requirement uses two main parameters from the estimated workload: estimated number of foups and the average order size. These parameters are used in order to retrieve the processing time information from the time study results, regarding a specific order size.

Therefore, in this chapter we first explain why the number of foups instead of the number of wafers was chosen to be used in the manpower need calculation (Section 6.1). Then we describe the time studies conducted in the Process lab regarding the coating and developing of foups and provide the results (Section 6.2). Lastly, we explain how the estimated workload in a specific time period can be converted into the estimated manpower need by combining the estimated number of foups and average order size with the results of the time study (Section 6.3).

6.1. Number of Foups vs. Number of Wafers

Currently inside ASML there is a tendency to mention the workload of the Process lab in terms of the number of wafers (to be) processed. However, there are many steps in the flow of processing the wafers which do not depend on the number of wafers. Moreover, the required time in the track to process the wafers is not a linear function of the number of wafers inside the foup.

Therefore, we base the manpower need calculation method on the number of foups to be processed and the average order size in order to provide more realistic estimations of the time needed to process them.

The following section describes the time studies conducted in the Process lab to calculate the time needed to process the foup based on the order size.

6.2. Time Studies Conducted in ASML Process lab

6.2.1. Fundamental Approach Followed during Time Studies

The time studies were conducted for the Coating and Developing operations[9]. During the time studies the processing of foups were observed and measured, following the three step procedure that Baines (1995) recommends for work measurement studies, which can be described as follows:

Step 1. Analysis: In this step the work to be measured was analyzed and broken into smaller steps which are suitable for measuring. Time study templates were created after the observations in the Process lab, examination of current process flow documents and walking with the operators in the Process lab during coating and developing operations.

Step 2. Data Collection & Measurement: This is the step where the work under observation is timed to see to calculate the standard time of completion of the job by an average, qualified worker. Note that in this thesis, we assume all experienced operators have the same qualifications and we do not differentiate between individual operators.

Baines (1995) recommends to combine the real data measurement with historical records kept for the same data if during the time study not all potential instances are visible. As mentioned before, the number of wafers processed in a single foup can change between 1 and 25. During the time studies that were conducted on random time intervals during a period of two months, it was not possible to measure the time needed for each order size from 1 to 25. . Hence, some part of the time study results presented in this report are real time data recorded with a timing device during observations in the Process lab and some of them are historical data taken from demand databases of the Process lab and previous presentations of ASML Processing Group.

Step 3. Synthesis: This step is the point where the various parts of the job which is measured are summed up together to form the complete time standard of the job. In this step, the time it takes to process a foup is calculated for each order size, in terms of track time (i.e. the time that the foup is being coated / developed inside the machine) and overhead time (i.e. the time that the operator spends for processing the order).

6.2.2. Time Study Results for Coating

During the analysis step of the coating operations the flow of coating is broken down into smaller steps and the work study template seen in Figure 19 was created. The average durations of the steps that are independent of the number of wafers inside the foup are shown next to the associated step on this figure. In the time study template, the steps that are highlighted with pink are the work steps whose durations change according to the number of wafers to be coated. The

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[9] Detailed descriptions of the Coating and Developing operations are given in 1)a)i)(1)(a)Appendix VII

work step highlighted with yellow is the step whose duration changes because of the locations of the tracks. The durations for these work steps are not shown in Figure 19 but given in the remainder of this subsection together with the measurement approaches used and assumptions made.

	Date: Operator: number of wafers:		Average duration of the steps independent of order size and track locations
	Time start	Duration	(in minutes)
COATING			
Validate the request			0,08
Record in Popdab			0,17
Prepare the lottraveler			0,27
Print the lottraveler			0,17
Prepare the wafers			
Take the foup to the track			
Program the track			0,37
Update the lottraveler			0,42
Wafers coated			
Inspect the wafers			
Finish record in Popdab database			0,08
Finish record in Wafer Request Tool			0,08
Update the lottraveler			0,17
Take the foup to the hatch			
Total duration			Total: 1,80

Figure 19: Time Study Template for Coating[10]

Average duration of "Prepare the wafers" and "Inspect the wafers" steps:

"Prepare the wafer" step represents the step in which the operator takes the necessary amount of wafers from the bare wafer stock one by one and puts them in a separate foup. "Inspect the wafers step" is the step where the operator has to inspect the wafers for any type of saturations (deformations in the chemicals applied which leads to shape distortions on the wafer) after the coating is completed. The inspection is done by taking the wafers one by one out of the foup, and and then putting them back in the foup if they can be used or putting them to another foup to be recycled if there are saturations.

Therefore the durations of these two steps are a linear function of the number of wafers to be coated for a specific order. According to the time studies, 10 seconds per wafer was used as the average duration of these steps.

Average duration of "Take the foup to the track" and "Take the foup to the hatch" steps:

Due to the layout of the Process lab, the two tracks that are used for coating (or developing) the wafers are located in different locations of the Process lab, one close to the main computer used for recording the executions (the first work steps in coating) and the other one located further. Thus, the durations of the "Take the foup to the track" and "Take the foup to the hatch'' steps depend on which track is used to process the wafers. **During this thesis it was**

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[10] See Appendix VII for the definitions of lottraveler, Wafer request Tool and Popdab Database.

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assumed that the execution of orders is separated equally between the two tracks. On average it takes 30 seconds to take the foups to the closer track and bring them back to put in the hatch of coated foups. The duration increases on average 1 minute if the foups is taken to the further track. Therefore, the average durations of the "Take the foup to the track" and "Take the foup to the hatch'' steps are calculated as

$$Duration\ of\ work\ steps$$
$$= \sum_{tr=1}^{total\ number\ of\ tracks=2} Probability\ (Using\ track_{tr}) * duration\ of\ handling\ time\ _{tr}$$
$$= 0.5 * 0.5 + 0.5 * 1.5 = 1\ minute$$

Average duration of the "Wafers Coated" step:

This step is the step that the wafers are coated inside the tracks. It was mentioned that during the time studies only limited number of order sizes have been observed. The order sizes that were observed are shown as orange in Table 6 together with the average duration measured. The order sizes shown in green and the associated durations for coating are taken from the previous presentations of ASML Processing Group. The time to coat the foups with other order sizes are extrapolated. The curve seen in Figure 23 represents the resulted Coating time as a function of the order size, which was approved by the managers of ASML Process lab.

Table 6: Coating Time vs. Order Size
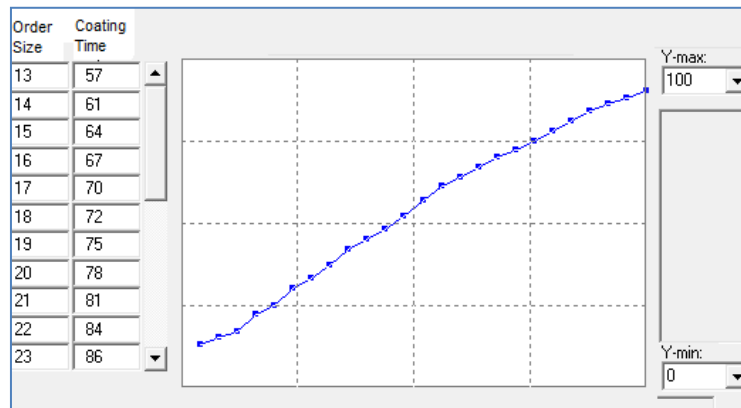
Figure 20: Fitted Curve for Coating Time as a function of the Order Size

Order size	Time to coat the foup (minutes)
1	13
2	15
3	17
4	22
5	25
6	30
7	33
8	37
9	42
10	45
11	48
12	52
13	57
14	61
15	64
16	67
17	70
18	72
19	75
20	78
21	81
22	84
23	86
24	88
25	90

6.2.3. Time Study Results for Developing

During the analysis step of the developing operations the flow of coating is broken down into smaller steps and the work study template seen in Figure 21 was created. The average durations of the steps are calculated in the same manner as explained in the time study results for coating. Next subsection explains how the developing time for each orders size was calculated.

	Date: Operator: number of wafers:		Average duration of the steps independent of order size and track locations (in minutes)
	Time start	Duration	
DEVELOPING			
Validate the request			0,08
Record in Popdab			0,17
Update the lottraveler			0,25
Take the foup to the track			1,00
Program the track			0,37
Wafers developed			
Take the foup to the hatch			1,00
Call requester (only if needed)			0,42
Total duration			Total: 1,28
			Total: 2,00

Figure 21: Time Study Template for Developing

Average duration of the "Wafers Developed" step:

Table 7: Developing Time vs. Order Size

Throughput capacity of tracks			Time to Develop the Foup
Order Size	wafers/hr developing	Order Size	(in minutes)
1	4,6	1	13,04
2	8,6	2	13,95
3	12	3	15,00
4	15,2	4	15,79
5	17,8	5	16,85
6	20,2	6	17,82
7	22,5	7	18,67
8	24,4	8	19,67
9	26,3	9	20,53
10	27,9	10	21,51
11	29,6	11	22,30
12	30,9	12	23,30
13	32,3	13	24,15
14	33,4	14	25,15
15	34,6	15	26,01
16	35,6	16	26,97
17	36,6	17	27,87
18	37,5	18	28,80
19	38,4	19	29,69
20	39,1	20	30,69
21	40	21	31,50
22	40,4	22	32,67
23	41,2	23	33,50
24	41,7	24	34,53
25	42,5	25	35,29

The "Wafers Developed" step is the step that the wafers are developed inside the tracks. In order to calculate the duration of this step for each order size the throughput capacity of the tracks are used and the developing time for each order size is calculated with the following formula:

$$Developing\ Time(Order\ Size) = Order\ Size * \frac{1}{Throughput\ Capacity\ (Order\ Size)}$$

The throughput capacity of tracks for each order size and the resulted Developing Times can be seen in Table 7.

6.3. Method to Calculate the Manpower Need in a Specific Period

The time study results described in Section 6.2 were combined for each order size and some lookup tables were formed in which the total time for the work steps of Coating and Developing activities can be accessed for each order size. The lookup tables can be found Appendix XXIV.

Note that the lookup tables assume that 20% of the coating orders are for bare wafers. For the orders where only bare wafers are ordered (no coating), "Wafers coated" step is not applied on these orders and these wafers are not developed afterwards. Similarly, the "Inspect the wafers" and "Program the Track" steps during coating. Therefore, the Lookup Tables for coating result in an average time of:

$$20\% * Total\ Duration\ for\ bare\ wafers\ orders\ (Order\ Size) +$$

$$80\% * Total\ Duration\ for\ coated\ wafers\ orders\ (Order\ Size)$$

By using the lookup tables and the results of the Workload Calculations the Manpower need can be calculated in terms of manhours.[11] In Chapter 5 the methods for workload calculation were explained and it was mentioned that separate tables formed for each wafer usage parameter of interest that will show the wafer need of each machine on a specific week. By using these tables the manpower need for each period t, where $t1$ and $t2$ represent the start and finish time of the period, can be calculated as:

$Manpower\ need\ for\ coating\ (t) =$

$$\sum_{t=t1}^{t2} \sum_{order\ size=1}^{25} Number\ of\ foups\ to\ be\ coated\ (t, order\ size) * Coating\ Time\ Overhead\ (Order\ Size)$$

$Manpower\ need\ for\ developing\ (t) =$

$$\sum_{t=t1}^{t2} \sum_{order\ size=1}^{25} Number\ of\ foups\ to\ be\ developed\ (t, order\ size) * Developing\ Time\ Overhead(Order\ Size)$$

Where *Coating(Developing) Time Overhead (Order Size)* represents the total time of work steps excluding the "Wafers Coated" and "Wafers Developed", for which no manpower is needed.

6.4. Conclusions

Within this chapter we proposed a method to calculate the expected manpower need based on the expected workload in the Process lab With this method, we found answers for our third research question, which was interested in methods for transforming the expected workload into expected manpower need and adaptability of these methods to changing situations. It can be assessed that since the method proposed in this chapter is based on the production plan and employs simple algebraic equations to calculate the manpower needs for an estimated workload,

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[11] Since the scheduling decisions were not part of the scope of this research, it was agreed with ASML that the manhour need could be given in terms of manhours instead of FTEs. The manhour requirements provided as a result of this master thesis can be used for the shift design and scheduling decisions in a further study.

it reflects the up-to-date information about the product mix and easy to modify if any other parameters of interest about the manpower need emerge.

By using the methods explained in this section for manpower need calculations, the resulted manhours need for the workload estimations of 2010 and 2011 for the XT19x0 machine type can be seen in Figure 22. For comparison, Figure 23 provides the output of the workload estimation, calculated with the methods described in Chapter 5.
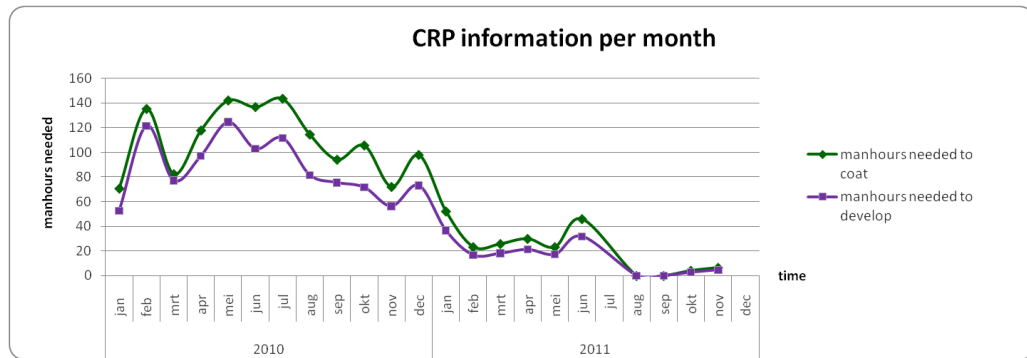
Figure 22: Estimated manhour need for XT19x0 machine family, years 2010-2011
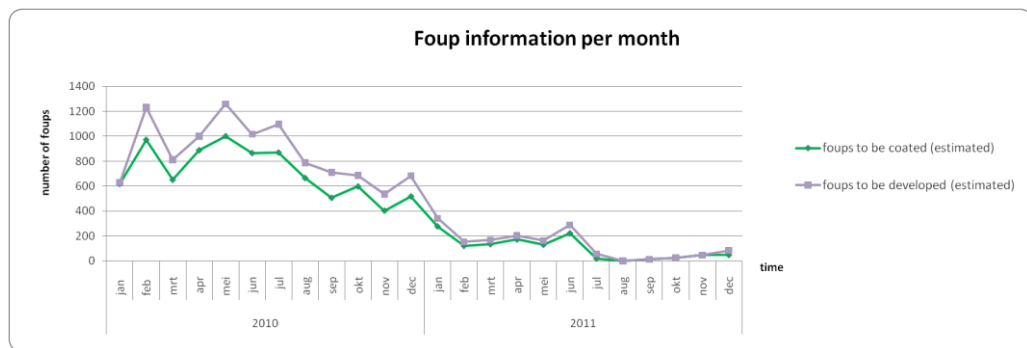
Figure 23: Estimated workload (foups to be processed) for XT19x0 machine family, years 2010-2011

Following these figures it can be said that, the manhours requirement follows the same pattern as the workload on monthly level. This is because the changes in duration of the work steps due to different order size are in terms of minutes, much smaller than months, and the effect of changes in the duration of these worksteps are negligible when aggregated to months. However, since during this thesis the main aim is to provide a manpower need planning method for long term, this level of detail was decided to be sufficient.

All in all, it can be concluded that the discussions about the relationships between the workload and the MR / shipment rates continue to be valid for the relationships between the manpower need and the MR / shipment rates as well.

7. SYSTEM DYNAMICS EXTENSION FOR MANPOWER CAPACITY PLANNING IN ASML PROCESS LAB

 In Chapter 4 the complex relationship structure between the workload of the Process lab and the factors affecting the workload was explained. Chapter 5 and 6 aimed to provide methods to formulate these relationships and to estimate the future workload and manpower capacity needs of the Process lab. These methods provide a fundamental basis to understand the relationships governing the manpower need in the problem environment. The Visual Basic codes developed to apply these methods help the managers of ASML Process lab in their manpower planning decisions, as they provide an efficient forecasting tool.

However, due to the limitations in Excel and similar applications, these methods and the tool designed by using them can only to a certain degree reflect the interactions between different variables in the problem environment. The fact that different methods result in different performances in different planning periods supports this concern. Thus, our last research interest was seeking additional tools to more accurately represent the cause-effect relations between the important factors for manpower capacity planning in the problem environment, to extend the relationship structure that was already taken into account in Chapters 4, 5, and 6 and to simulate the changes in the important variables through time for a long term planning. This way, the learning obtained from the results of the manpower planning methods that were already provided in Chapter 5 and 6 could be enhanced and the important feedback structures which might have been overlooked in those chapters can be captured.

System Dynamics is an approach "to build computer simulations of complex systems, to use these simulations to understand the structure and behavior of systems and to design more effective policies" (Sterman, 2000). It is a relatively new field of simulation and to the best of our knowledge it has not been applied to the manpower capacity planning problem in semiconductor industry before.[12] Thus in this chapter, we aim to understand the usability of System Dynamics approach to gain better insights on the manpower capacity planning problem of ASML Process lab (presented in Section 3.1).

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[12] For the readers who do not have a prior knowledge about System Dynamics, and introductory appendix is available (Appendix XXV).

The remainder of this chapter is organized as follows: Section 7.1 explains in detail the reasons to employ the System Dynamics approach to model the manpower planning problem in ASML Process lab. Section 7.2 gives a high level overview of the System Dynamics model created during this thesis. Section 7.3 describes the important relationships identified in the system for manpower planning decisions and explains how they were modeled. Section 7.4 provides the Base Run results and Section 7.5 concludes this chapter by commenting on the suitability of System Dynamics simulation approach for the manpower planning problem in the semiconductor industry.

7.1. Reasons to Use System Dynamics to Model the Problem Environment

In this thesis System Dynamics simulation approach was chosen to model the manpower capacity planning problem in ASML Process lab and to use this model as an extension to the workload and manpower calculation methods provided in the previous chapters. The reasons to choose System Dynamics can be listed as follows:

- The relationship structure affecting the workload and the manpower need of the Process lab is complex. There are many significant factors that affect the workload and the manpower of the Process lab and there are nonlinear interactions of numerous factors. This complexity makes it hard to analytically track and predict the behavior of the system, unless many simplifications are done.

- Time is an important element in the systems which are governed by dynamic variables and their relations changing over time. When the variable demand dominant in the semiconductor sector and the changes in the cycle time of production due to learning effects, reworks and technological advancements are considered, the attractiveness of a simulation approach that can represent the changes in the variables and their relations over a definite time horizon increases.

- Human actions and decisions can be specifically modeled in System Dynamics, which are often left out in other solution approaches because of the difficulty of quantification. System Dynamics models can include, besides numerical data, many soft, hard to quantify variables that are explicitly modeled such as work pressure, customer satisfaction etc.

- Each decision maker in a complex system tends to have a narrow view of the total dynamic governing the system. Most of the time they only see their own part of the system and try to optimize it. However, this might cause problems in the optimization of the whole system, especially when the actors are unaware of each other's plans and actions. This was often the case observed among ASML Process lab and related parties during this research. The complexity of the system requires the system to be examined, understood, and treated as a whole.

Because of these reasons, during this master thesis the problem of manpower capacity planning in the semiconductor industry is modeled by using the System Dynamics approach.[13] The particular dynamics affecting the manpower need are modeled for the manufacturing environment of ASML Process lab. However, the feedback relations, stock and flow equations are kept in such a form that they can be applied to similar environments in order to enable researchers and industry managers to make better informed decisions about manpower capacity planning.

7.2. Overview of the System Dynamics Model for Manpower Capacity Planning in ASML Process lab

In the System Dynamics model designed for the manpower capacity planning problem for ASML Process lab, has five major subsystems interacting with each other, namely Manufacturing Systems Production, Development Systems Production, Process lab Workload, Process lab Manpower and Cost subsystems.

The subsystem diagram in Figure 24 shows the overall architecture of the model, with each major subsystem along with the flows coupling the subsystems to one another.
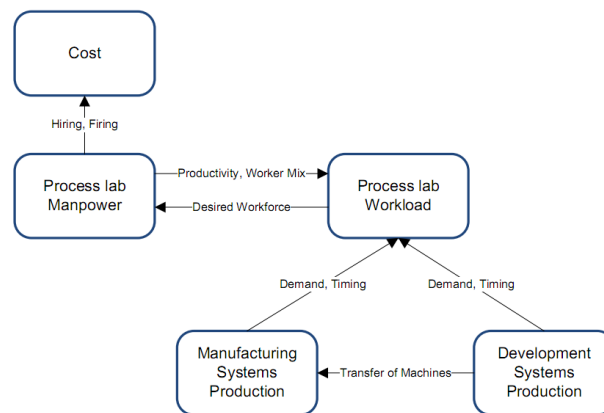
Figure 24: Subsystem Diagram of the System Dynamics model

The stock and flow diagrams of each subsystem is given in Appendix XXVI, together with the whole model. The complete set of equations describing the structure of the model can be found in Appendix XXVII.

7.3. Important Structures and Feedback Loops in the Model

The System Dynamics Model representing the manpower capacity planning problem in ASML Process lab is constructed in such a way that the workload of the period in the future 3 months from now determines the desired workforce level. 3 months is the average training time

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[13] The VENSIM software is used during this thesis for System Dynamics modeling.

of newly hired operators in the Process lab and after the training period they are assumed to be as qualified as the experienced workers.

Figure 25 shows this structure with the stock and flow diagram containing the related variables. Three important feedback loops are identified in this relationship structure. In this report we call them the Hiring Loop, Firing Loop and Training Loop, and the overall causal diagram containing all feedback loops are given in Figure 29. Note that the "Firing Rate of Experienced workers" is not shown in these figures because at ASML the main policy is not firing any experienced workers, therefore the rate is assumed to be zero.
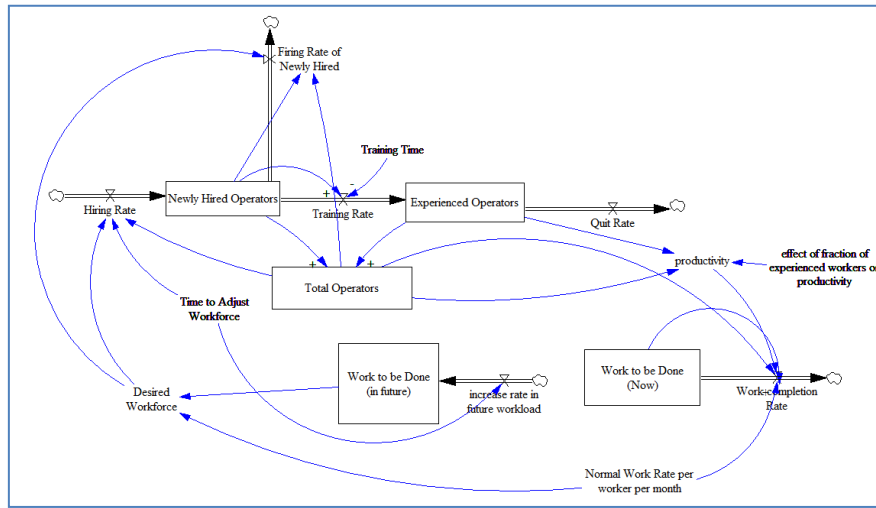
Figure 25: Relationship structure between the Workload, Desired Workforce and Hiring/Firing Decisions
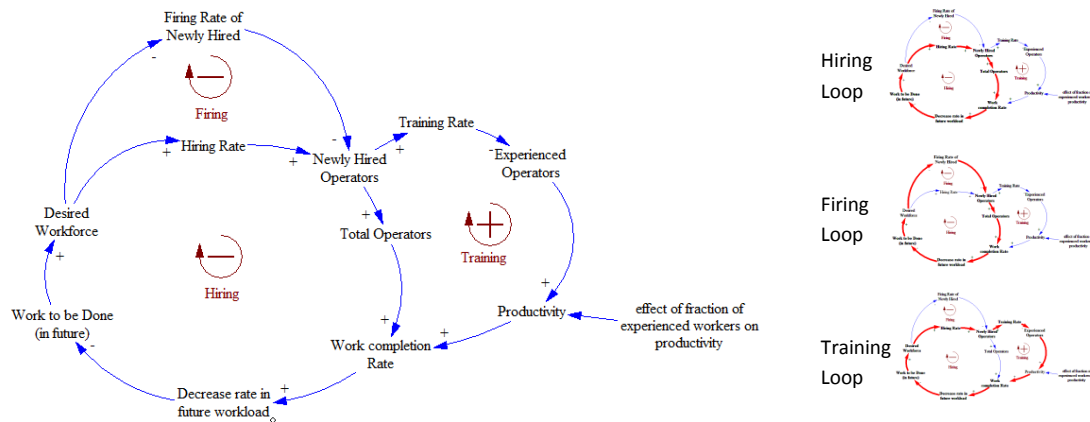
Figure 26: Hiring, Firing and Training Loops

The feedback loops have many common parameters interacting with each other but for the sake of clarity they will be described individually. Individual loops can be seen in the second part of Figure 29.

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The Hiring Loop describes that as the future workload increases the workforce level needed also increases ("Desired Workforce") to process the amount of wafers on time. The increase in the desired workforce means that more operators need to be hired than already available in the system. This means an increase in the "Hiring Rate" to reach the desired workforce level, which increases the number of "Newly Hired Operators" and the number of "Total Operators" in turn. Therefore the "Work Completion Rate" increases, which decreases the workload in the future in the upcoming periods (when the future workload is realized).

The Firing Loop is quite similar to the Hiring Loop and it is dominant in the system when the desired workforce level drops below the total number of operators in the system. As the desired workforce level decreases the "Firing Rate of Newly Hired operators" increases in order to level the total operators in the system to the desired workforce level.

The Training Loop reflects some assumptions made during this thesis:

- Newly Hired Operators reach the same level of qualifications as the Experienced Operators after their training period is completed.
- During the training period the productivity of the Newly Hired Operators are assumed to be constant and half of the productivity of the Experienced Operators.
- Some of the Experienced Operators are assigned to train the Newly Hired Operators during the training period. This also leads to a reduction in the productivity of the experienced operators during the training period.
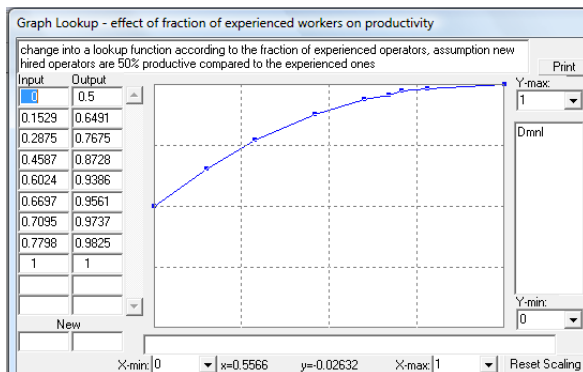
Figure 27: Productivity as function of the worker mix

In order to reflect these assumptions in the model the variables "productivity" and "effect of fraction of workers on productivity" were defined. These two variables cause the Work Completion Rate to change according to the worker mix. Figure 30 shows productivity as a function of the fraction of experienced operators in the system. As it can be seen in this figure, if there are no experienced workers in the system, the productivity drops to half of the normal productivity and as the worker mix changes in favor of the experienced operators the productivity increases to normal level.

7.4. Base Run Results

The Base Run of the model is the simulation run that is conducted with the real historical values obtained from the demand databases and the managers of ASML Process lab for the time period between January 2008 and December 2009. Some of the important parameters used are given in Appendix XXVIII.

The validity of the model was checked by comparing the simulated behavior of the "Work to be Done" variable with real historical data. "Work to be Done" shows the number of foups to be processed in the system, for which real values can be seen in the Process lab databases. Note that the model assumes that the wafer usage of all type of machines follow the same distribution. Although this assumption is known to be unrealistic according to the results of the wafer usage distributions calculated in Section 5.2, it was still followed in order to keep the model simple and capture a high level representation of the system. In system dynamics models an exact matching between the real data and model data values is not required because system dynamics models are designed to represent high-level interactions. The purpose of a system dynamics model is to generate the major dynamic pattern behavior of the system. Therefore what is required is a match between the major behavioral patterns of the model and the system. The following figure gives the expected workload in the Process lab as a function of time both obtained as the output of the model and from real data (years 2008-2009). The broad resemblance can be seen in the behavior of the model output and the real system values; they follow a similar pattern within comparable ranges. Hence, it is concluded that the model is acceptable.
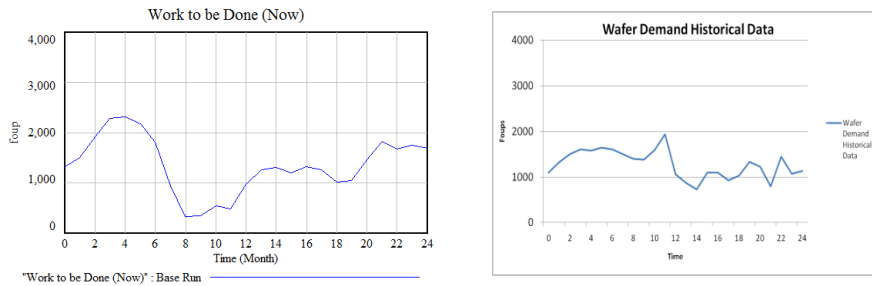
Figure 28: Base Run Results vs. Real Data

7.5. Scenario Analysis

During manpower capacity planning, some important variables should be set before in order to satisfy the workload on time. Therefore the values of some important variables such as the hiring time and the training time, as well as the change in their values, are significant during the planning process. System Dynamics provides a suitable setting to make the changes in these variables and compare the results for each scenario. Figure 32 and Figure 33 show the comparison of workload and the desired workforce, respectively for different values of the hiring time ("Time to Adjust Workforce") and the training time after they are increased/reduced by 50% compared to the Base Run.
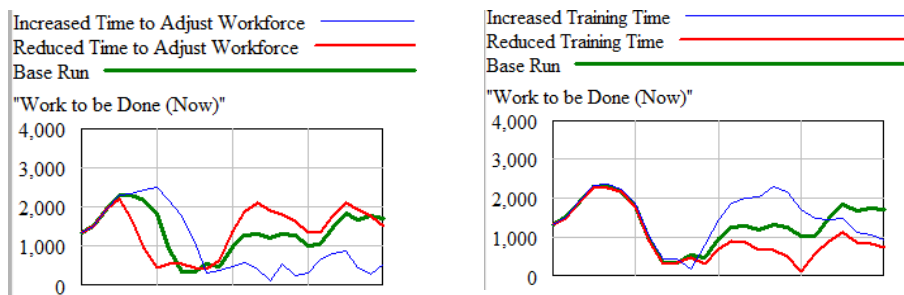
Figure 29: Results of Scenario Analysis for Work to be Done

Figure 30: Results of Scenario Analysis for Desired Workforce

Comparing the behavior of the Work to be Done and the Desired Workforce in the system for different scenarios the following conclusions can be drawn: If the hiring time is reduced to half, the workload in the system increases until the needed number of operators are hired. As the hiring is not completed the desired workforce keeps increasing (1-2 people more than the Base Run). But at the end when the desired workforce is hired, there are no long queues formed for the work to be done since the number of operators are higher and the work can be processed in shorter time. When the hiring time is increased however, initially the workload drops earlier compared to the Base Run since the number operators in the system increase earlier. In the upcoming periods, the workload becomes higher than the Base Run since the number of operators available in the system is not yet as high as the Base Run case, which results from the fact that the desired workforce was lower in the reduced hiring time case. When the effect of the change in the Training Time is considered, it can be said that as the training time increases (reduces), the number of foups to be processed accumulates (depletes), increasing (decreasing) the Work to be Done in the system, which leads to higher (lower) level of desired workforce.

The effect of changes in other variables can be examined in a similar way with the system dynamics model. System Dynamics provides user-friendly simulation environment for scenario analysis, facilitating the manpower capacity planning decisions.

7.6. Conclusions

Our last research question was the suitability of the System Dynamics approach to model the manpower capacity problem in semiconductor sector. The model developed during this thesis sought answers to this research question.

As mentioned before, System Dynamics approach provides promising simulation facilities because of various reasons (change in the values of the parameters through can be directly introduced in the model, significant but hard to quantify variables can be described as simple differential equations resulting from the cause-effect relations between other system variables, etc.) Because of these reasons it was decided that the System Dynamics could be a beneficial simulation tool for the semiconductor sector, since the sector is characterized by dynamic variables changing over time, learning curves, product/worker mixes.

The System Dynamics model presented in this chapter was created in order to represent the relationships identified for the Manpower Planning Problem in ASML Process lab. The change

in demand patterns through time, pressure on the workers due to increasing shipment rates and their effect on the wafer demand patterns, randomness of the wafer demand especially from the Development systems and productivity changes due to worker mix were explicitly modeled together with the other important parameters. The effects of changes in of some values in the system on the workload and the desired workforce were investigated.

Considering this comprehensiveness of the model and the interest of the managers at ASML in System Dynamics, it can be concluded that more attention should be paid to employ System Dynamics simulation approaches in the semiconductor sector for manpower planning problems. With this thesis we aimed to provide a basis for System Dynamic approach as a solution of the manpower planning problem in the semiconductor industry as an attempt to fill the gaps both in the literature and the industry about the application of System Dynamics simulation in the semiconductor sector. Therefore, this thesis provides a fundamental basis for future research on this subject.

8. CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH OPTIONS

In this chapter we summarize the findings provided in the previous chapters (Section 8.1.). Next, we give some recommendations that resulted from the analysis, studies and observations made during this thesis (Section 8.2). Last but not the least, we provide some future research options (Section 8.3).

8.1. Conclusions

The manpower planning decisions in a semiconductor industry are affected by a large group of factors.

Since the semiconductor sector is dominated by volatile demand and high technology requirements, manpower capacity planning in the sector is challenging. Process lab is affected by a large group of factors influencing the manpower need due to its upper end position in the semiconductor supply chain. The complex relationship structure affecting the workload and the manpower need results in a complexity in predicting the workload and making related manpower planning decisions.

The MR cannot solely be a parameter in estimating the wafer usage of machines and the required manpower to process these wafers.

The wafer usage distribution through the cycle time of the machine is not constant and it changes between the machine types. According to the different algorithms investigating the relationship between the MR and the shipment rate, the wafer usage distribution is more affected by the shipments, since a big portion of the wafer demand is realized close to the shipment of machines.

Estimating the workload of the Process lab requires jointly taking into account the machine plans and the wafer usage distribution of machines.

A new method for estimating the workload in the Process lab was proposed in this thesis. This method takes the Gantt-chart of machines as an input and combines this Gantt-chart with wafer usage parameters calculated for each machine type on a weekly basis.

The manpower decisions should be based on the number of foups to be processed, not only on the number of wafers.

The wafers are processed in separate foups for each order and many of the steps during the handling of the orders by the operators remain the same. The duration of steps change according to the number of wafers to be processed. Therefore during this thesis a new method was developed to estimate the manpower need that uses the number of foups and the average order size as two important inputs.

The manhours requirement in the Process lab follows the same pattern as the workload on monthly level.

This is because the changes in duration of the work steps due to different order size are in terms of minutes, much smaller than months, and the effect of changes in the duration of these worksteps are negligible when aggregated to months.

System Dynamics is a promising simulation approach to enhance the manpower planning decisions in the semiconductor industry.

In System Dynamics change of variables through time and hard to quantify variables can be explicitly modeled. By changing the values scenario analysis can be done and change in important variables could be observed. A System Dynamics model for manpower capacity planning in ASML Process lab was developed during this thesis. By this, contributions were done both to the industry and the literature.

8.2. Recommendations

For the academy:

- The manpower planning decision in the semiconductor industry requires good forecasting techniques to calculate the future workload because of the high variability caused by increasing technological requirements and the cyclic demand pattern.
- More case studies would be beneficial to improve applications in practice on manpower capacity planning in the semiconductor industry
- System Dynamics approaches could be employed for simulation purposes and providing more realistic overview of the complex structure of important variables for manpower planning, interacting with each other and complicating the manpower calculations.

For the industry:

- Data management is important during the production of the machines. The databases should be standardized and unique and correct information should be available in all related departments.

- Tests during a machine production are important, thus required attention should be paid for the departments that help the tests to be conducted. Therefore, measures should be taken for keeping correct data and sharing information on time between the production and supportive departments.

8.3. Future Research Options

- In the workload method proposed in this thesis, the wafer usage distribution of pilot and volume machines was regarded as the same because of lack of data. More studies should be conducted to formulate separate wafer usage distribution for the pilot and volume machines.
- The effect of the downturn and upturn periods on the wafer usage should be investigated.
- The reasons for different performances of the three different policies proposed for calculating the overall wafer usage should be investigated in more detail. The method should be adapted according to the findings for better accuracy and one standard policy should be developed. This requires applying the method proposed in this chapter for different machine types for subsequent planning periods and learning from the results.
- The manpower needs are calculated in terms of required manhours per week during this thesis. This method can be a basis for Full Time Equivalent Workers (FTE) calculations and shift designs in the Process lab.
- The System Dynamics model could be enhanced to include more variables regarding the Base Line capacity calculations. The time step of the model could be reduced to days instead of weeks and conclusions could be drawn for manpower capacity planning in the Process lab.
- System Dynamics modeling could be applied to other production environments in the semiconductor industry for manpower capacity planning problems.
- More case studies can be conducted for manpower capacity planning in make-to-order production environments where the products have short expiry dates and short processing times.

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APPENDICES

Appendix I: IC manufacturing steps and use of ASML machine during IC manufacturing

The structure of the transistors is imaged multiple times (20-30) on the wafer. Between this "imaging" steps, other steps are performed like coating, developing and etching which can be defined as the processes to make the image on the wafer more durable and visible. A simple overview of IC manufacturing steps is shown in the following figure.
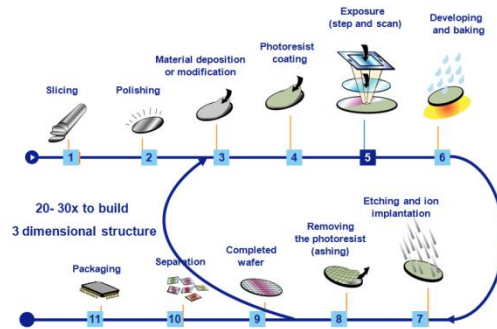
Figure: IC manufacturing steps

ASML products are used during Step 5 of the IC manufacturing cycle: the exposure ("imaging") of the transistors structure on the wafers. The image of the transistors structure that needs to be placed on the wafer, so-called reticle or mask, is placed in the ASML machine, in the wafer scanner. Then a wafer is loaded in to the machine and laser emitted light is sent through a series of lenses and through the reticle and again through a series of lenses for shrinking purposes. Through chemical reactions of the coating on the wafer with the light exposed, the image is printed on the wafer. Then the wafer is unloaded from the machine for developing and baking and the following steps, after which these projected images of lines are converted to real network of lines that are able to store electricity and information. Following figure shows an ASML machine and the positioning of the mentioned reticle, lenses and wafer in the machine.
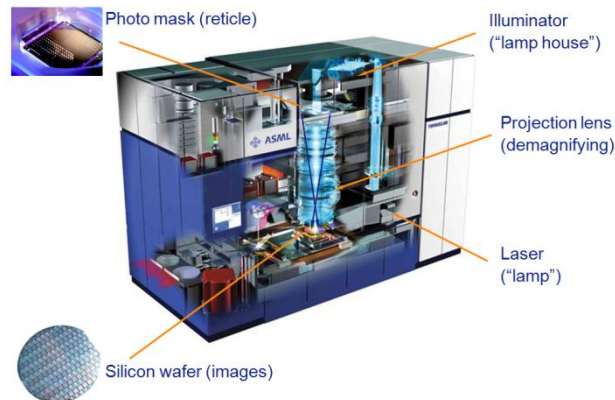
Figure: Wafer exposure in ASML machine

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Appendix II: MP MOS Organizational Chart (as of Feb 15th, 2010)

This appendix describes the role of the Manufacturing and Operational Services (MOS) Unit in the organization of ASML by starting from the highest level in the organization chart. Next, it gives the current organization chart of MOS, showing the place of the direct stakeholders of this research in the organization, namely the Business Reporting and the Processing and Metrology Units.

On the highest level, ASML organizational structure is divided into departments that belong to one of the following separated units: Corporate Support, Support, Product, Market and **Operations**.

Operations Unit is mainly responsible for the manufacturing of the machines. It is divided into departments ACE, Industrial Engineering, Supply Chain Management and **Planning and Manufacturing.**

Planning and Manufacturing (MP) department coordinates the internal manufacturing process in ASML through its subunits Build Operations, Delivery Operations, Manufacturing Engineering & NPI, **Manufacturing Operational Services**, Quality and Operations Wilton.

This master thesis is conducted in collaboration with the Manufacturing Operational Services (MOS) Unit of the Planning and Manufacturing (MP) department. It is supervised by the manager of Business Engineering and conducted in the Processing & Metrology division of the Cleanroom Services. Business Engineering department is responsible for improvement projects in order fulfillment processes, through efficient use of all production factors during manufacturing. Process lab is responsible for wafer handling. Following chart shows the current organizational breakdown of the MP MOS unit.
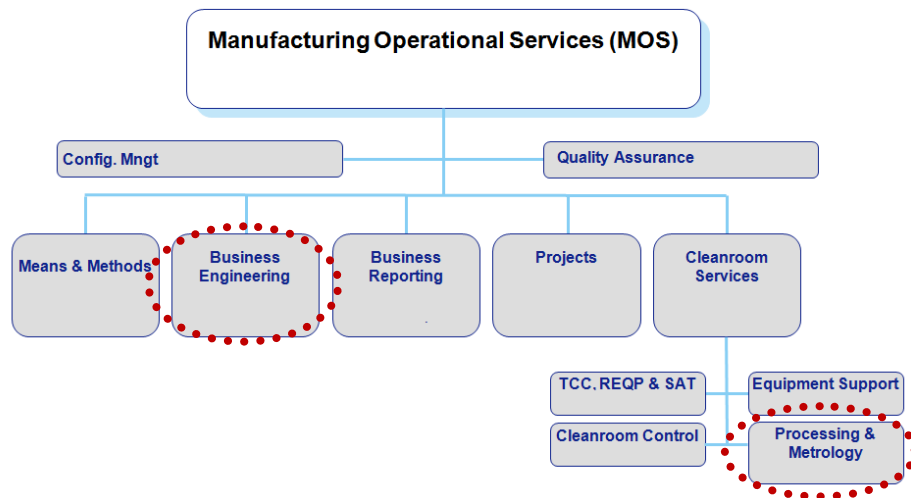
Figure: MP MOS Organizational Chart (as of Feb 15th, 2010)

Appendix III: Similarities and Differences between ASML Process lab and Ordinary Semiconductor Manufacturers

Important distinctions between the demand patterns of ASML Process lab and an ordinary semiconductor manufacturer could be made. The semiconductor manufacturing industry is highly shaped by volatile demand and the effects are the demand volatility are more severe in the Process lab because of the Bullwhip Effect.

Other than the change in the workload caused by demand volatility, both the Process lab and the semiconductor manufacturer both suffer from random yields which result in reworks. Compared to a regular semiconductor manufacturing firm, in the Process lab, the reasons of these random yields might be two fold, i.e. the reasons due to operator errors in the Process lab or in the Test departments, equipment problems in the Process lab or in the modules/machines produced in the production floor, etc. However, in a semiconductor manufacturing company, it is expected that most of the time the reasons for production mistake can be more easily traced back.

Process lab operates only partly in the IC manufacturing flow. In a regular semiconductor manufacturer, the end product is a chip, for which the steps of coating, exposing and developing must be completed. In a regular IC manufacturing flow, exposing is also repetitive to form the layers of a microchip. However, in the Process lab, the end product is wafers that can be of any type demanded, i.e. bare wafers, coated wafers and developed wafers, depending on the machines already on the production floor and on the position of these machines in the cycle time. The following figure highlights the steps that the Process lab executes among the steps of IC manufacturing cycle. The 5th step can be regarded as the tests conducted during the Test Phase of a machine production.
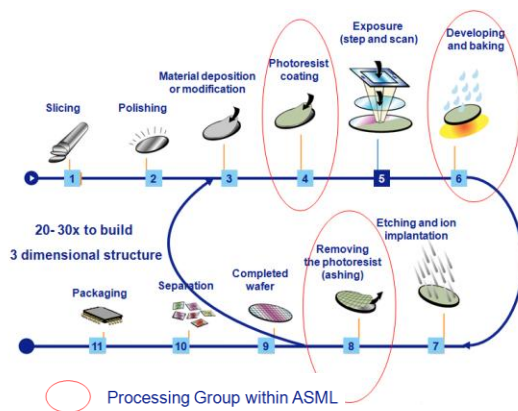
Figure: IC manufacturing steps and main operations in ASML Process lab

In addition to the steps shown in the Figure, another operation in the Process lab is recycling of the wafers. Through recycling in the Process lab, after being used in some tests the wafers are prepared to be used again in other tests. In recycling in the Process lab, the chemicals (photoresist) on the wafers are completely removed. In an ordinary semiconductor manufacturing cycle, after developing, etching and ion implantation is done. In etching the material is removed from the wafer surface parts that are not protected by the photoresist and then with ion implantation the wafer gains electrical characteristics. After that by completely removing the photoresist, a wafer including numerous ICs is ready. However, in the Process lab after developing and measuring for errors, the wafers are sent to recycling and they are not processed further for any electrical characteristics.

Appendix IV: Similarities and Differences between ASML Process lab and Other Manufacturing Units at ASML

Different than the regular machine manufacturing processes and the associated units in the ASML production floor, Process Lab is not directly involved in the manufacturing of the modules of the machine or the machine itself, but provides wafers whenever the need arises for a test that will use wafers to check various specifications regarding the modules or the complete machine produced. In this regard, it resembles more a regular semiconductor manufacturer involved in wafer processing but not in machine building.

The working hours and shift structure is designed as to follow the working hours of manufacturing departments in order to provide wafers whenever the need arises.

Reworks are an internal part of both the machine manufacturing departments and the Process lab. One reason for this is that they all operate in the clean room environment. The smallest dust or other particles may result in serious incompliance with the specifications for the products. Although the end products differ in the manufacturing departments (modules or whole machine) and the Process lab (wafers) all operations require specific conditions of the clean room environment. The differences in terms of end products between the manufacturing departments of ASML and ASML Process lab also create differences that must be taken into account in calculating the capacity needs.

Appendix V: ASML machine types and families

There are two main product subgroups in ASML: PAS 5500 and TWINSCAN machines. PAS 5500 machines are designed for wafers up to 200 mm in diamater while TWINSCAN machines are designed for 300 mm wafers. During this research we were interested in the TWINCAN machines since the demand for PAS5500 machines are severely reduced.

TWINSCAN product names start with some letters showing the type of the platform (bottom part of the machine) (e.g.: XT), followed by a number that designates the lens (e.g.: 1950), followed by a letter that show the productivity upgrades (e.g.: H). The immersion systems are recognized by the "i" that is put behind the letter. Following this representation for example, XT1950Hi shows a machine type, which is a member of XT19x0 machine family.

However, it is possible to add one level more to this naming system. Although not used by every department and every data at ASML, we encountered that the upgrades in the machine platform could also be represented by roman numbers following the platform. The table on the left shows different types of platforms with upgrades shown in Roman numbers and it makes it clear which letter is associated with which platform. It is possible to depict these machine families in a break down structure shown in the following figure.

Table: TWINSCAN machines naming system

Platform with Roman numbers	Letters for Upgrades	Example Machine Family	Example Machine Type
AT	A,B		
XTII	C-E		
XTIII	F-G	XTIII19x0	XT1900Gi or XTIII1900Gi
XTIV	H-K	XTIV19x0	XT1950Hi or XTIV1950Hi
NXT			NXT1950i
NXE			NXE3300B
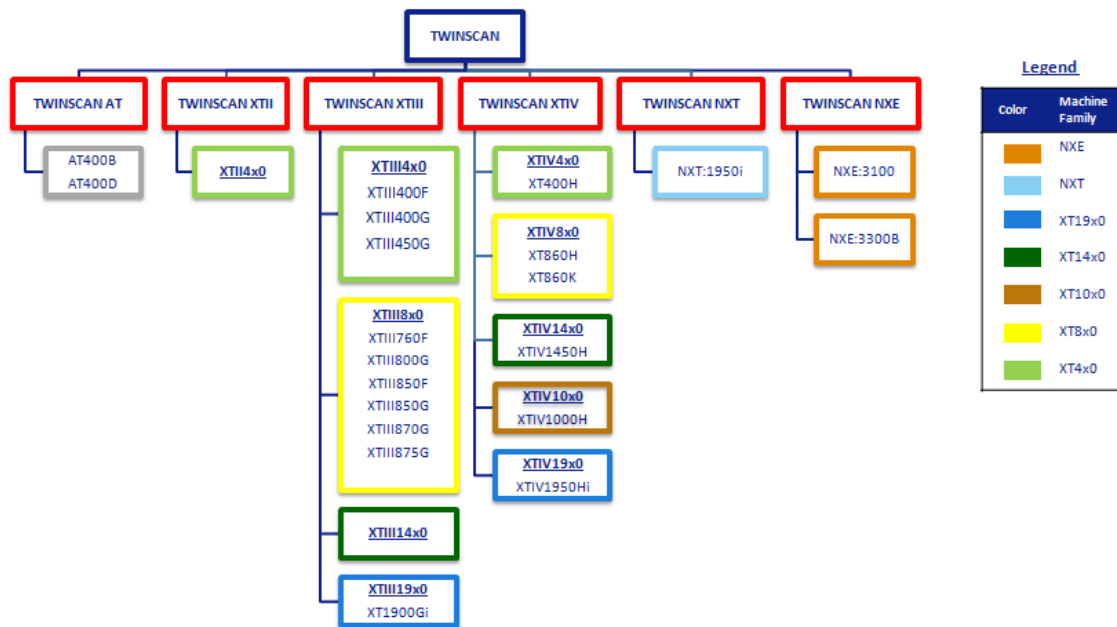
Figure: TWINSCAN machine families

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Appendix VI: Distribution of machines shipped according to the machine families

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Appendix VII: Verbal Definition for Operations in the Process lab

Definition of Terms

Wafer Monitor Tool: Coating Orders are done by using the online Wafer Monitor Tool.

Popdab: Popdab is a database where operators in the Process lab record each coating and developing activity.

Lottraveler: The lottraveler shows all information about the foups such as the chemicals applied on wafers during coating, the time of coating, number of wafers inside the foup, foup id, name of the operator processing the foup , random number of the machine for which the wafers are ordered, etc. Also with a recent change in the documentation, the developing requests are done on this lot traveler by the testers after exposure.

200mm lab and 300mm labs: The operations and the machinery used in the Process lab are mostly divided according to the size of the wafers processed. The operations and the machinery are separated into two labs, called as 200 mm lab and 300 mm labs.

SEM: SEM is another subunit in the Processing and Metrology group that also contains the Process lab. The name comes from the machines called SEM, that are used for checking the quality of the images exposed on wafers during the tests and assessing whether the machines produced work according to the specifications or not.

Coating

The operators in the Process lab constantly check the Wafer Monitor tool to see if there are any new orders. They coat the wafers according to the time the testers need to use them so that the chemicals on the wafers will not get deformed. Before starting with coating they validate the request to see if there are any strange combinations of chemicals requested in order to prevent possible reworks because of wrong requests. If there are no problems, one of the operators who are idle starts with coating.

First the operator records the coating in the popdab. He/she writes the random number of the machine in this new popdab record and gets a new popdab id number from the database. Then he/she copies and pastes this popdab id number in the lottraveler document. This lottraveler is printed and taped on the foup. As the name implies, the foup is travelled always with this lottraveler on it for its history to be available anytime needed. When the operator completes the necessary records on the computer to start the coating, he/she first takes necessary amount of wafers from the bare wafer stock, put them in a separate foup and take them to the track in which they will be coated.

To start coating, the operators have to program the track manually. They do this by selecting the correct chemicals in the track's menu, writing the machine random number and their names in the database of the track. After this step, the wafers are coated. The duration of the coating depends on the number of wafers in the foup. When the coating is finished, the operators have to inspect the wafers for any type of saturations (deformations in the chemicals applied which leads to shape distortions on the wafer). The inspection is done by taking the wafers one by one out of the foup, checking them under special light, and then putting them back in the foup if they can be used or putting them to another foup to be recycled (in this case they have to coat additional wafers to complete the processing of the request). When the inspection is finished and all wafers are ready to be delivered, the operator closes the record in the Wafer monitor tool so that the testers can see that their wafers are ready and waiting for them to be picked up. After closing the record, the operator fills in the time that the coating request is completed on the lottraveler and put the foup in the coated foups hatch from where it can be picked up by the testers.

Developing

Before an operator starts developing the wafers, he/she first validates the requests by checking if any information provided by the tester is missing or misleading. If there are no problems with the request he/she starts with developing the wafers.

During processing the developing request, the operator first records the information for the request in the popdab database, entering the machine random number and getting a new popdab id number for the process. Then he/she updates the lottraveler with the popdab id for developing and the start time of developing. Then in a similar manner done in the coating, he/she takes the foup to the track where the wafers are going to be developed, program the track according to the specifications on the developing request (See the definition for coating in the previous subsection for more information). The wafers are then developed in the track. The duration of this time step also depends on the number of wafers to be developed, like in the process flow for coating. When the wafers are ready, the operator takes the foup from the track and leaves them to the hatch of the developed foups. The testers then come and pick up the wafers from the hatch.

Unlike the coated wafers, developed wafers can wait after the developing is completed; there is no risk of distortion in chemicals. Since the developed wafers are not sensitive to waiting, currently there is not a direct system that lets the testers know that their wafers are ready to be picked up after developing. However, since after the developing processes the wafers are measured in SEM to understand if there were any problems during the test that was done using those wafers, the need to get the test results as soon as possible triggers the testers to follow the situation of their developing requests. Sometimes if the results of the tests are urgent, the testers may ask the Process lab to call when the developing is completed or the Process lab has to call the owner of the request to go to the Process lab and pick up their foup in order to decrease the number of foups waiting in the hatch.

Recycling, Foup Cleaning and Monitoring

The wafers that are used can be recycled to be used in other tests. Recycling is done in the 200 mm lab. The testers bring the wafers in the foup to the 200 mm lab after their tests are completed and the results of the tests are obtained in SEM.

There are different types of wafers used in the process lab (called LQ wafers, flat edge wafers, ALTIC wafers, etc.) which differ according to some characteristics about the shape like thickness. When the wafers to be recycled are left to the Process lab by the testers, the operator first has to check which type the wafers are and then put them in associated foups in which the wafers to be recycled of the same type are accumulated. This accumulation is done because the recycling machines work with full foups. In these machines the chemicals on the wafers are removed and the wafers are made ready to be used again for next coating requests.

The foups also need to be cleaned for the wafers not to contain any particles that may harm the test processes. Hence, once in every two weeks the foups are cleaned in special foup cleaning machines which clean the wafers with water and detergent. The machine can clean two foups at the same time and this takes around 15 minutes.

Other operations in the Process lab include operations like checking if the tracks work accordingly by running some test wafers in them and checking the thickness and flatness of the chemicals applied on the wafers, checking the chemicals level in the tracks and changing the chemicals bottle if necessary, general cleaning activities, checking the humidity and temperature in the Process lab etc. Some of these activities are done on daily basis, some of them on weekly basis and some of them on monthly basis. We collect all these activities under the name of Monitoring.

Appendix VIII: Wafer Request Lead time Calculations

Histogram of Lead time for Coated Wafers (in days)

	-2	-1	0	1	2	3	4	5	6	7	
Frequency	1	1	6982	37385	1611	1173	670	364	238	154	305
Cumulative %	0,00%	0,00%	14,29%	90,76%	94,06%	96,46%	97,83%	98,57%	99,06%	99,38%	100,00%

Histogram of Lead time for Coated Wafers (in hours)

	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Frequency	21	3	17	6941	22897	4518	2052	1080	604	439	314	389	319	287	203	148	144	165	241	435	541	533	390	383	359	316	242	386	0
Cumulative %	0,05%	0,05%	0,09%	15,74	67,35	77,53	82,15	84,59	85,95	86,94	87,65	88,52	89,24	89,89	90,35	90,68	91,00	91,38	91,92	92,90	94,12	95,32	96,20	97,06	97,87	98,58	99,13	100,0	100,0

Histogram of Lead time for Coated Wafers (in minutes)

	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	More
Frequency	2	4	6	5	10	33	6882	9132	4369	3097	2140	1446	2713	1017	815	740	544	486	916	84
Cumulative %	0,01%	0,02%	0,03%	0,05%	0,08%	0,17%	20,16%	46,67%	59,36%	68,35%	74,56%	78,76%	86,64%	89,59%	91,96%	94,11%	95,69%	97,10%	99,76%	100,00%

Following the histograms it can be calculated that almost 42 % of wafers are requested only within 30 minutes before the tests (~62% of wafers are requested 1 hour before). [14]

$$P(wafers\ request\ lead\ time \leq 30\ minutes)$$
$$= P(wafers\ request\ lead\ time\ (days)) \leq 1\ day) * P(wafers\ request\ lead\ time\ (hours)) \leq 1\ hour)$$
$$* P(wafers\ request\ lead\ time\ (minutes)) \leq 30\ minutes) = 90.76\% * 67.35\% * 68.35\% = 41.78\%$$

---

[14] Note that the records which seemed erroneous such as wafers requested after the time needed or with lead times of 1 year etc. were removed from the database to come up with a more realistic calculation.

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Appendix IX: Start FASY and GSD share of the machine families

(2008-2011)

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Appendix X: Explanation of the Relations between the Factors Affecting the Workload in the Process lab

Relationship no	Name of the Relationship	Explanation
1	Learning <-> Man.Sys.	The learning curve specifies how the cycle time changes for each additional product produced (Argote and Epple, 1990). Cycle time of the production is expected to decrease with each additional machine until it converges to an average value. According to the interviews, at ASML the machines are released for volume before the learning curve gets steady. This affects the cycle time during which the machines require wafers for tests. In addition, as learning increases the rate of rework is expected to decrease, which decreases the number of tests required on a machine, decreasing the workload of the Process lab
2	Learning <-> Dev. Sys.	Learning in a specific type of machine starts with the first prototypes and continues with the pilots. So, the first part of a learning curve is created by the development machines. As in the manufacturing systems, the cycle time of production is expected to decrease with each additional machine.
3	Forgetting <-> Man.Sys.	Complexity of operations and turnover rate due to flexible workers increase the risk of organizational forgetting. Product mix (workers switching to work on different product types) causes discontinuities in the learning process (Stratman et al. 2004, Candar 2010)
4	Reworks <-> Man.Sys.	The higher the reworks in tests on these machines, the more wafers are ordered from the Process lab for these tests. Reworks can stem from a test resulting negative, a tester error while conducting the test, an operator error while processing the wafers required for the test., the tracks in the process lab yielding wafers that cannot be used or in the extreme case when the machines are down and coated wafers cannot be used till they expire.
5	Reworks <-> Dev. Sys.	
6	Vol. Mach. -> Coating	The higher the number of tests that use wafers the higher the coating workload of the Process lab
7	Dev. Mach. -> Coating	
8	R&D P.lab -> Coating	These customers order the wafers to be coated only of they have capacity problems with their tracks or their tracks are down
9	Demo lab -> Coating	
10	Vol. Mach. -> Developing	The higher the number of tests that use wafers the higher the developing workload of the Process lab
11	Dev. Mach. -> Developing	
12	R&D P.lab -> Developing	These customers order the wafers to be developed only of they have capacity problems with their tracks or their tracks are down
13	Demo lab -> Developing	
14	Vol. Mach. -> Recycling	Process lab 4 is the only location within ASML that has the recycling facilities. Hence, all wafers used within ASML are recycled in the Procss lab 4
15	Dev. Mach. -> Recycling	
16	R&D P. lab -> Recycling	
17	Demo lab -> Recycling	
18	Vol. Mach. -> Foup Cleaning	Process lab 4 is the only location within ASML that has the foup cleaning machinery. All foups within ASML production facilities are cleaned in Process lab 4.
19	Dev. Mach.-> Foup Cleaning	
20	R&D P.lab -> Foup Cleaning	
21	Demo lab -> Foup Cleaning	

Appendix XI: Current Way of Manpower Capacity Planning in ASML Process lab

Currently there is no systematic tool used for Manpower Planning in the Process lab. The interviews revealed that the manpower decisions are done on a gut feeling based on the upturn/downturn situations, determined by the change in the Move Rate. According to the increase/decrease in the Move Rate, Processing group determines to increase/decrease the number of Operators in the Process lab. The figures below show the target increase and division of tasks between the operations in the Process lab.

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Appendix XII: Manpower Capacity Planning in the TEST departments of ASML

Using the Gantt-chart of machines, the TEST departments first calculate the expected WIP in a horizon of two planning years (from the start of the current year till the end of the next year). In order to calculate WIP, Little's Law is used. Little's Law states that the average number of customers in a system equals to the arrival rate of customers multiplied by the average time a customer spends in the system. In the production environment this notion can be formulated as:

*WIP= MR*CT*

where WIP: Work in Process inventory (number of machines on the production floor)
MR: Mover Rate, number of machine starts per week
CT: Cycle Time

Once the number of machines from each machine type is calculated this way, the test departments use the Man to Machine Ratio to calculate the necessary manpower during the planning horizon. They basically multiply the WIP by Man to Machine Ratio to calculate the necessary manpower to obtain the necessary FTE (Full Time Equivalent worker).

The following figure represents this process schematically.
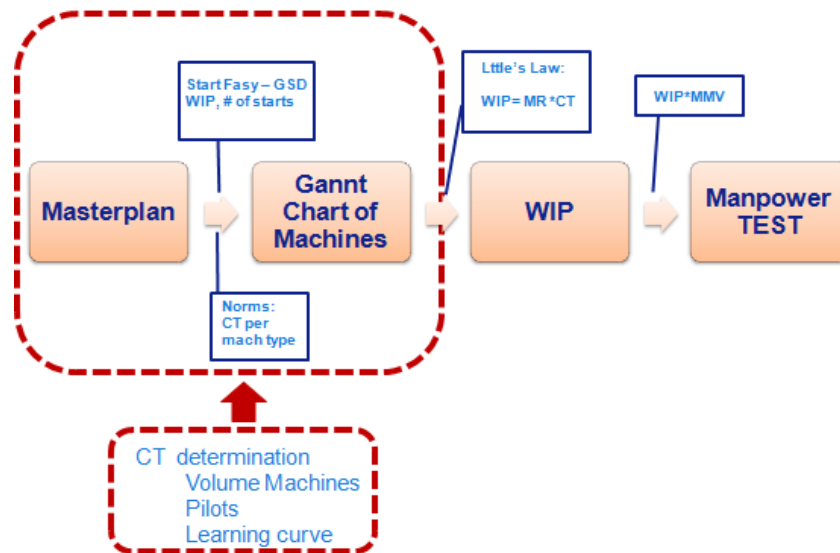
Figure: Flow of Manpower Planning in the TEST departments

Using Gantt-Chart for Manpower Planning in Process lab vs. Using it for Manpower Planning of Other Departments

One difference between the manufacturing departments and the Process lab in using the Gantt-chart for manpower planning is that, for the other departments this information provides the expected workload while for the Process lab this information is part of the expected demand information which will create the workload. This is because of the fact that Process lab is the supplier of wafers for production of the machines. By using the production planning information of the machines, we can only obtain the machine type and the start and end dates of the test phase during which the machine is expected to use wafers. The amount and timing of the wafer orders however, should be added into the manpower planning tool of ASML Process lab to obtain the expected workload in long term. This information will be added from our data analysis of the wafer requests.

Another difference is that other departments are interested in seeing the WIP on a specific time. This is because after the machine production starts, the need for manpower is taken as a constant (multiplication by the constant "Man to Machine Ratio") per machine type. However in the case of the Process lab, since the wafer need of machines is expected not to be constant through the cycle time of the machine, we need to see the on which part of the cycle time a machine is on a particular date. To check the situation of each machine regarding the position in the planned cycle time on a specific date is possible with the Gantt-chart approach.
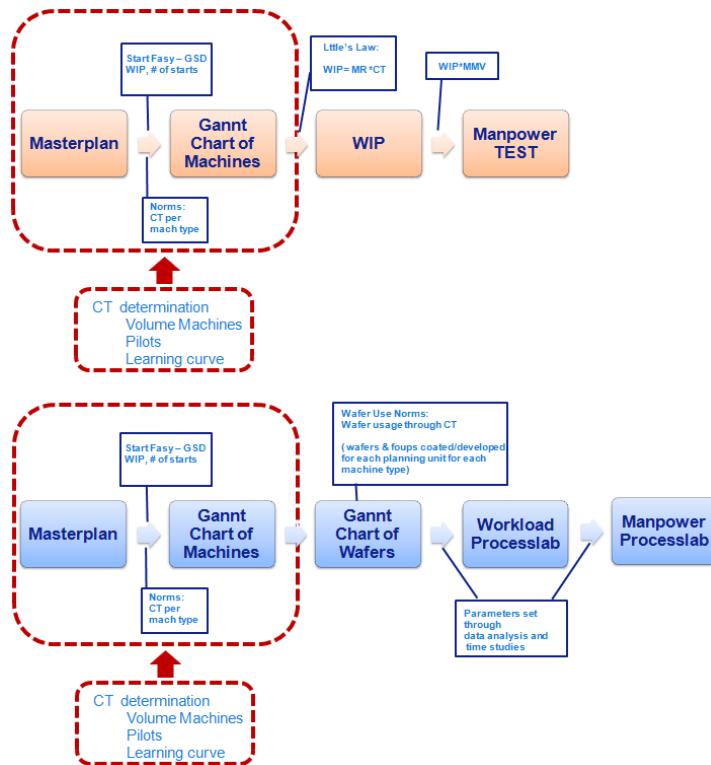
The figure on the left summarizes these differences in using the Gantt-Chart for calculation of manpower need between the Process lab and the TEST department at ASML.

Figure: Flow of manpower capacity planning strategies for the TEST departments and the Process lab

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Appendix XIII: Databases used in the Process lab

Wafer Monitor Tool Interfaces and Use

Figure: Wafer Monitor Tool interface for Testers

Figure: Wafer Monitor Tool Interface for the Operators in the Process lab

Using the wafer monitor tool the testers first choose the random number of the machine. The random number is sort of the identification of the machines. When they choose the random number other information regarding the machine, such as its type and the cabin (the work center dedicated for the production of that machine) is automatically filled in.

After filling in the information of the machine for which they place the coating request, the testers need to do indicate the specifications for the coating. In other words they need to choose the wafer size and the properties of the chemicals to be applied on the wafer. This is either done by selecting the test procedure in which these specifications are already given or they can manually enter the coating they want. If the tester do not require any coating on the wafers, i.e. if they ask for bare wafers, they leave they do not fill in any information for the chemical layers to be applied during coating. In all cases they choose the amount of wafers to be coated (lot size) and the time they need to have the wafers ready (time needed) manually.

In the wafer monitor tool interface that the operators in the Process lab use, the orders placed and not coated yet are listed according to the time needed. This is because in most cases the order of execution in the process lab follows the EDD (Earliest Due Date) approach, to prevent the coated wafers from getting deteriorated because of the chemical sensitivity. When they start a coating they press the "Execute" button and when they finish the coating they press the "Finish" button for the particular order that they will deliver. By pressing these buttons, the time that the wafers are started to be coated and the time they are ready can be traced by the testers and also they can be recorded in the Wafer Monitor database.

Popdab Interface and Database

Figure: Popdab Interface   Figure: Popdab Database View

The Popdab database shows the records for both coating and developing operations. However, in the database it is not directly seen which record is for coating and which record is for developing. Popdab Database only shows the Popdab id, machine random number, the start time timof the operation and the name of the operator who executed it.

During our data analysis step we aimed at linking the Wafer Request Tool and Popdab databases to each other by using the Popdab id that is common in both databases. We did this in order to find the developed wafers need of a machine during its lifetime. During this process we encountered some difficulties stemming from the misuse of the databases, such as wrong data entry or not entering the data at all. However, since they were our most important data sources for the workload information in the Process lab, we continued using them.

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Appendix XIV: Methods for Calculating WUP using the Process lab databases

Method to Calculate the Wafer Usage Period for Coating (WUPcoating)

In order to calculate the start and end time of wafer usage, the "time needed" information in the Wafer Request Tool was used. For each machine that has ordered wafers anytime from 2007 to July 2010[15], the day on which they needed coated wafers for the first time and the day on which they needed coated wafers for the last time were extracted from the Wafer Request database. This database only shows the coating requests (i.e. bare or coated wafers use, not the developed wafers use). So, we call the WUP we found using this database as $WUP_{coating.}$. Below we give the input/output, algorithm and the code of the VBA program that calculates the $WUP_{coating}$.

MS Excel VBA code to calculate WUPcoating

Aim: To extract the first day of wafer usage and the last day of wafer usage of each machine.

Input: Wafer Request Database and the list of machine random numbers in the database

Output: The date on which the machine needed the first wafer, the date on which the machine needed the last wafer (based on "time needed" column in the Wafer Request database), WUP (Wafer Usage Period, difference between the last and first wafer usage day)

Algorithm: (ctd. in the next page)

---

[15] This analysis is done for the PAS systems as well together with the TWINSCAN systems since some random numbers in the Wafer Request database belong to the PAS machines. The results are available by the author but they were not used in this thesis since the scope includes only the TWINSCAN machines.

Repeat for each machine in the machine list

For each machine in the machine list
Keep random no of the machine

Assign variables first and last date of the machine
Assign "first" to a large date
Assign "last" to a small date

For each record in the wafer request
Check random no

Find WUP coating
Print the "first" and "last"

Is it the same random no as the machine whose WUP is being calculated — N

Y

Check the "time needed"

Is time needed smaller than "first" — N

Y

Assign "first" to the "time needed" date

Is time needed greater than "last" — N

Y

Assign "last" to the "time needed" date

Repeat for each record in Wafer Request

MS Excel VBA Code:

```vba
Option Explicit

Sub find_first_last_waferreq_dates()

Dim first As Date 'to hold the first wafer usage date of a machine
Dim last As Date  'to hold the last wafer usage date of a machine
Dim randomno As Long

Dim i As Long 'counter to loop through the rows of the excel sheet to be filled with wafer info
Dim j As Long

Dim endrow_machineinfo As Long
Dim endrow_waferreq As Long

Dim Basesheet As String 'holds the name of the current sheet (the sheet to fill with wafer information)
                        '(a variable in case the name of the file changes later)
```

```vba
Application.ScreenUpdating = False
Application.Calculation = xlManual

Basesheet = ActiveSheet.Name
endrow_machineinfo = Range("A3").End(xlDown).Row

Sheets("waferreq database").Activate
endrow_waferreq = Range("A2").End(xlDown).Row

Sheets(Basesheet).Activate

For i = 3 To endrow_machineinfo
    randomno = Cells(i, 1)
    first = "12-12-2222"  'assign first to a very large date
    last = "1-1-1980"     'assign last to a very small date

    Sheets("waferreq database").Activate

    For j = 1 To endrow_waferreq
        If Cells(1 + j, 23) = randomno And Cells(1 + j, 4) < first Then  'comparisons for time needed
            first = DateValue(Cells(1 + j, 4))
        End If
        If Cells(1 + j, 23) = randomno And Cells(1 + j, 4) > last Then
            last = DateValue(Cells(1 + j, 4))
        End If
    Next j

    Sheets(Basesheet).Activate
    Cells(i, 15) = first
    Cells(i, 16) = last

Next i

Cells(1, 8) = Date


MsgBox "ok"

Application.ScreenUpdating = True
Application.Calculation = xlAutomatic

End Sub
```

Method to Calculate the Wafer Usage Period for Developing (WUPdeveloping)

As explained before, the Popdab database is the data archive for the developing processes. It also holds the historical data for the coating processes. A drawback of this mixed database is that it does not differentiate between the coating and developing requests. In order to calculate the workload of coating and developing, separate historical data for each of them are needed. The method that was used in this thesis to reach the separate developing information by linking the two databases with a program written in MS Excel VBA, which uses the common columns of both databases as a bridge (i.e. random no of the machine and the popdab id number). One output of this program is a list showing if each record was a coating or developing process. The whole algorithm, inputs/outputs and the VBA code of this program can be seen is given in Appendix XV. After obtaining the developing information as such, the WUP$_{developing}$ is calculated with a MS Excel VBA program, in a similar manner as the WUP$_{coating}$.

The following subsection comments on the results for WUP.

Results for WUP (Expected Results vs. Results obtained in case study)

When the *WUP* $_{coating}$ and *WUP* $_{developing}$ for each machine were calculated by using the data in the Process lab databases, some unexpected results were observed such as a machine makes developing requests in a week where actually in that week no coating orders were done. This situation highlights the reliability issues about data management in the Process lab. Due to the inconsistencies in the data, we chose to use only the WUP $_{coating}$ as the wafer usage period of the machines because of the discussions above.

After the first day and last day of the WUP were completed for each machine, another analysis was done comparing these dates with the Start of FASY and GSD respectively. Normally it is expected that the first day of WUP is a later date than Start FASY and the last day of WUP is before the GSD for each machine. However, the opposite results were observed for some machines. What is more, the difference (first day of WUP- Start FASY) and (GSD-last day of WUP) changes in a large scale from minus 145 weeks to plus 30 weeks in the databases kept in the Process lab. This situation increased the concerns about the reliability of the databases used. Hence, a assumptions were done during this thesis

Appendix XV: MS Excel VBA code to link Wafer Request and Popdab databases

Aim: To link two databases to each other, to separate developing information from coating information, to form a base in order to get relevant developing information for machines, to assess the reliability of each databases and to make recommendations for improvement

Input: Wafer Request Database, the list of machine random numbers in the database, Popdab database (with random no column as the first column) [16]

Output: Separation of popdab records as coating or developing, checks for the way of using the popdab database, overview of correct and missing/erroneous records, basis for improvements in the database

Algorithm:

Example execution of the code

MS Excel VBA Code:

```
Option Explicit
Const popdabsheet = "popdab_300mm_original_till 30ma"  'name of the sheet that keeps the  popdab data table
Const waferreqsheet = "WaferCoatOrder till 30 may wexc" 'name of the sheet that keeps thewafer request data table

Sub link_popdab_to_waferreq()
' this macro searches the popdab database according to the random number of the machines,
'tries to find a match in waferreq using the random number and the popdab id

'aim is to understand how many coating requests and how many developing requests each machine has per week/month

' this macro doesn't take into account the wafers processed to/from stock
' this macro doesn't take into account the records when popdab/waferreq is broken (popdab id: 0, 1111, weird numbers)
```

---

[16] The time span of the databases should end on the same date.

```vba
Dim i As Long 'COUNTERS FOR THE LOOPS THROUGH ROWS
Dim j As Long

Dim randomno As Integer
Dim randomno_waferreq As Integer
Dim popdabid As Long
Dim count As Integer 'counts how many times a popdab id is in waferreq _
(normally it should be 0 or 1)
Dim check_if_coat As Boolean 'true if the record is also in waferreq false otherwise _
(true if coating false if developing)

Dim waferreqdate As Date
Dim waferreqtime As Date
Dim addrecord As Long
Dim endrow_popdab As Long
Dim endrow_waferreq As Long
Dim operator As String

Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

ThisWorkbook.Sheets(popdabsheet).Activate
endrow_popdab = Range("A2").End(xlDown).Row

ThisWorkbook.Sheets(waferreqsheet).Activate
endrow_waferreq = Range("A2").End(xlDown).Row

ThisWorkbook.Sheets(popdabsheet).Activate
Range("a2").Activate

addrecord = 0

For i = 1 To endrow_popdab
    randomno = ActiveCell.Value
    popdabid = ActiveCell.Offset(0, 1).Value
    count = 0
    check_if_coat = False

    For j = 1 To endrow_waferreq
        If ThisWorkbook.Sheets(waferreqsheet).Range("I1").Offset(j, 0).Value = popdabid Then
            'check to see if the record in waferreq is in popdab 'normally all rows should be "y"
            ThisWorkbook.Sheets(waferreqsheet).Range("ah1").Offset(j, 0).Value = "y"
            check_if_coat = True 'if it is in waferreq this means it is a coating request
            count = count + 1  'for the how many times popdab id in wafer req coloumn   (normally it should be 1 or 0)

            'to check random no if popdab id same coloumn (normally it should be the same)
            randomno_waferreq = ThisWorkbook.Sheets(waferreqsheet).Range("w1").Offset(j, 0).Value
            'takes the date of the execution in waferreq 'to check if it is the same date as in popdab
            waferreqdate = DateValue(ThisWorkbook.Sheets(waferreqsheet).Range("g1").Offset(j, 0).Value)
            waferreqtime = ThisWorkbook.Sheets(waferreqsheet).Range("g1").Offset(j, 0).Value
            operator = ThisWorkbook.Sheets(waferreqsheet).Range("h1").Offset(j, 0).Value


            'ADD THE MISSING/ERRONEOUS RECORDS AT THE END OF THE FILE
            If randomno_waferreq <> randomno Then
                addrecord = addrecord + 1
                Range("a103193").Offset(addrecord, 0).Value = randomno_waferreq
                Range("a103193").Offset(addrecord, 1).Value = popdabid
                Range("a103193").Offset(addrecord, 2).Value = ThisWorkbook.Sheets(waferreqsheet).Range("H1").Offset(j, 0).Value
                Range("a103193").Offset(addrecord, 3).Value = waferreqdate
                Range("a103193").Offset(addrecord, 4).Value = ThisWorkbook.Sheets(waferreqsheet).Range("g1").Offset(j, 0).Value

            End If
        End If

    Next j

    If check_if_coat = True Then
        ActiveCell.Offset(0, 5).Value = "y"
        ActiveCell.Offset(0, 7).Value = randomno_waferreq
        ActiveCell.Offset(0, 9).Value = waferreqdate
    Else
        ActiveCell.Offset(0, 5).Value = "n"
    End If

    ActiveCell.Offset(0, 6).Value = count

    ActiveCell.Offset(1, 0).Activate

Next i

MsgBox "ok"

Application.ScreenUpdating = True
Application.Calculation = xlAutomatic

End Sub
```

Appendix XVI: MS Excel VBA code to Calculating the Wafer Demand through the WUP of a single machine

Calculating the Wafer Demand for Coating through the WUP of a single machine

In order to calculate the wafer usage of a machine during each week of its WUP, the "time needed" information in the Wafer Request Tool was used. The algorithm of the calculations is shown in the following figure. Note that the planning horizon for this program is taken as the maximum WUP to calculate the wafer usage information for all the machines. Thanks to the algorithm, if a wafer has not ordered/used any wafers during any week in its WUP, the wafer information of those weeks is shown as zero.

Note that the algorithm and the VBA code are developed by taking the Start of FASY of machines as the reference point. In other words, the algorithm checks the first day of WUP for each machine, and calculates the weeks according to this date (forward calculation method). When the GSD is taken as a reference point the only part that changes in the algorithm is the part shown in dashed circles. The weeks are calculated according to the last day of WUP this time (backwards calculation method).
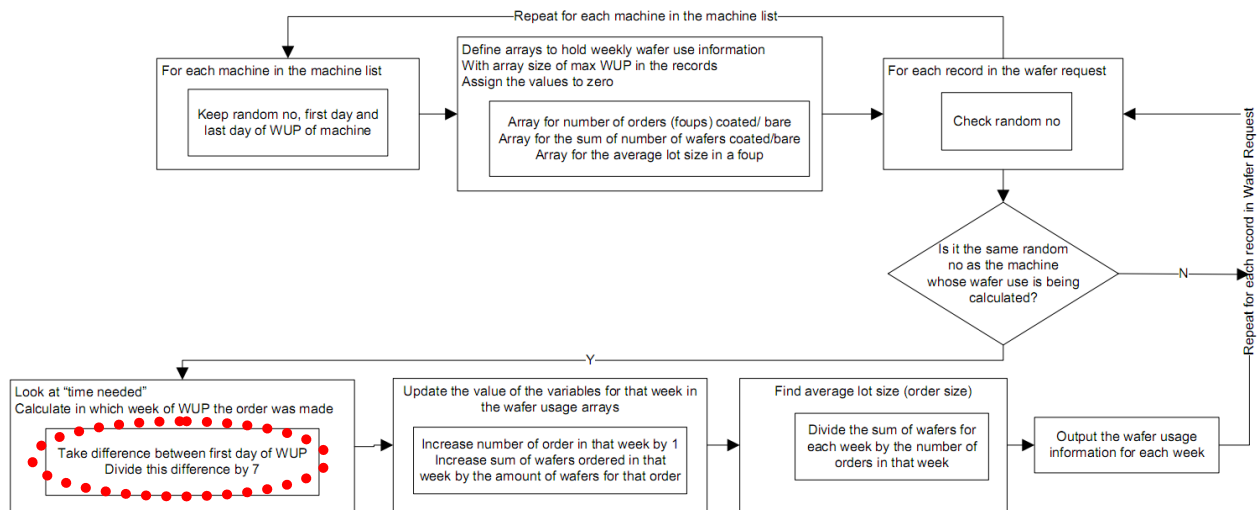
Figure: Algorithm to calculate the weekly wafer usage information (Reference point: Start of FASY)

MS Excel VBA code to calculate the weekly wafer usage information for coating

Aim: To calculate the weekly wafer usage information for each machine in order to see the distribution of wafer usage over the cycle time of the machine

Input: Wafer Request Database, the list of machine random numbers in the database,

Output: Weekly wafer usage information for each week the machine used wafers. Sum of coated&bare wafers ordered, number of orders, average lot size

MS Excel VBA Code:

```vba
Option Explicit
Option Base 1
Const weeks_to_show = 30 'due to the limitations of excel max WUP is separated into three sheets
'weeks 31 to 107 and weeks 108 to 164 on other sheets

Sub weekly_wafer_first30()

Dim randomno As Long

Dim first As Date 'to hold the first wafer usage date of a machine
Dim last As Date  'to hold the last wafer usage date of a machine

Dim endrow_machineinfo As Long
Dim endrow_waferreq As Long

Dim Basesheet As String 'holds the name of the current sheet (the sheet to fill with wafer information)
                        '(a variable in case the name of the file changes later)

Dim diff As Long
Dim index As Integer
Dim waferamount As Integer

Dim numberororders_week(weeks_to_show) As Integer
Dim sum_waferamount_week(weeks_to_show) As Integer
Dim avg_waferamount_week(weeks_to_show) As Double

Application.ScreenUpdating = False
Application.Calculation = xlManual

Dim i As Long 'COUNTERS FOR THE LOOPS THROUGH ROWS
Dim j As Long
Dim k As Long
Dim l As Long


Basesheet = ActiveSheet.Name
endrow_machineinfo = Range("A7").End(xlDown).Row

Sheets("waferreq database").Activate
endrow_waferreq = Range("A2").End(xlDown).Row

Sheets(Basesheet).Activate
Range("A7").Activate

'Print coloumn names for weekly wafer information
j = 1
For i = 1 To weeks_to_show
    Cells(6, 19 + j) = "w" & i & "  wafers coated"
    Cells(6, 20 + j) = "w" & i & "  foups coated"
    Cells(6, 21 + j) = "w" & i & "  avg order size"
    j = j + 3
Next i

 'assign zero to the array values
 For k = 1 To weeks_to_show
     numberororders_week(k) = 0
     sum_waferamount_week(k) = 0
     avg_waferamount_week(k) = 0
 Next k
```

```
For i = 7 To endrow_machineinfo
    randomno = Cells(i, 1)
    first = Cells(i, 15)
    last = Cells(i, 16)

    For k = 1 To weeks_to_show
        numberororders_week(k) = 0
        sum_waferamount_week(k) = 0
        avg_waferamount_week(k) = 0
    Next k

    Sheets("waferreq database").Activate

    For j = 2 To endrow_waferreq

        If Cells(j, 23) = randomno Then
        ' take the difference between the time needed and the date of first wafer use
            diff = DateDiff("d", first, Cells(j, 4), vbMonday)
            index = diff \ 7 + 1

            If index < weeks_to_show + 1 Then
                numberororders_week(index) = numberororders_week(index) + 1
                waferamount = Cells(j, 11)
                sum_waferamount_week(index) = sum_waferamount_week(index) + waferamount
            End If
        End If

    Next j

    'find avg order size
    For k = 1 To weeks_to_show
        If numberororders_week(k) = 0 Then
            avg_waferamount_week(k) = 0 'to prevent division by zero
        Else
            avg_waferamount_week(k) = sum_waferamount_week(k) / numberororders_week(k)
        End If
    Next k

    'print the wafer information
    Sheets(Basesheet).Activate

     'print the wafer information
     Sheets(Basesheet).Activate

     l = 1
     For k = 1 To weeks_to_show
         Cells(i, 19 + l) = sum_waferamount_week(k)
         Cells(i, 20 + l) = numberororders_week(k)
         Cells(i, 21 + l) = avg_waferamount_week(k)
         l = l + 3
     Next k

Next i

Cells(1, 8) = Date

MsgBox "ok"

Application.ScreenUpdating = True
Application.Calculation = xlAutomatic

End Sub
```

The following figure shows an example output of the calculations for one machine both forward and backwards (i.e. based on the first day and the last day of WUP respectively).

Random_n umber	machine type from wafer req	first wafer usage	last wafer usage	wup (weeks)	wup (months)
5959	XT1900G	22-nov-07	13-feb-08	11,9	2,8

Forward_Calculation (Based on the first day of WUP, w1: first week after the first day of WUP, w2: second week after the first day of WUP etc.)

Backwards_Calculation (Based on the last day of WUP, w1: last week before the last day of WUP, w2: second last week before the last day of WUP etc.)

Figure: Example output of weekly wafer usage calculation for one machine

Calculating the Wafer Demand for Developing through the WUP of a single machine

The Popdab database was divided into two as coating records and developing records with the VBA program given in Appendix XV. In order to calculate the demand for developing during the WUP of the machines, the algorithm explained above was adapted to the Popdab database and the developing information for each week during the WUP of machines was calculated for each machine.

Appendix XVII: Weekly wafer usage information for coating (Sample machines with same machine type and same WUP)

Random _number	machine type from wafer req	Sum of wafera mount	Count of orders	wup (weeks)	w1 wafers coated	w1 foups coated	w1 avg order size	w2 wafers coated	w2 foups coated	w2 avg order size	w3 wafers coated	w3 foups coated	w3 avg order size	w4 wafers coated	w4 foups coated	w4 avg order size	w5 wafers coated	w5 foups coated	w5 avg order size	w6 wafers coated	w6 foups coated	w6 avg order size	w7 wafers coated	w7 foups coated	w7 avg order size	w8 wafers coated	w8 foups coated	w8 avg order size	w9 wafers coated	w9 foups coated	w9 avg order size	w10 wafers coated	w10 foups coated	w10 avg order size	w11 wafers coated	w11 foups coated	w11 avg order size	w12 wafers coated	w12 foups coated	w12 avg order size
3604	XT1900G	619	92	11,0	30,0	3,0	10,0	13,0	1,0	13,0	67,0	7,0	9,6	0,0	0,0	0,0	14,0	2,0	7,0	30,0	5,0	6,0	25,0	3,0	8,3	57,0	6,0	9,5	55,0	7,0	7,9	192,0	38,0	5,1	128,0	18,0	7,1	8,0	2,0	4,0
4796	XT1900G	1326	145	11,0	12,0	1,0	12,0	34,0	4,0	8,5	2,0	1,0	2,0	8,0	2,0	4,0	17,0	3,0	5,7	18,0	4,0	4,5	169,0	17,0	9,9	247,0	30,0	8,2	539,0	50,0	10,8	123,0	12,0	10,3	155,0	20,0	7,8	2,0	1,0	2,0
5505	XT1900G	1121	109	10,1	13	1	13	0	0	0	0	0	0	2	1	2	0	0	0	53	6	8,83	54	7	7,71	133	18	7,39	274	22	12,5	567	51	11,1	25	3	8,33	0	0	0,0
6049	XT1900G	656	98	10,0	16,0	5,0	3,2	23,0	3,0	7,7	2,0	1,0	2,0	7,0	1,0	7,0	40,0	3,0	13,3	73,0	8,0	9,1	66,0	9,0	7,3	144,0	23,0	6,3	208,0	27,0	7,7	75,0	17,0	4,4	2,0	1,0	2,0	0,0	0,0	0,0
6531	XT1900G	1133	150	10,0	16,0	3,0	5,3	14,0	3,0	4,7	94,0	9,0	10,4	40,0	4,0	10,0	13,0	1,0	13,0	105,0	9,0	11,7	118,0	17,0	6,9	93,0	15,0	6,2	260,0	43,0	6,0	350,0	44,0	8,0	30,0	2,0	15,0	0,0	0,0	0,0
7066	XT1900G	1149	159	11,0	40,0	5,0	8,0	14,0	2,0	7,0	87,0	9,0	9,7	76,0	9,0	8,4	33,0	5,0	6,6	33,0	3,0	11,0	66,0	9,0	7,3	150,0	21,0	7,1	167,0	28,0	6,0	179,0	37,0	4,8	282,0	29,0	9,7	22,0	2,0	11,0
7595	XT1900G	758	88	10,0	36,0	3,0	12,0	12,0	1,0	12,0	26,0	3,0	8,7	28,0	3,0	9,3	34,0	3,0	11,3	6,0	1,0	6,0	73,0	7,0	10,4	156,0	22,0	7,1	216,0	25,0	8,6	170,0	19,0	8,9	1,0	1,0	1,0	0,0	0,0	0,0
7827	XT1900G	478	61	10,6	27,0	3,0	9,0	20,0	3,0	6,7	28,0	4,0	7,0	10,0	1,0	10,0	14,0	2,0	7,0	38,0	3,0	12,7	55,0	4,0	13,8	2,0	1,0	2,0	98,0	15,0	6,5	148,0	20,0	7,4	38,0	5,0	7,6	0,0	0,0	0,0
8239	XT1900G	896	126	10,4	14,0	2,0	7,0	15,0	2,0	7,5	22,0	2,0	11,0	70,0	8,0	8,8	46,0	4,0	11,5	58,0	5,0	11,6	56,0	7,0	8,0	164,0	29,0	5,7	187,0	27,0	6,9	135,0	24,0	5,6	129,0	16,0	8,1	0,0	0,0	0,0
8258	XT1900G	892	108	11,0	12	1	12	0	0	0	6	1	6	18	2	9	80	10	8	54	7	7,71	56	9	6,22	32	4	8	78	10	7,8	99	30	3,3	432	33	13,1	25	1	25
8422	XT1900G	655	78	10,1	6,0	1,0	6,0	2,0	1,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	39,0	3,0	13,0	12,0	1,0	12,0	54,0	6,0	9,0	102,0	9,0	11,3	77,0	12,0	6,4	259,0	36,0	7,2	104,0	9,0	11,6	0,0	0,0	0,0
9303	XT1900G	790	98	10,1	12,0	1,0	12,0	28,0	3,0	9,3	29,0	4,0	7,3	89,0	10,0	8,9	54,0	6,0	9,0	28,0	4,0	7,0	105,0	12,0	8,8	117,0	22,0	5,3	200,0	23,0	8,7	58,0	7,0	8,3	70,0	6,0	11,7	0,0	0,0	0,0

Appendix XVIII: Bare vs. Coated Wafers Ratio from Wafer Request Database

Years			
2008	2009	2010	Grand Total

2008

Track	Qtr1				Qtr2				Qtr3				Qtr4				Total
	jan	feb	mrt	Total	apr	mei	jun	Total	jul	aug	sep	Total	okt	nov	dec	Total	
	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder
bare	30,62%	30,61%	26,09%	28,98%	27,45%	26,53%	25,09%	26,35%	27,52%	25,61%	26,79%	26,66%	24,02%	17,83%	19,39%	20,33%	25,55%
coat	69,38%	69,39%	73,91%	71,02%	72,55%	73,47%	74,91%	73,65%	72,48%	74,39%	73,21%	73,34%	75,98%	82,17%	80,61%	79,67%	74,45%
Grand Tot	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

2009

Track	Qtr1				Qtr2				Qtr3				Qtr4				Total
	jan	feb	mrt	Total	apr	mei	jun	Total	jul	aug	sep	Total	okt	nov	dec	Total	
	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder
bare	21,89%	21,23%	20,09%	20,98%	19,38%	21,38%	21,22%	20,61%	15,03%	16,80%	22,81%	17,51%	18,04%	21,21%	21,47%	20,03%	19,71%
coat	78,11%	78,77%	79,91%	79,02%	80,62%	78,62%	78,78%	79,39%	84,97%	83,20%	77,19%	82,49%	81,96%	78,79%	78,53%	79,97%	80,29%
Grand Tot	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

2010

Track	Qtr1				Qtr2				Qtr3		Qtr4	Total	Grand Tot
	jan	feb	mrt	Total	apr	mei	jun	Total	jul	Total			
	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder	Count of idorder
bare	17,48%	18,06%	20,61%	18,73%	16,75%	7,29%	7,65%	10,17%	12,30%	12,30%		13,80%	20,67%
coat	82,52%	81,94%	79,39%	81,27%	83,25%	92,71%	92,35%	89,83%	87,70%	87,70%	100,00%	86,20%	79,33%
Grand Tot	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Appendix XIX: Machine Groups and Wafer Usage Distribution Parameters Defined in the Tool

Table: Machine groups used in the Manpower Planning Tool

Machine Types (Group Navigation Table)									
1	XTIII4x0	6	XTIV8x0	11	Pilot XTIV8x0	16	NXT	21	additional for WUP>30 wks
2	XTIII8x0	7	XTIV10x0	12	Pilot XTIV10x0	17	NRA TPG (4x0, 8x0, 14x0)		
3	XTIII14x0	8	XTIV14x0	13	Pilot XTIV14x0	18	NRA Test (19x0)		
4	XTIII19x0	9	XTIV19x0	14	Pilot XTIV19x0	19	XTIII14x0 + URS 14x0		
5	XTIV4x0	10	Pilot XTIV4x0	15	Pilot NXT	20	URS 17x0		

NRA machines are the own used machines inside ASML, which enter a normal production sequence after some period of training or other purposes. Discussions in ASML concluded that NRA machine can have the same wafer norms as the groups that show the volume machines from the same machine type. For example, in the tool Group 18 is assumed to have the same wafer norms as Group 9. URS type machines are machines that were previously shipped to a customer but that are back for some additional tests, or to enter the manufacturing process again to be sold to another customer. Again, they are assumed to have the same wafer usage distribution as the volume machines from the same machine type.

Appendix XX: Algorithms and MS VBA code for Wafer fill in Policy 1

Policy 1: Based on Start FASY for all weeks of the machine cycle time

This policy uses the week of the Start FASY as a reference. It takes the wafer norms for each machine, calculated with respect to the first day of the WUP.[17] Since the Policy is based on the Start FASY, the machines seen on the Gantt-chart are separated into two groups for the ease of calculation. First group consists of the machines whose Start FASY weeks are seen on the Gantt-chart. For these machines the wafer norms can be filled in by starting from the first week of the defined wafer usage parameters (showing the wafer needs just after the FASY stage is over). Second group consists of the machines whose Start FASY weeks are not within the timeline of the Gantt-chart. For these machines, additional calculations are needed in order to see how many weeks have passed since the Start FASY till the start of the bar of the Gantt-chart. Following figure illustrates this difference: First machine's Start FASY time is not seen on the Gantt-Chart. Its bar starts with some week belonging to the TEST phase. The Start FASY weeks of the second and third machines are visible on the Gantt-Chart (red cells).

Therefore, this policy first checks if the Start FASY of the machine is in the timeline seen on the Gantt-Chart. According to the result it fills in the wafer information by the use of two separate algorithms called "fill_in with start FASY" (for the first group of machines) and "fill_in without start FASY" (for the second group of machines). The Process lab tables are filled in with wafer usage parameters week by week for each machine till their GSD. During the fill in process the program constantly checks if there are more than 30 weeks between the Start FASY week and the week that is being filled in. If so, the group number of the machine is changed (to 21) and the parameters are started to be taken by using the overall average of all machine types.

Following figures show the algorithms described above.

---

[17] See Appendix XIV for the difference of calculating the wafer usage of machines with respect to the first or last day of the WUP.

Fill_wafer_gantt chart_Policy 1

Repeat for each machine in the Gantt-chart

For each machine in the Gannt-chart

Calculate cycle time

Check if the Start FASY and GSD is in the Gantt-chart timeline

Keep the cell for the corresponding Start FASY and GSD cells,
(If they are not in the time line of the Gantt-chart keep the cell one before and one after the timeline of Gantt-chart)

Find the right group in the wafer norms sheet

Use the group number in the Gantt-chart
Keep the start row for the wafer parameters cell

Is the Start FASY of the machine on a date in the timeline of the chart?

Y

Call the Process "fill_in with start fasy"

N

Call the Process "fill_in without start fasy"

fill_in_with_start fasy

Repeat until the last cell of the Gannt-chart of the machine

Find what is the first WUP week
(from which cell to start to fill in the wafer information)

Check the day of Start FASY
FASY takes around one week
Approximation: if the Start FASY is Monday, Tuesday or Wednesday, assume the next week the wafer usage starts.
If not, the other week

Take the wafer parameters for the first week after Start FASY

Fill in the Process lab tables for that machine

(wafers to be coated, foups to be coated, wafers to be developed, foups to be developed, average lot size)

Don't fill in the GSD week (Assumption: there are no tests in the GSD week)

Don't fill if there are blank cells in the Gantt-chart (Assumption: No tests are done in those weeks)

Increase the wafer parameters week by one

Is it the wafer parameters week greater than 30?

N

Y

Change the group of the machine to the last group, continue by taking the first wafer parameter in that group (week 31 after Start FASY)

Figure: Algorithms for wafer fill in Policy 1

MS VBA code for Wafer fill in Policy 1

```
Option Explicit
Function YearStart(WhichYear As Integer) As Date
  Dim WeekDay As Integer
  Dim NewYear As Date

  NewYear = DateSerial(WhichYear, 1, 1)
  WeekDay = (NewYear - 2) Mod 7
  If WeekDay < 4 Then
    YearStart = NewYear - WeekDay
  Else
    YearStart = NewYear - WeekDay + 7
  End If
End Function
Public Function ISOWeekNum(AnyDate As Date, _
  Optional WhichFormat As Variant) As Integer
  '
  ' WhichFormat: missing or <> 2 then returns week number,
  '              = 2 then YYWW
  '
  Dim ThisYear As Integer
  Dim PreviousYearStart As Date
  Dim ThisYearStart As Date
  Dim NextYearStart As Date
  Dim YearNum As Integer

  ThisYear = Year(AnyDate)
  ThisYearStart = YearStart(ThisYear)
  PreviousYearStart = YearStart(ThisYear - 1)
  NextYearStart = YearStart(ThisYear + 1)
  Select Case AnyDate
    Case Is >= NextYearStart
        ISOWeekNum = (AnyDate - NextYearStart) \ 7 + 1
        YearNum = Year(AnyDate) + 1
    Case Is < ThisYearStart
        ISOWeekNum = (AnyDate - PreviousYearStart) \ 7 + 1
        YearNum = Year(AnyDate) - 1
    Case Else
        ISOWeekNum = (AnyDate - ThisYearStart) \ 7 + 1
        YearNum = Year(AnyDate)
  End Select
```

```vba
    If IsMissing(WhichFormat) Then
        Exit Function
    End If
    If WhichFormat = 2 Then
        ISOWeekNum = CInt(Format(Right(YearNum, 2), "00") & _
        Format(ISOWeekNum, "00"))
    End If
End Function


Function DateToWeek(ADate As Date)
    DateToWeek = ISOWeekNum(ADate, 2) + (Format(ADate, "w", vbMonday, vbFirstFourDays) / 10)
End Function
Function DateToCode1(ADate)  'returns workday number holidays and weekends not included
    DateToCode1 = Application.VLookup(ADate, Sheets("Kalender").Range("B5:F6000"), 4)
End Function
Function DateToCode2(ADate) 'returns workday number holidays included, weekends not included
    DateToCode2 = Application.VLookup(ADate, Sheets("Kalender").Range("B5:F6000"), 5)
End Function
Function ASMLDate_to_NormalDate(ADate)
    ASMLDate_to_NormalDate = Application.VLookup(ADate, Sheets("Kalender").Range("AF5:AG6000"), 2)
End Function
Sub fill_in_with_stfasy(ByVal i As Integer, ByVal j1 As Integer, ByVal j2 As Integer, ByVal ifdevelop As Boolean _
, ByVal fontcolor As Integer, ByVal normrow As Integer, ByVal i_norm As Integer, ByVal length As Double)


Dim j As Integer
Dim j_norm As Integer
Dim j_stop As Integer

If Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then ' if the start of fasy is in the beginning of the week (mon, tue, wed) next week is the test week
    j = j1 + 1
Else
    Cells(i, j1 + 1).Interior.ColorIndex = 3 'red (assume the next week is also fasy week if the start of fasy is at the end of the week _
                                                (fasy takes around 1 wk))
    j = j1 + 2                               'the tests start the week after that   (even if somewhere in the middle it is ok, _
                                                these considerations are included in the wafer norms)
End If

j_norm = 3

If j2 <> 124 Then
    j_stop = j2 - 1 'if gsd is in the timeline don't fill in the gsd week
Else
    j_stop = j2 'if gsd is not in the timeline check the cells to be filled in till the end of the timeline
End If
Do While j <= j_stop ' fill in the gannt-chart (color and wafer info)

    If Cells(i, j).Interior.ColorIndex <> xlColorIndexNone Then 'if there are blank cells don't fill anything in

        If ifdevelop = True Then
            Cells(i, j) = Sheets("Norms Plab _ Avg stfasy").Cells(normrow, j_norm) * Sheets("Norms Plab _ Avg stfasy").Cells(i_norm + 7, j_norm)
            Cells(i, j).Interior.ColorIndex = 39 '39: purple
        Else
            Cells(i, j) = Sheets("Norms Plab _ Avg stfasy").Cells(normrow, j_norm)
            Cells(i, j).Interior.ColorIndex = 50 'dark green
        End If

        Cells(i, j).Font.ColorIndex = fontcolor

    End If

    j = j + 1
    j_norm = j_norm + 1

    If length > 30 And j_norm = 33 Then
        normrow = 234
        j_norm = 3
    End If
 Loop


End Sub


Sub fill_in_without_stfasy(ByVal i As Integer, ByVal j2 As Integer, ByVal ifdevelop As Boolean, ByVal fontcolor As Integer _
, ByVal normrow As Integer, ByVal i_norm As Integer, ByVal length As Double)

Dim j As Integer  'to hold the possible start week of the tests
Dim stfasydate As Date 'st of fasy from the plan
Dim stfasyweek As Integer
Dim j_norm As Integer
Dim j3 As Integer
Dim yeardiff As Integer


Dim normchanged As Boolean  'in order to change the norm table only once

j3 = 20    'where to begin filling
Do Until Cells(i, j3).Interior.ColorIndex <> xlColorIndexNone Or j3 > 124
    j3 = j3 + 1
Loop
```

```vba
normchanged = False

If j3 < 124 Then
    stfasydate = ASMLDate_to_NormalDate(Cells(i, 8))
    stfasyweek = DateToWeek(stfasydate)
    j = stfasyweek


    If stfasyweek \ 100 < 51 Then
        If Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then ' if the start of fasy is in the beginning of the week (mon, tue, wed) next week is the test we
            j = j + 1 'j shows the week in which tests normally start yyww
        Else
            j = j + 2
        End If
    Else
        If stfasyweek \ 100 = 51 And Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then ' if the start of fasy is in the beginning of the week (mon, tue, wed
            j = j + 1 'j shows the week in which tests normally start yy52
        ElseIf stfasyweek \ 100 = 51 And Cells(i, 8) - Int(Cells(i, 8)) > 0.3 Then
            j = (Int(j / 100) + 1) * 100 + 1 'yy+1)01
        ElseIf Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then 'stfasyweek yy52 or yy53
            j = (Int(j / 100) + 1) * 100 + 1
        Else  'stfasyweek yy52 or yy53, end of week
            j = (Int(j / 100) + 1) * 100 + 2
        End If
    End If

    yeardiff = Int(Cells(4, j3) / 100) - Int(j / 100)

    If yeardiff = 0 Or yeardiff = 1 Then
        j_norm = (1 - yeardiff) * (Cells(4, j3) - j + 1) + yeardiff * (52 - Right(j, 2) + 1 + Right(Cells(4, j3), 2))
    Else
        j_norm = 52 - Right(j, 2) + 1 + Right(Cells(4, j3), 2) + 52 * (yeardiff - 1)
    End If

    'check could j_norm be zero?

    j_norm = j_norm + 2 'to take the corresponding norm (the norm table starts from the 3rd coloumn

    If j_norm = 2 Then j_norm = 3 'to correct for the situations where in the gannt chart the tests start is shown as the same week as start fasy

    If j_norm >= 33 Then
        normrow = 234
        i_norm = 230
        j_norm = j_norm - 30 'example: if j_norm 35 this means week 33, it should take wafer number from the last table coloumn 5
        normchanged = True
    End If
End If



j = j3  'j now shows which cell to fill
Do While Cells(i, j).Interior.ColorIndex <> 34 And j < 124 ' not blue (not GSD)  ' fill in the gannt-chart (color and wafer info)

'if there are blank cells don't fill anything in

    If Cells(i, j).Interior.ColorIndex <> xlColorIndexNone Then

        If ifdevelop = True Then
            Cells(i, j) = Sheets("Norms Plab _ Avg stfasy").Cells(normrow, j_norm) * Sheets("Norms Plab _ Avg stfasy").Cells(i_norm + 7, j_norm)
            Cells(i, j).Interior.ColorIndex = 39 'purple
        Else
            Cells(i, j) = Sheets("Norms Plab _ Avg stfasy").Cells(normrow, j_norm)
            Cells(i, j).Interior.ColorIndex = 50 'dark green
        End If

        Cells(i, j).Font.ColorIndex = fontcolor

    End If

    j = j + 1
    j_norm = j_norm + 1

    If j_norm >= 33 And normchanged = False Then
        normrow = 234
        i_norm = 230
        j_norm = j_norm - 30
        normchanged = True
    End If
Loop


End Sub
Sub fill_wafer_gannt_chart_stfasy()

Application.ScreenUpdating = False
Application.Calculation = xlCalculationManual

Dim outputsheet1 As String
Dim outputsheet2 As String
Dim outputsheet3 As String
Dim outputsheet4 As String

outputsheet1 = "Gantt-chart_Plab_coat wafer"
outputsheet2 = "Gantt-chart_Plab_develop wafer"
outputsheet3 = "Gantt-chart_Plab_coat foup"
outputsheet4 = "Gantt-chart_Plab_develop foup"
```

```vba
        Dim i As Integer
        Dim j As Integer

        Dim j1 As Integer 'to hold Start Fasy week location
        Dim j2 As Integer 'to hold GSD week location

        j1 = 20
        j2 = 20

        Dim i_norm As Integer
        Dim j_norm As Integer

        Dim group As Integer
        Dim groupfound As Boolean

        Dim length As Double   'approximate cycle time GSD-Start Fasy

    Worksheets(outputsheet1).Activate
    i = 5
    Do Until Cells(i, 6) = ""

        length = DateDiff("d", ASMLDate_to_NormalDate(Cells(i, 8)), ASMLDate_to_NormalDate(Cells(i, 16)), vbMonday) / 7

        ''''''''''''''''''''''
        'to see the cycle time
        Cells(i, 125) = length
        ''''''''''''''''''''''''

        group = Cells(i, 7)
        j = 20
        Do Until Cells(i, j).Interior.ColorIndex = 3 Or j = 124      'Red start of fasy
            j = j + 1
        Loop

        j1 = j   'shows the cell of start fasy week or 124 (means no start fasy in timeline)

        j = 20
        Do Until Cells(i, j).Interior.ColorIndex = 34 Or j = 124      '34 'Light-Turkoise gsd
            j = j + 1
        Loop

        j2 = j   'shows the cell of gsd week or 124 (means no gsd in timeline)


        'find the right group norm in norms_processlab sheet
        i_norm = 10
        groupfound = False
        Worksheets("Norms Plab _ Avg stfasy").Activate

        Do Until i_norm = 230 Or groupfound = True
            If Cells(i_norm, 3) = group Then
                groupfound = True
            Else
                i_norm = i_norm + 11
            End If
        Loop

        If j1 <> 124 Then 'if the start of fasy is in the timeline (gsd might or might not be in the timeline)
            'update "Gantt-chart_Plab_coat wafer" sheet
            Worksheets(outputsheet1).Activate
            Call fill_in_with_stfasy(i, j1, j2, False, 1, i_norm + 4, i_norm, length) '1: black

            'update "Gantt-chart_Plab_develop wafer" sheet
            Worksheets(outputsheet2).Activate
            Call fill_in_with_stfasy(i, j1, j2, True, 1, i_norm + 4, i_norm, length)

            'update "Gantt-chart_Plab_coat foup" sheet
            Worksheets(outputsheet3).Activate   '2: white
            Call fill_in_with_stfasy(i, j1, j2, False, 2, i_norm + 5, i_norm, length)

            'update "Gantt-chart_Plab_develop foup" sheet
            Worksheets(outputsheet4).Activate
            Call fill_in_with_stfasy(i, j1, j2, True, 2, i_norm + 5, i_norm, length)


        Else 'if the start of fasy is not in the chart (gsd gsd might or might not be in the timeline)
            Worksheets(outputsheet1).Activate
            Call fill_in_without_stfasy(i, j2, False, 1, i_norm + 4, i_norm, length) '1: black

            Worksheets(outputsheet2).Activate
            Call fill_in_without_stfasy(i, j2, True, 1, i_norm + 4, i_norm, length)

            Worksheets(outputsheet3).Activate   '2: white
            Call fill_in_without_stfasy(i, j2, False, 2, i_norm + 5, i_norm, length)

            Worksheets(outputsheet4).Activate
            Call fill_in_without_stfasy(i, j2, True, 2, i_norm + 5, i_norm, length)

        End If


    i = i + 1
    Worksheets(outputsheet1).Activate
Loop

Application.ScreenUpdating = True
Application.Calculation = xlCalculationAutomatic

Worksheets("overview").Activate
```

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Appendix XXI: Algorithms for Wafer fill in Policy 2

Policy 2: Based on GSD for all weeks of the machine cycle time

This algorithm is basically the backwards algorithm of the one described for Policy 1. This policy uses the week of the GSD of the machines as a reference. It takes the wafer parameters for each week, calculated with respect to the last day of the WUP. Since the algorithm is based on the GSD, the machines seen on the Gantt-chart are separated into two groups as the machines whose GSD is on the Gantt-chart and the machines whose GSD is not on the Gantt-chart. Because of the similarity with Policy 1, we do not provide the algorithm or the VBA code in this report.

The following figures explain the algorithm for the "fill_in with Start FASY" process for Policy 3. The yellow highlighted blocks show the blocks different than Policy 1. Note that the first part of the policy is not given because it is the same as Policy 1 and the last part "fill_in without Start FASY" has similar modifications, whose algorithm is also not provided.
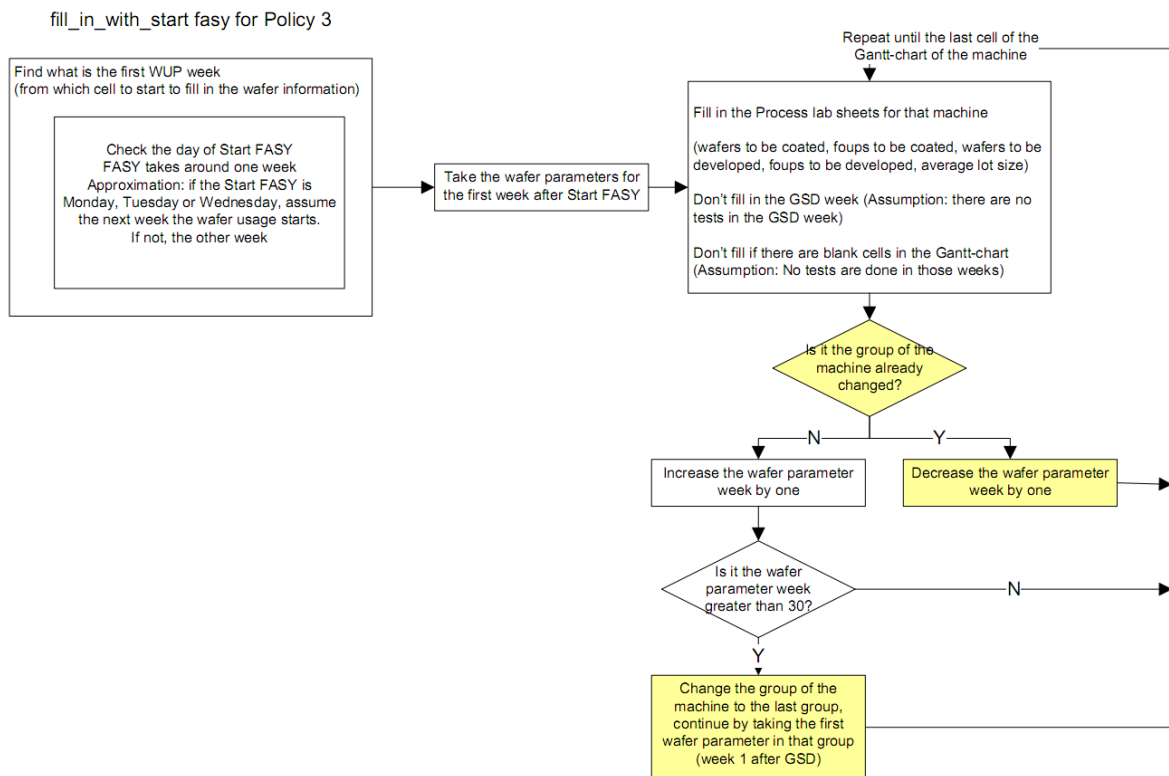
Figure: Algorithm for the "fill_in with start Fasy" process for Policy 3

Appendix XXII: Algorithm and MS VBA code for Wafer fill in Policy 3

Date functions same as Policy1 (not shown here)

```vba
Sub fill_in_with_stfasy(ByVal i As Integer, ByVal j1 As Integer, ByVal j2 As Integer, ByVal ifdevelop As Boolean _
, ByVal fontcolor As Integer, ByVal normrow As Integer, ByVal i_norm As Integer, ByVal length As Double)

Dim j As Integer
Dim j_norm As Integer
Dim j_stop As Integer
Dim gsddate As Date
Dim gsdweek As Integer
Dim yeardiff As Integer
Dim normchanged As Boolean

If Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then ' if the start of fasy is in the beginning of the week (mon, tue, wed) next week is the test week
    j = j1 + 1
Else
    Cells(i, j1 + 1).Interior.ColorIndex = 3 'red (assume the next week is also fasy week if the start of fasy is at the end of the week
                                             '(fasy takes around 1 wk))
    j = j1 + 2                               'the tests start the week after that _
                                              (even if somewhere in the middle it is ok, these considerations are included in the wafer norms)
End If

j_norm = 3

If j2 <> 124 Then
    j_stop = j2 - 1 'if gsd is in the timeline don't fill in the gsd week
Else
    j_stop = j2 'if gsd is not in the timeline check the cells to be filled in till the end of the timeline
End If

normchanged = False

Do While j <= j_stop ' fill in the gantt-chart (color and wafer info)

    If Cells(i, j).Interior.ColorIndex <> xlColorIndexNone Then 'if there are blank cells don't fill anything in

        If ifdevelop = True Then
            Cells(i, j) = Sheets("Norms Plab _ Average Weekly").Cells(normrow, j_norm) * Sheets("Norms Plab _ Average Weekly").Cells(i_norm + 7, j_norm)
            Cells(i, j).Interior.ColorIndex = 39 '39: purple
        Else
            Cells(i, j) = Sheets("Norms Plab _ Average Weekly").Cells(normrow, j_norm)
            Cells(i, j).Interior.ColorIndex = 50 'dark green
        End If

        Cells(i, j).Font.ColorIndex = fontcolor

    End If


    j = j + 1

    If normchanged = False Then
        j_norm = j_norm + 1
    Else
        j_norm = j_norm - 1
    End If

    If j_norm >= 33 And normchanged = False Then
        normrow = 234

        gsddate = ASMLDate_to_NormalDate(Cells(i, 16))
        gsdweek = Int(Cells(i, 16))
        yeardiff = Int(gsdweek / 100) - Int(Cells(4, j) / 100)

         If Cells(4, j) >= gsdweek Then
            j_norm = 1
         Else
            If yeardiff = 0 Or yeardiff = 1 Then
                If Int(gsdweek / 100) = Int(Cells(4, 20) / 100) Then
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j)) + yeardiff * (Right(gsdweek, 2) + 52 + 1 - Right(Cells(4, j), 2))
                Else
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j)) + yeardiff * (Right(gsdweek, 2) + 52 - Right(Cells(4, j), 2))
                End If
            Else
                j_norm = Right(gsdweek, 2) + 53 - Right(Cells(4, j), 2) + 52 * (yeardiff - 1)
            End If
        End If


        j_norm = j_norm + 2 'to take the corresponding norm (the norm table starts from the 3rd coloumn


        normchanged = True

    End If
Loop

End Sub
```

```vb
Sub fill_in_without_stfasy(ByVal i As Integer, ByVal j2 As Integer, ByVal ifdevelop As Boolean, ByVal fontcolor As Integer _
, ByVal normrow As Integer, ByVal i_norm As Integer, ByVal length As Double)

Dim j As Integer   'to hold the possible start week of the tests
Dim stfasydate As Date 'st of fasy from the plan
Dim stfasyweek As Integer
Dim j_norm As Integer
Dim j3 As Integer
Dim yeardiff As Integer
Dim gsddate As Date
Dim gsdweek As Integer


Dim normchanged As Boolean  'in order to change the norm table only once

j3 = 20   'where to begin filling
Do Until Cells(i, j3).Interior.ColorIndex <> xlColorIndexNone Or j3 > 124  'find start cell of filling
    j3 = j3 + 1
Loop

normchanged = False

If j3 < 124 Then
    stfasydate = ASMLDate_to_NormalDate(Cells(i, 8))
    stfasyweek = Int(Cells(i, 8))
    j = stfasyweek

    If stfasyweek \ 100 < 51 Then
        If Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then ' if the start of fasy is in the beginning of the week (mon, tue, wed) next week is
            j = j + 1 'j shows the week in which tests normally start yyww
        Else
            j = j + 2
        End If
    Else
    ' if the start of fasy is in the beginning of the week (mon, tue, wed) next week is the test week
        If stfasyweek \ 100 = 51 And Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then
            j = j + 1 'j shows the week in which tests normally start yy52
        ElseIf stfasyweek \ 100 = 51 And Cells(i, 8) - Int(Cells(i, 8)) > 0.3 Then
            j = (Int(j / 100) + 1) * 100 + 1 'yy+1)01
        ElseIf Cells(i, 8) - Int(Cells(i, 8)) <= 0.3 Then 'stfasyweek yy52 or yy53
            j = (Int(j / 100) + 1) * 100 + 1
        Else  'stfasyweek yy52 or yy53, end of week
            j = (Int(j / 100) + 1) * 100 + 2
        End If
    End If
    yeardiff = Int(Cells(4, j3) / 100) - Int(j / 100)

    If Cells(4, j3) <= j Then
        j_norm = 1
    Else
        If yeardiff = 0 Or yeardiff = 1 Then
            j_norm = (1 - yeardiff) * (Cells(4, j3) - j + 1) + yeardiff * (52 - Right(j, 2) + 1 + Right(Cells(4, j3), 2))
        Else
            j_norm = 52 - Right(j, 2) + 1 + Right(Cells(4, j3), 2) + 52 * (yeardiff - 1)
        End If
    End If

    j_norm = j_norm + 2 'to take the corresponding norm (the norm table starts from the 3rd coloumn

    If j_norm = 2 Then j_norm = 3 'to correct for the situations where in the gantt chart the tests start is shown as the same week as start fasy

    If j_norm >= 33 Then 'the don't care any more about the stfasy date but base the counting of weeks on gsd backwards
        normrow = 234
        i_norm = 230
        'j_norm = j_norm - 30 'example: if j_norm 35 this means week 33, it should take wafer number from the last table coloumn 5

        gsddate = ASMLDate_to_NormalDate(Cells(i, 16))
        gsdweek = Int(Cells(i, 16))
        yeardiff = Int(gsdweek / 100) - Int(Cells(4, j3) / 100)

        If Cells(4, j3) >= gsdweek Then
            j_norm = 1
        Else
            If yeardiff = 0 Or yeardiff = 1 Then
                If Int(gsdweek / 100) = Int(Cells(4, 20) / 100) Then
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j3)) + yeardiff * (Right(gsdweek, 2) + 52 + 1 - Right(Cells(4, j3), 2))
                Else
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j3)) + yeardiff * (Right(gsdweek, 2) + 52 - Right(Cells(4, j3), 2))
                End If
            Else
                j_norm = Right(gsdweek, 2) + 53 - Right(Cells(4, j3), 2) + 52 * (yeardiff - 1) 'dogru mu denemek lazim
            End If
        End If

        If Right(Cells(4, j3), 2) = 53 Then j_norm = j_norm + 1

        j_norm = j_norm + 2 'to take the corresponding norm (the norm table starts from the 3rd coloumn
        normchanged = True
    End If
End If
```

```vba
j = j3  'j now shows which cell to fill
Do While Cells(i, j).Interior.ColorIndex <> 34 And j < 124 ' not blue (not GSD)  ' fill in the gantt-chart (color and wafer info)

'if there are blank cells don't fill anything in
'skips the weeks in the wafer usage norm as well if there are blank weeks in the gantt chart
    If Cells(i, j).Interior.ColorIndex <> xlColorIndexNone Then

        If ifdevelop = True Then
            Cells(i, j) = Sheets("Norms Plab _ Average Weekly").Cells(normrow, j_norm) * Sheets("Norms Plab _ Average Weekly").Cells(i_norm + 7, j_norm)
            Cells(i, j).Interior.ColorIndex = 39 'purple
        Else
            Cells(i, j) = Sheets("Norms Plab _ Average Weekly").Cells(normrow, j_norm)
            Cells(i, j).Interior.ColorIndex = 50 'dark green
        End If

        Cells(i, j).Font.ColorIndex = fontcolor

    End If

    j = j + 1
    If normchanged = False Then
        j_norm = j_norm + 1
    Else
        j_norm = j_norm - 1
    End If

    'check if jnorm became >33 inside this loop
    If j_norm >= 33 And normchanged = False Then
        normrow = 234
        i_norm = 230

        gsddate = ASMLDate_to_NormalDate(Cells(i, 16))
        gsdweek = Int(Cells(i, 16))
        yeardiff = Int(gsdweek / 100) - Int(Cells(4, j) / 100)

        If Cells(4, j) >= gsdweek Then
            j_norm = 1
        Else
            If yeardiff = 0 Or yeardiff = 1 Then
                If Int(gsdweek / 100) = Int(Cells(4, 20) / 100) Then
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j)) + yeardiff * (Right(gsdweek, 2) + 52 + 1 - Right(Cells(4, j), 2))
                Else
                    j_norm = (1 - yeardiff) * (gsdweek - Cells(4, j)) + yeardiff * (Right(gsdweek, 2) + 52 - Right(Cells(4, j), 2))
                End If
            Else
                j_norm = Right(gsdweek, 2) + 53 - Right(Cells(4, j), 2) + 52 * (yeardiff - 1)
            End If
        End If
            j_norm = j_norm + 2 'to take the corresponding norm (the norm table starts from the 3rd coloumn
            normchanged = True
    End If
Loop


End Sub
Sub Fill_wafer_gantt_chart_stfasygsd()
```

Same as Policy1 (not shown)

Appendix XXIII: Results of the Validation Runs for Workload Calculation

Policy 1 Results for XT19x0 machine family for year 2008

QUARTERLY VALIDATION	Validation (quarters)	2008				
		Q1	Q2	Q3	Q4	
	% error wafers (actual-forecast)/actual (wafers)	4%	4%	-3%	10%	Mean Absolute Error (MAE)
	% error foup (actual-forecast)/actual (foups)	-5%	-7%	-12%	3%	MAE
	% absolute error (wafers)	4%	4%	3%	10%	5%
	% absolute error (foups)	5%	7%	12%	3%	7%

MONTHLY VALIDATION		2008												
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	
	Validation (months)	1	2	3	4	5	6	7	8	9	10	11	12	
	% error wafers (actual-forecast)/actual (wafers)	-2%	5%	6%	1%	10%	0%	-8%	-4%	7%	10%	23%	-10%	Mean Absolute Error (MAE)
	% error foup (actual-forecast)/actual (foups)	-5%	-4%	-5%	-11%	-1%	-9%	-18%	-14%	-2%	2%	19%	-18%	MAE
	% absolute error (wafers)	2%	5%	6%	1%	10%	0%	8%	4%	7%	10%	23%	10%	7%
	% absolute error (foups)	5%	4%	5%	11%	1%	9%	18%	14%	2%	2%	19%	18%	9%

Wafer information per month

Foup information per month

Policy 2 Results for XT19x0 machine family for year 2008

MONTHLY VALIDATION	Validation (months)	2008												
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	Mean Absolute Error (MAE)
		1	2	3	4	5	6	7	8	9	10	11	12	
	% error wafers (actual-forecast)/actual (wafers)	3%	-16%	-9%	-5%	11%	-4%	-12%	0%	-16%	16%	28%	23%	MAE
	% error foup (actual-forecast)/actual (foups)	8%	-21%	-17%	-14%	6%	-8%	-19%	-3%	-20%	14%	25%	16%	
	% absolute error (wafers)	3%	16%	9%	5%	11%	4%	12%	0%	16%	16%	28%	23%	12%
	% absolute error (foups)	8%	21%	17%	14%	6%	8%	19%	3%	20%	14%	25%	16%	14%

Foup information per month

Policy 3 Results for XT19x0 machine family for year 2008

MONTHLY VALIDATION	Validation (months)	2008												
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	okt	nov	dec	Mean Absolute Error (MAE)
		1	2	3	4	5	6	7	8	9	10	11	12	
	% error wafers (actual-forecast)/actual (wafers)	1%	14%	24%	23%	34%	27%	36%	37%	53%	58%	63%	63%	MAE
	% error foup (actual-forecast)/actual (foups)	-2%	5%	15%	15%	26%	20%	29%	30%	50%	55%	61%	61%	
	% absolute error (wafers)	1%	14%	24%	23%	34%	27%	36%	37%	53%	58%	63%	63%	36%
	% absolute error (foups)	2%	5%	15%	15%	26%	20%	29%	30%	50%	55%	61%	61%	31%

Foup information per month

Policy 1 Results for XT19x0 machine family for year 2010

MONTHLY VALIDATION	Validation (months)	2010									Mean Absolute Error (MAE)
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	
		1	2	3	4	5	6	7	8	9	
	% error wafers (actual-forecast)/actual (wafers)	-19%	28%	30%	4%	3%	-45%	-19%	-37%	13%	
	% error foup (actual-forecast)/actual (foups)	-13%	20%	13%	-8%	11%	-47%	-27%	-20%	14%	MAE
	% absolute error (wafers)	19%	28%	30%	4%	3%	45%	19%	37%	13%	22%
	% absolute error (foups)	13%	20%	13%	8%	11%	47%	27%	20%	14%	19%

Foup information per month

Policy 2 Results for XT19x0 machine family for year 2010

MONTHLY VALIDATION	Validation (months)	2010									Mean Absolute Error (MAE)
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	
		1	2	3	4	5	6	7	8	9	
	% error wafers (actual-forecast)/actual (wafers)	1%	3%	18%	15%	-11%	-63%	-28%	-42%	-3%	
	% error foup (actual-forecast)/actual (foups)	2%	-2%	7%	3%	3%	-59%	-31%	-23%	5%	MAE
	% absolute error (wafers)	1%	3%	18%	15%	11%	63%	28%	42%	3%	21%
	% absolute error (foups)	2%	2%	7%	3%	3%	59%	31%	23%	5%	15%

Foup information per month

Policy 3 Results for XT19x0 machine family for year 2010

MONTHLY VALIDATION	Validation (months)	2010									Mean Absolute Error (MAE)
		jan	feb	mrt	apr	mei	jun	jul	aug	sep	
		1	2	3	4	5	6	7	8	9	
	% error wafers (actual-forecast)/actual (wafers)	2%	43%	43%	21%	22%	-15%	3%	-18%	31%	
	% error foup (actual-forecast)/actual (foups)	8%	37%	30%	12%	29%	-16%	-4%	-3%	32%	MAE
	% absolute error (wafers)	2%	43%	43%	21%	22%	15%	3%	18%	31%	22%
	% absolute error (foups)	8%	37%	30%	12%	29%	16%	4%	3%	32%	19%

Foup information per month
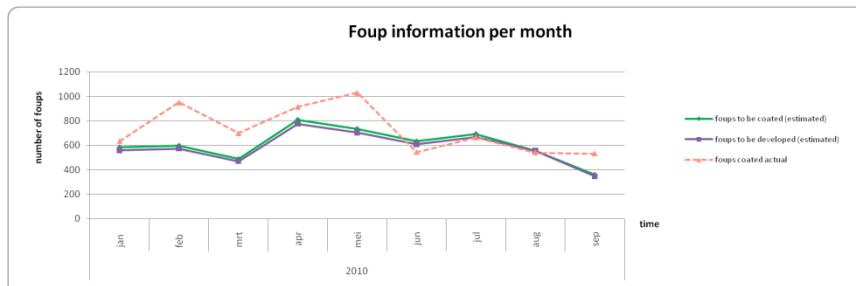
Results for 2008 with Policy 1 (Compariosn with MR and Shipment Rates)

Wafer s Forecast vs. Actual

	Q1	Q2	Q3	Q4
wafers tb coated forecast	21871	26438	25063	22949
wafers coated actual	22711	27460	24416	25396

Machine starts and shipments

	Q1	Q2	Q3	Q4
Start of fasy XT19x0	17	18	12	8
GSD XT19x0	13	18	14	14
start with one quarter before	13	17	18	12

Foups Forecast vs. Actual

	Q1	Q2	Q3	Q4
foups to be coated (forecast)	2845	3422	3209	2977
foups coated actual	2718	3209	2868	3071

Results for 2010 with Policy 2 (Compariosn with MR and Shipment Rates)

Wafer s Forecast vs. Actual

	Q1	Q2	Q3
wafers tb coated forecast	16602	20065	15511
wafers coated actual	17950	17905	12463

Quarters
2010

Machine starts and shipments

	Q1	Q2	Q3
Start of fasy XT19x0	19	13	10
GSD XT19x0	14	19	13
start with one quarter before	15	19	13

Quarters
2010

Foups F orecast vs. Actual

	Q1	Q2	Q3
foups to be coated (forecast)	2238	2750	2040
foups coated actual	2280	2487	1735

Quarters
2010

Appendix XXIV: Look up Tables for Coating and Developing Durations

Coating

number of wafers	coating time (min)	preparation time (min)	inspection time (min)	vrb coating time (min)	fix coating time (min)	total coating time (hrs)
1	13,00	0,08	0,08	13,95	1,80	0,26
2	15,00	0,17	0,17	16,10	1,80	0,30
3	17,00	0,25	0,25	18,25	1,80	0,33
4	22,00	0,33	0,33	23,40	1,80	0,42
5	25,00	0,42	0,42	26,55	1,80	0,47
6	30,00	0,50	1,00	32,10	1,80	0,57
7	33,00	0,58	1,17	35,32	1,80	0,62
8	37,00	0,67	1,33	39,53	1,80	0,69
9	42,00	0,75	1,50	44,75	1,80	0,78
10	45,00	0,83	1,67	47,97	1,80	0,83
11	48,00	0,92	1,83	51,18	1,80	0,88
12	52,00	1,00	2,00	55,40	1,80	0,95
13	57,00	1,08	2,17	60,62	1,80	1,04
14	61,00	1,17	2,33	64,83	1,80	1,11
15	64,00	1,25	2,50	68,05	1,80	1,16
16	67,00	1,33	2,67	71,27	1,80	1,22
17	70,00	1,42	2,83	74,48	1,80	1,27
18	72,00	1,50	3,00	76,70	1,80	1,31
19	75,00	1,58	3,17	79,92	1,80	1,36
20	78,00	1,67	3,33	83,13	1,80	1,42
21	81,00	1,75	3,50	86,35	1,80	1,47
22	84,00	1,83	3,67	89,57	1,80	1,52
23	86,00	1,92	3,83	91,78	1,80	1,56
24	88,00	2,00	4,00	94,00	1,80	1,60
25	90,00	2,08	4,17	96,22	1,80	1,63

Developing

number of wafers	developing time (min)	preparation time (min)	inspection time (min)	vrb developing time (min)	fix developing time (min)	total developing time (hrs)
1	13,04	0,00	0,00	13,84	1,75	0,26
2	13,95	0,00	0,00	14,75	1,75	0,28
3	15,00	0,00	0,00	15,80	1,75	0,29
4	15,79	0,00	0,00	16,59	1,75	0,31
5	16,85	0,00	0,00	17,65	1,75	0,32
6	17,82	0,00	0,00	18,62	1,75	0,34
7	18,67	0,00	0,00	19,47	1,75	0,35
8	19,67	0,00	0,00	20,47	1,75	0,37
9	20,53	0,00	0,00	21,33	1,75	0,38
10	21,51	0,00	0,00	22,31	1,75	0,40
11	22,30	0,00	0,00	23,10	1,75	0,41
12	23,30	0,00	0,00	24,10	1,75	0,43
13	24,15	0,00	0,00	24,95	1,75	0,44
14	25,15	0,00	0,00	25,95	1,75	0,46
15	26,01	0,00	0,00	26,81	1,75	0,48
16	26,97	0,00	0,00	27,77	1,75	0,49
17	27,87	0,00	0,00	28,67	1,75	0,51
18	28,80	0,00	0,00	29,60	1,75	0,52
19	29,69	0,00	0,00	30,49	1,75	0,54
20	30,69	0,00	0,00	31,49	1,75	0,55
21	31,50	0,00	0,00	32,30	1,75	0,57
22	32,67	0,00	0,00	33,47	1,75	0,59
23	33,50	0,00	0,00	34,30	1,75	0,60
24	34,53	0,00	0,00	35,33	1,75	0,62
25	35,29	0,00	0,00	36,09	1,75	0,63

Appendix XXV: Introduction to System Dynamics

System Dynamics discipline is an attempt to address dynamic, long-term policy problems and today interest in system dynamics is growing very fast (Barlas, 2002). System Dynamics discipline emerged in the late 1950s, with the initiation of a group of researchers from M.I.T. under the leadership of Jay W. Forrester.

The "structure" of a system is a totality of the system that exists between system variables. The dynamic behavior patterns of the system variables are created as a result of operating of the structure of the system through time (Saysel, 2007). For a real system the structure is not exactly known. For a "model" of the real system, the structure is a representation of those aspects of the real structure that we hypothesize to be important for the problem of interest.

The structure of a System Dynamics model is represented by stocks, flows, delays and feedback loops. Once the model is built with these building blocks, it can be simulated. By connecting the building blocks with arrows and formulating the relations with integral equations, the relationship structure of the systems is represented in the models. The general objective of System Dynamics models is to capture the interaction of different system variables and to analyze their impact on policy implementations in long-term (Saysel, 2007). The basic explanation of the building blocks in System Dynamics can be given as follows:
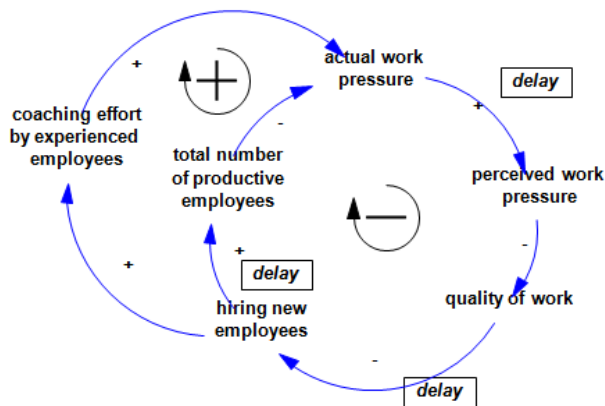
Figure: Causal Loop Diagram example

Causal Loop (Feedback Loop) Diagrams: Causal Loop Diagrams represent the feedback structure in the system. Causal Loop Diagrams are formed by linking the variables to each other and representing the direction of the relationship by the link polarities as + or -. It is important to note that these polarities describe the structure of the system, not the behavior of the system. This is because variables might have more than one influencing factor changing in different directions. Figure above depicts an example causal loop diagram.

Note that the loops in the diagram also have polarities. The positive loop means that it is a reinforcing loop, which reinforces the initial change in the starting variable when the loop is closed. On the contrary, negative loops seek a balance, therefore they are also called balancing loops. A delay is a process whose output lags behind its input. All delays involve stocks.

Stock: Stocks are also called the levels, accumulations, or state variables. During the modeling process, the key stocks in a system can be identified by the "snapshot test". Stocks would be the things that can be counted or measured, if the system would freeze for a moment.

Flow: Flows change the values of the stocks through integral equations. In general flows are functions of stocks and other parameters. Stocks can change values only via their flows.

Sink and Source: The use of "clouds" in the stock flow representation tells the boundaries of the system beyond which we are not interested.

Stock and Flow Diagrams: While the causal loops diagrams emphasize the feedback structure of the system, the stock and flow diagrams emphasize the underlying physical structure. Stocks characterize the state of the system and generate the information upon which decisions are based. The decisions then alter the rates of flow, altering the values of stocks as well closing the feedback loops in the system (Sterman, 2000). Following figure shows an example stock and flow diagram for a manufacturing process.
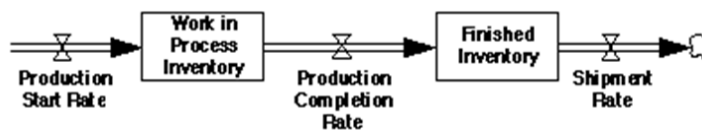
Figure: Stock and Flow Diagram Representation of a Manufacturing Process

The quantity of material in any stock is the accumulation of material in less the flows of material out, such as the level of water in a bathtub accumulating with the water flowing through the tap less the water flowing out through the drain (Sterman, 2000). Figure below explains the mathematical representation (integral equations) governing the stock and flow relations. Each representation contains the same information in a different way.

Hydraulic Metaphor:

Stock and Flow Diagram:

Integral Equation:

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0)$$

Differential Equation:

$$d(Stock)/dt = \text{Net Change in Stock} = Inflow(t) - Outflow(t)$$
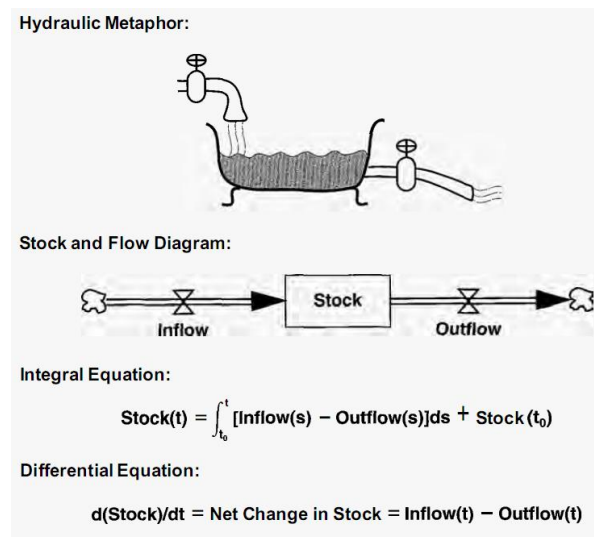
Figure: Different representations for stock and flow diagrams *(Source: Sterman, 2000)*

Appendix XXVI: System Dynamics Model (Whole Model and Subsystems)

Whole Model

Manufacturing Systems Production Subsystem

Scheduled Pressure due to time restrictions

Effect of Change in Production Start Rate

Expected Demand Rate per machine

Demand Rate from Tests

Demand Rate from Development

Production Start Rate

WIP Tests (Manufacturing Sys.)

Initial Production Start Rate

Rate of Transfer of Machines

Initial Shipment Rate

Shipment Rate

Effect of Change in Production Shipment Rate

Avg time in development

Development Systems Production Subsystem

Demand Rate from Development

Effect of technology conferences

WIP Development

Rate of Transfer of Machines

Start Rate of development Machines

Avg time in development

Process lab Workload Subsystem

Newly Hired Operators

Hiring Rate

Training Rate

Experienced Operators

Quit Rate

productivity

effect of fraction of experienced workers on productivity

Time to Adjust Workforce

Total Operators

Work to be Done (in future)

increase rate in future workload

Work to be Done (Now)

Work completion Rate

Work Done

coating time needed per foup for avg lot size

Desired Workforce

time unit

Normal Work Rate per worker per month

developing time needed per foup for avg lot size

number of tracks for coating

decrease rate in future workload

number of tracks for developing

Machine Capacity in Plab

Random Accuracy

coating capacity per time per track

Scheduled Pressure due to time restrictions

Expected Demand Rate per dev machine

developing capacity per time per track

Effect of technology conferences

Effect of Change in Production Start Rate

Expected Demand Rate per machine

Demand Rate from Tests

Demand Rate from Development

Production Start Rate

WIP Tests (Manufacturing Sys.)

WIP Development

Process lab Manpower Subsystem

Cost Subsystem

Appendix XXVII : Complete Set of Equations in the System Dynamics Model

(01)   Avg time in development=
                12
         Units: Month

(02)   coating capacity per time per track=
                20/8*24*30
         Units: foup/track/Month
         20 wafers per hour for avg lot size 8; 7/24 production

(03)   coating time needed per foup for avg lot size=
                40/(60*6*8*4)
         Units: Month*person/foup
         40 mins for avg lot size 8, 6 work days 8 hours

(04)   Cost of Experienced Operators= INTEG (
                increase rate of experienced operators costs,
                        0)
         Units: Euro

(05)   Cost of Firing Exp Opr=
                0
         Units: Euro/person

(06)   Cost of Firing New Opr=
                0
         Units: Euro/person
         No cost of firing new (flexible operators) -> good arrangements
                        with the flex agencies

(07)   Cost of Newly Hired Operators= INTEG (
                increase rate of newly hired operator costs,
                        0)
         Units: Euro

(08)   Cost per exp operator per time unit=
                1150*4
         Units: Euro/(Month*person)
         1150 euro per week

(09)   Cost per new operator per time unit=
                35*40*45/12
         Units: Euro/person/Month
         35 euro/hr, 40 working hours per week, 45 working week per year
                        excluding vacation/holidays

(10)   Decrease rate in future workload=
                DELAY FIXED(Work completion Rate, Time to Adjust Workforce , Increase rate in future workload
)
         Units: foup/Month
         Same assumption as Increase rate in future workload

(11)   Demand Rate from Development=
                max(0,Expected Demand Rate per dev machine*WIP Development*Random Accuracy
         *Effect of technology conferences)

Units: foup/Month

(12)   Demand Rate from Tests=
             Expected Demand Rate per machine*Scheduled Pressure due to time restrictions
*"WIP Tests (Manufacturing Sys.)"
Units: foup/Month

(13)   Desired Workforce=
             min(Machine Capacity in Plab*time needed to finish work,"Work to be Done (in future)"
)/(Normal Work Rate per worker per month
             *time needed to finish work)
Units: person

(14)   developing capacity per time per track=
             30/8*24*30
Units: foup/(Month)/track
30 wafers per hour for avg lot size 8; 7/24 production

(15)   developing time needed per foup for avg lot size=
             22*0.8*1.2/(60*6*8*4)
Units: Month*person/foup
80%of the foups are developed on average 1.2 times; 22 mins per
             foup for avg lot size 8

(16)   Effect of Change in Production Shipment Rate=
             1
Units: Dmnl
for scenario analysis with demand (to increse decrease demand),
             right now assumed constant 1

(17)   Effect of Change in Production Start Rate=
             1
Units: Dmnl
for scenario analysis with demand (to increse decrease demand),
             right now assumed constant 1

(18)   effect of fraction of experienced workers on productivity(
             [(0,0)-(1,1)],(0,0.5),(0.152905,0.649123),(0.287462,0.767544),(0.458716,0.872807
),(0.602446,0.938596),(0.669725,0.95614
             ),(0.70948,0.973684),(0.779817,0.982456),(1,1))
Units: Dmnl
change into a lookup function according to the fraction of
             experienced operators, assumption new hired operators are 50%
             productive compared to the experienced ones

(19)   effect of holidays:=
             GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b27')
Units: Dmnl

(20)   Effect of technology conferences:=
             GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b14')
Units: Dmnl
in nov,dec and july,aug 20% and 30% change in demand for dev
             machines can be expected

(21)   Expected Demand Rate per dev machine:=
             GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b20')
Units: foup/(Month*machine)

same as manufacturing systems, will change with random accuracy

(22)   Expected Demand Rate per machine:=
                GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b20')
        Units: foup/machine/Month
        count of orders/count of machines per month from wafer request
                tool

(23)   Experienced Operators= INTEG (
                Training Rate-Firing Rate of Experienced-Quit Rate,
                        Initial Experienced Operators)
        Units: person

(24)   FINAL TIME = 24
        Units: Month
        The final time for the simulation.

(25)   Fired Exp Operators= INTEG (
                Firing Rate of Experienced,
                        0)
        Units: person
        assumption: experienced operators will be fired only if all
                newly hired operators are already fired (general case) (should
                always be zero in this model)

(26)   Fired New Operators= INTEG (
                Firing Rate of Newly Hired,
                        0)
        Units: person

(27)   Firing Rate of Experienced=
                if then else(Experienced Operators/Total Operators=1,0*(max(0,Experienced Operators
        -Desired Workforce)/Time to adjust for firing exp opr
                ),0)
        Units: person/Month
        Always zero at ASML if fraction of experienced =100% (see
                assumption in fired exp operators stock) But at asml no firing
                fix people (according to the flex model they should not hire
                pay-roll employees above the base capacity level.) so the
                multiplication with 0

(28)   Firing Rate of Newly Hired=
                min(Newly Hired Operators, (Total Operators-Desired Workforce))/Time to adjust for firing new opr
        Units: person/Month
        no firing of experienced. so firing can only be done if there
                are new hired workers what happends in des work>total???

(29)   Fixed Cost of Hiring=
                0
        Units: Euro/person
        although no fixed costs still shown in the model for a general
                representation

(30)   Hiring Rate=
                max(0,(Desired Workforce-Total Operators))/Time to Adjust Workforce
        Units: person/Month

(31)   Increase rate in future workload=

DELAY FIXED(Demand Rate from Development+Demand Rate from Tests, Time to Adjust Workforce
, Demand Rate from Development+Demand Rate from Tests)
Units: foup/Month
assumption: last three months of 2007 follow similar pattern as
               the first three months of 2008

(32)   increase rate of experienced operators costs=
               Cost per exp operator per time unit*Experienced Operators
       Units: Euro/Month

(33)   increase rate of newly hired operator costs=
               Hiring Rate*Fixed Cost of Hiring+Newly Hired Operators*Cost per new operator per time unit
       Units: Euro/Month

(34)   Initial Experienced Operators=
               5
       Units: person

(35)   Initial newly hired operators=
               4
       Units: person

(36)   Initial Production Start Rate:=
               GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b2')
       Units: machine/Month

(37)   Initial Shipment Rate:=
               GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b5')
       Units: machine/Month

(38)   INITIAL TIME = 0
       Units: Month
       The initial time for the simulation.

(39)   Machine Capacity in Plab=
               coating capacity per time per track*number of tracks for coating+developing capacity per time per

track
       *number of tracks for developing
       Units: foup/Month

(40)   min number of operators needed=
               1
       Units: person

(41)   Newly Hired Operators= INTEG (
               Hiring Rate-Firing Rate of Newly Hired-Training Rate,
                 Initial newly hired operators)
       Units: person

(42)   Normal Work Rate per worker per month=
               1/(coating time needed per foup for avg lot size+developing time needed per foup for avg lot size
)
       Units: foup/Month/person

(43)   number of tracks for coating=
               2
       Units: track

(44)   number of tracks for developing=
                2
         Units: track

(45)   Production Start Rate=
                Effect of Change in Production Start Rate*Initial Production Start Rate
         Units: machine/Month

(46)   Productivity=
                effect of fraction of experienced workers on productivity(Experienced Operators
         /Total Operators)
         Units: Dmnl
         1 experienced is assigned as supervisor to new ones

(47)   Quit Rate=
                1/12
         Units: person/Month
         1 person per year

(48)   Random Accuracy=
                RANDOM UNIFORM(0.5, 1.5 , 0)
         Units: Dmnl

(49)   Rate of Transfer of Machines=
                DELAY FIXED(Start Rate of development Machines, Avg time in development ,
          2)
         Units: machine/Month
         2 is an approximation based the data of 2008, the start rate of
                        machines are assumed to be 2 till at month 18, the real start
                        rate for teh first month in the simulation timeline can be taken

(50)   SAVEPER = 1
         Units: Month
         The frequency with which output is stored.

(51)   Scheduled Pressure due to time restrictions:=
                GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b10')
         Units: Dmnl
         if shipments(t)>starts(t-4), there is pressure. for each machine
                        diffence, 5% increase in demand

(52)   Shipment Rate=
                Effect of Change in Production Shipment Rate*Initial Shipment Rate
         Units: machine/Month
         equals a func of production start rate with a time delay of CT

(53)   Start Rate of development Machines:=
                GET XLS DATA('inputs SD.xls' , 'Sheet1' , '1' , 'b17')
         Units: machine/Month
         from gantt chart 2008 end, starts of the development systems
                        counted

(54)   time needed to finish work=
                1
         Units: Month

(55)   TIME STEP = 0.25
         Units: Month

The time step for the simulation.

(56)   Time to adjust for firing exp opr=
               RANDOM UNIFORM(1/30, 1 , 0)
          Units: Month [1,1,1]

(57)   Time to adjust for firing new opr=
               RANDOM UNIFORM(1/30, 1 , 0)
          Units: Month

(58)   Time to Adjust Workforce=
               3
          Units: Month
          (CV check, interviews etc. time to get the new workers)

(59)   Total Cost=
               Cost of Experienced Operators+Cost of Newly Hired Operators+Cost of Firing New Opr
          *Fired New Operators+Cost of Firing Exp Opr*Fired Exp Operators
          Units: Euro
          in this model, no firing costs, no hiring cost, so the total
                         cost only shows the vrb costs per worker

(60)   Total Operators=
               Experienced Operators+Newly Hired Operators
          Units: person

(61)   Training Rate=
               if then else(Newly Hired Operators>=1,Newly Hired Operators/Training Time
          ,0)
          Units: person/Month

(62)   Training Time=
               3
          Units: Month

(63)   WIP Development= INTEG (
               Start Rate of development Machines-Rate of Transfer of Machines,
                         10)
          Units: machine

(64)   "WIP Tests (Manufacturing Sys.)"= INTEG (
               Production Start Rate+Rate of Transfer of Machines-Shipment Rate,
                         53)
          Units: machine
          Initial value assigned by checking the first week in
                         Gantt-Chart-test issued in 2008 Dec (only the manufacturing
                         systems, Start FASYs not included)

(65)   Work completion Rate=
               if then else("Work to be Done (Now)"/time needed to finish work<(Normal Work Rate per worker
          per month
               *Productivity*min number of operators needed
                    ),0,
                    min(Normal Work Rate per worker per month
                    *Productivity*Total Operators,Machine Capacity in Plab))*effect of holidays
          Units: foup/Month
          3 workers per shift in the lab

(66)   Work Done= INTEG (
                Work completion Rate,
                        0)
         Units: foup

(67)   "Work to be Done (in future)"= INTEG (
                Increase rate in future workload-Decrease rate in future workload,
                        1602)
         Units: foup
         1602 (number of foups coated in march 2008)

(68)   "Work to be Done (Now)"= INTEG (
                Demand Rate from Development+Demand Rate from Tests-Work completion Rate,
                        1326)
         Units: foup
         1326: number of foups coated in jan 2008

Appendix XXVIII: Real Data Used in the Base Run of System Dynamics Model

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