MASTER

NXE volume organisation

the design and evaluation of an organisation structure for the volume production of ASMLs new NXE machine type

Schepens, A.J.A.

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A.J.A. Schepens
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Dankwoord

Deze master thesis is het resultaat van 6 maanden afstuderen bij ASML in Veldhoven en vormt de afsluiting van 3 jaar Operations Management and Logistics en 4 jaar Industrial Engineering studeren aan de Technische Universiteit in Eindhoven. Het onderwerp van deze thesis is het ontwerp en de evaluatie van een organisatiestructuur voor de productie van NXE-type machines in een volume situatie. Als zodanig is het een onderwerp dat binnen de organisatie structurering literatuur valt, maar waarbij een goed gevoel voor operationele processen onontbeerlijk was.

Het grote begrip van ASML's uniek product en productieproces dat hiervoor daarnaast nodig was, heeft mij de mogelijkheid gegeven om een kijkje in de keuken te nemen van een van Nederlands meest technologische geavanceerde bedrijven. ASML is dankzij zijn hoog innovatief vermogen, in staat gebleken om over de afgelopen 25 jaar een significante bijdrage te leveren aan het in stand houden van Moore's law.

Ondanks de vaak drukke werkschema's waren de mensen die mij tijdens dit onderzoek te woord hebben gestaan altijd bereid om mij te helpen bij het onder de knie krijgen van de ASML basics. Hierbij maakte de typische Brabantse gezelligheid die overal in het bedrijf aanwezig is, het voor mij ook een groot plezier om mijn onderzoek bij ASML te hebben kunnen uitvoeren. Ik wil hierbij dan ook alle mensen die mij tijdens het afgelopen half jaar bij ASML te woord hebben gestaan bedanken. Verder wil ik hierbij met name mijn ASML en TUe begeleiders bedanken. Mijn TUe begeleiders zijn Henny van Ooijen en Kim van Oorschot. Henny wil ik bedanken voor de steun en het begrip die ik kreeg toen ik mijn eerste afstudeerpoging helaas moest afbreken. Hij gaf mij daarmee de motivatie en mogelijkheid om weer opnieuw te beginnen bij ASML. Arie van de Schoot was mijn bedrijfsbegeleider en heeft mij daarbij op een altijd vrolijke, enthousiaste en uitstekende wijze ondersteund. Uiteraard kan ik bij deze opmerking ook niet mijn directe kantoorcollega Jos van Dongen onvermeld laten. Een menige opmerking uit zijn richting heeft me uit mijn concentratie gehaald, maar daarmee wel de algemene kantoorvreugd doen verhogen. Edwin Hulzenbos en Lars Verburg hebben mij verder uitstekend geholpen bij de eerste kennismaking met ASML en ik ben hen dan ook dankbaar voor alle ASML feitjes die in dit rapport terug te vinden zijn. Het zou verder onterecht zijn om hierbij alle andere collega's bij MOS-IE onvermeld te laten. Zij zijn collectief verantwoordelijk voor een groot gedeelte van de inzichten en data die ik in dit rapport gebruikt heb en ik ben hen hiervoor dan ook uitermate dankbaar. Het was zeer leerzaam om te zien hoe de kennis van mijn opleiding industrial engineering gebruikt kan worden binnen deze gelijknamige afdeling van ASML.

Ook de mensen die mij vanuit het thuisfront hebben ondersteund wil ik hierbij bedanken. Natuurlijk mijn ouders die het mogelijk hebben gemaakt dat ik deze opleiding op relatief onbezorgde wijze heb kunnen volgen. Mijn zusje Mirjam, mijn vrienden en natuurlijk mijn huisgenoot, die in deze periode altijd klaar stonden om met mij mijn dagelijkse beslommeringen door te nemen. Daarnaast wil ik alle mensen die ik tijdens de afgelopen 7 jaar op de TUe ben tegengekomen bedanken voor de mooie studententijd. Mijn periode als student zal ik hierbij helaas moeten afsluiten maar ik kijk met veel verwachting, plezier en ambitie uit naar de toekomst.

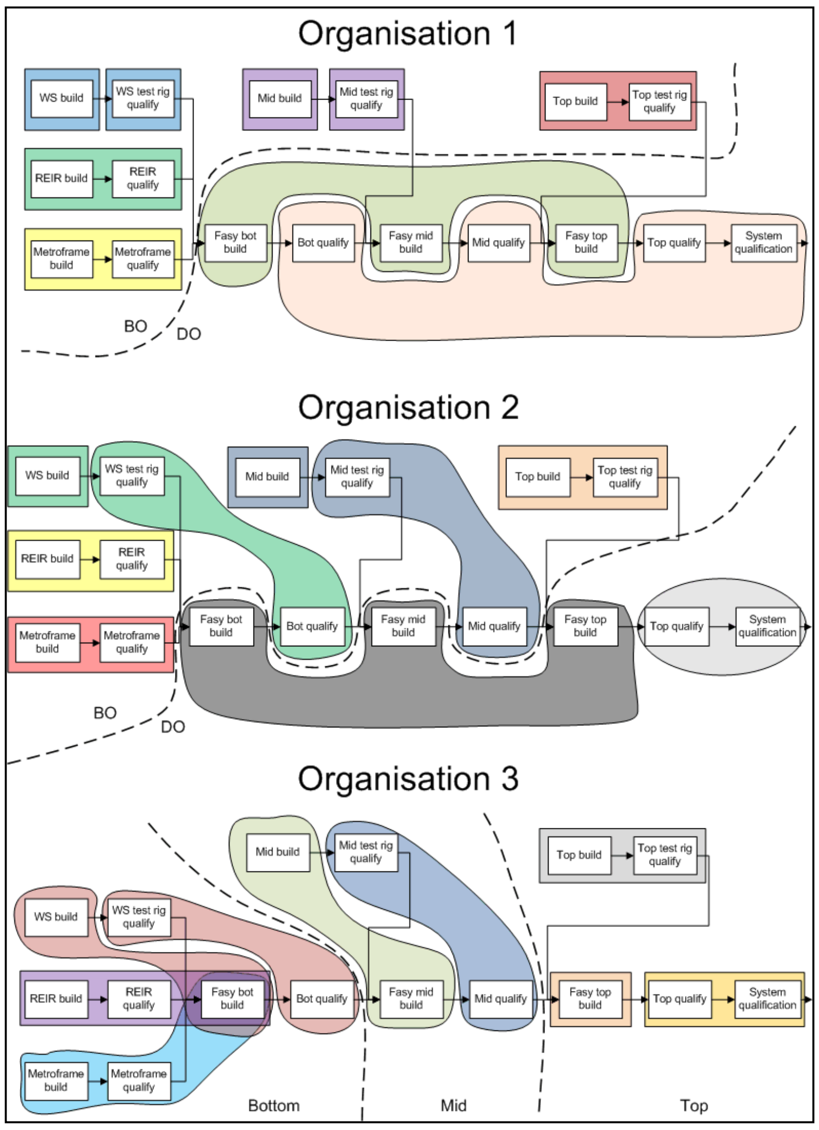
Abstract

This master thesis consisted of the design and evaluation of organisation structure options for the volume production of ASMLs next generation machines. Two existing organisations were compared with a new organisation by combining organisation structure literature and a simulation of the production process. This led to a combination of qualitative and quantitative arguments, that argue for an implementation of the new organisation structure.

Management Summary

ASML is an innovative company providing advanced lithography systems to semiconductor manufacturers. The construction of these systems is performed at ASMLs headquarters in Veldhoven. This construction involves the assembly of a large number of parts from suppliers into complete systems and testing these systems for functionality and performance. ASMLs newest machine type, the NXE, deviates from this traditional production process, by introducing system test phases during assembly. This has led to a new organisation structure for the production of NXE proto and pilot systems, which is thought to be more conducive for decreasing "problem time".

The initial subject of this thesis was the investigation of the effects this change in organisation would have. This subject was later extended to the design and comparison of organisation alternatives for the NXE volume production situation. The increased production volume is thought to be more of a problem for this new organisation, because of a more diffuse distribution of responsibilities and authority. To this end a third organisation was designed that was thought to fare better in this regard. In combination with the traditional twinscan production organisation, this meant that three organisations were compared and evaluated for the NXE volume production situation. These three organisations can be seen in the figure to the right.



In order to compare these organisations a number of criteria were found in literature and customized for ASML's specific situation. Given the abstract nature of these criteria however, a further investigation at ASML and in literature was conducted to the specific drivers for these criteria. From this investigation a number of organisation structure dependent drivers were identified. These drivers were subsequently used for an evaluation of the organisations with respect to the criteria. This resulted in a qualitative assessment of the organisations.

This qualitative assessment was then used as input for a quantitative comparison of these organisations. A simulation was used for this purpose, which resulted in an objective assessment of their financial and cycle time performances. Based on an analyses of the simulation, organisation 3 seemed to be the best choice from both a financial (costs) and a cycle time point of view. Organisation 2 was a close second and even scored better in the low demand scenario, because its more efficient use of production personnel outweighed organisation 3's other benefits in that case. Organisation 1 was in all cases the worst option and a continuation of the twinscan organisation to the NXE production is then also not advised.

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Chapter 1: Introduction to the semiconductor industry and to ASML

The first 2 chapters of this report are an introduction to the graduation project described in this report. The first chapter will introduce the semiconductor industry and ASML's role and situation in this industry. The second chapter describes the initial assignment, the orientation and analyses that has subsequently been carried out and the final assignment formulation that was agreed on with all project stakeholders. The end of chapter 2 will describe the structure of the rest of this report.

1.1 Industry

ASML develops, produces, markets and services complex lithographic systems that are used in the fabrication of integrated circuits. The integrated circuits (IC) fabrication industry and all related periphery activities is commonly called the semiconductor industry. This is a relatively new industry that has grown rapidly into a 260 billion dollar business, since the production of integrated circuits became economically viable at around 1960.

This growth was driven by rapid technological improvements in the technology and it's role as technological enabler for other industries. Integrated circuits are used in all sorts of appliances. Modern computing, communications, manufacturing and transport systems all depend heavily on integrated circuits. As more and more devices use ever faster chips the industry is still expected to have a large growth potential over the coming decade.

The large growth over the last 40 years was realized through a relative high investment in research and development and the ability to innovate and progress rapidly through successive product generations. The semiconductor industry however is very perceptible to economic cycles. Both periods of severe under- and overcapacity are common and need to be absorbed by industry players by using a large degree of (capacity) flexibility. Finally, the semiconductor industry is also a global industry with large players in Asia, Europe and the USA. This has ensured an aggressive competitive environment in which only those who know how to combine R&D, flexibility and efficiency are able to survive.

1.2 ASMLs role in the industry

ASML machines are used in the production process of integrated circuits. ASML's customers use these machines for projecting IC blueprints - a reticle - on wafers. A reticle is projected multiple times on a wafer during this process. The reticle represents a carefully designed network of lines that represent the blueprint of 1 layer in a chip. Wafers then undergo a number of steps to transform this image into a real network of lines that are able to store electricity - and thus information - into specific patterns. This process can be repeated a number of times to "build" a number of layers on the chip.

1.3 Customer demands

The imaging of the patterns on the wafer is certainly an important factor in the technical performance of chips. The technical performance – or speed – is depended on the number of lines that fit on a chip surface area. Line width then is a key customer demand for ASML. ASML has been able to improve consistently on this area by investing heavily in research and development. Another key customer demand is the speed with which a customer is able to perform this operation. Processing more ICs each minute, decreases the unit cost of integrated circuits and thus increases the potential profit per IC. A last key customer demand is the precision with which these lines are projected on top of each other over multiple runs through the machine. This is called the overlay and is a challenge because of the exact similar position that is required, each time a wafer is processed in the machine. The overlay ensures a correct alignment between the layers of an IC.

ASML has been able to outperform competitors on these three key customer demands and has consequently been able to grow steadily over the last 25 years to becoming the dominant player on its market. Although ASML scores high on these customer demands, other demands have had a lower

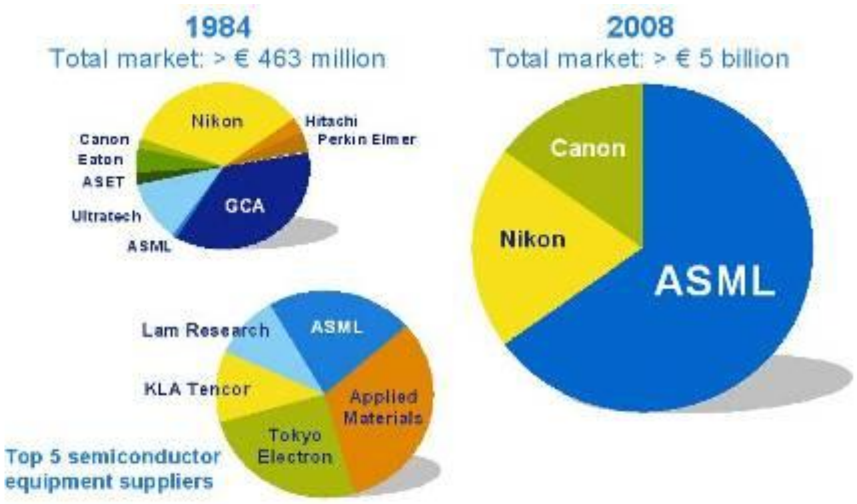

Figure 1: ASML's market share

priority. One aspect on which ASML's machines are less competitive is the cost aspect of its machines. However, since the economic lifetime of machines has always been relatively short and the above described key demands have always driven the market. These benefits have until now always outweighed the costs for customers. Older type machines however are also still used by some less demanding customers, and it is clear that competitors have an advantage there. The relative higher costs of ASML's machines is caused in part by the business model ASML has. Machines are first build and qualified at ASML's factory and then broken down, transported to the customer and then build up again. Competitors only build and qualify machines at the customer site and thus safe time and costs. This approach has been chosen by ASML because it enables a shorter "disturbance time" for the customer. It also enables ASML to build up expertise in new machines more quickly because of the concentration of knowledge in its factory. A third reason is the emphasize on new product development which sometimes cannibalizes on optimizing existing types for costs.

1.4 Market

ASML's customer base consists mainly of a set of large IC manufacturers. 90% of the top 20 semiconductor spenders are ASML customers. Intel, Samsung, Toshiba and Sandisk are some of the most well known customers. These customers mostly prefer to have 1 supplier for the specific type of machine ASML supplies, which eases the sales of new machinetypes. A large challenge however also exists in the unpredictability of customer demand. The way ASML is situated in the value chain of the semiconductor industry, makes it highly perceptible to changes in the overall economic situation. The combination of capital intensive products and being located upstream in the value chain, makes it difficult to predict changes in market demand. These changes moreover are also very dramatic. ASML struggles to meet demand when economic times are good, but a large part of its production capacity is unused when economic times are weak.

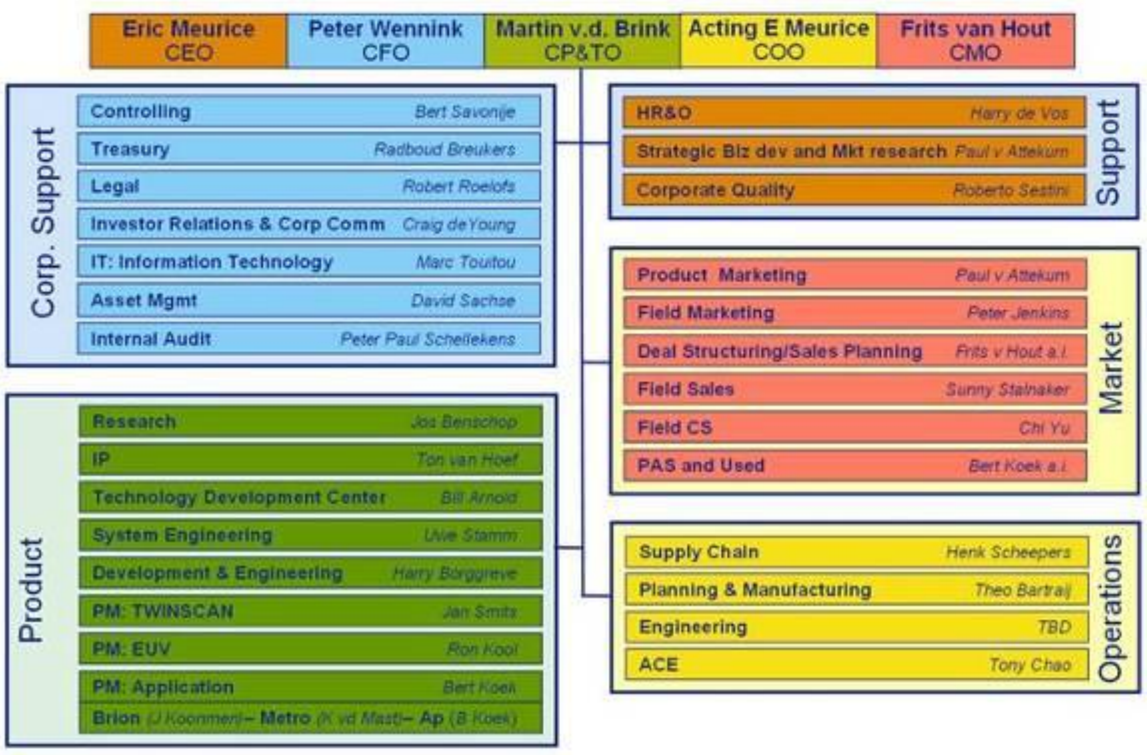

Figure 2: ASML organisation

1.5 Organisation structure

ASML on a high aggregate level is divided into departments that belong to either product, operations, market or corporate support related functions, as can be seen in figure 2.

'Product' is responsible for research and development of new technologies and machines. They do both theoretical and practical research on new technologies that might be used for improving new machines. They also translate this research into a product design and improve existing machines by means of engineering changes.

'Market' basically maintains contact with all ASML customers and is responsible for spotting and evaluating changes in customer demand both in a quantitative and qualitative sense. Existing machines are also supported and machine breakdowns are solved.

'Corporate support' performs staff functions for ASML as a whole by advising on legal, financial and IT related matters.

'Operations' is responsible for the actual manufacturing of machines. The details of production of new machines is developed here and the ASML production process is managed. A large part of the production process is outsourced however and this supplier base is also coordinated here.

Planning & Manufacturing (MP) manages the internal production process. A breakdown of the M&P organisation can be seen in figure 3. Facility management is responsible for all ASML facilities. Central planning balances customer demand and internal factory supply by changing factory capacity to demand forecasts of the market departments. MOS is a staff function which supports the factory. Product Introduction General is in charge of all new machine types during first product introduction. MP System Engineering is an organisation which keeps a bird's eye vision of new machine developments. MP Operations Wilton is responsible for production operations in Wilton USA. Build Operations (BO) manages the operational process of building system modules and Delivery Operations finally manages the operational process of assembling these modules, testing the system and packing and delivering the machine to the customer. BO and DO will be explained in more detail in chapter three.

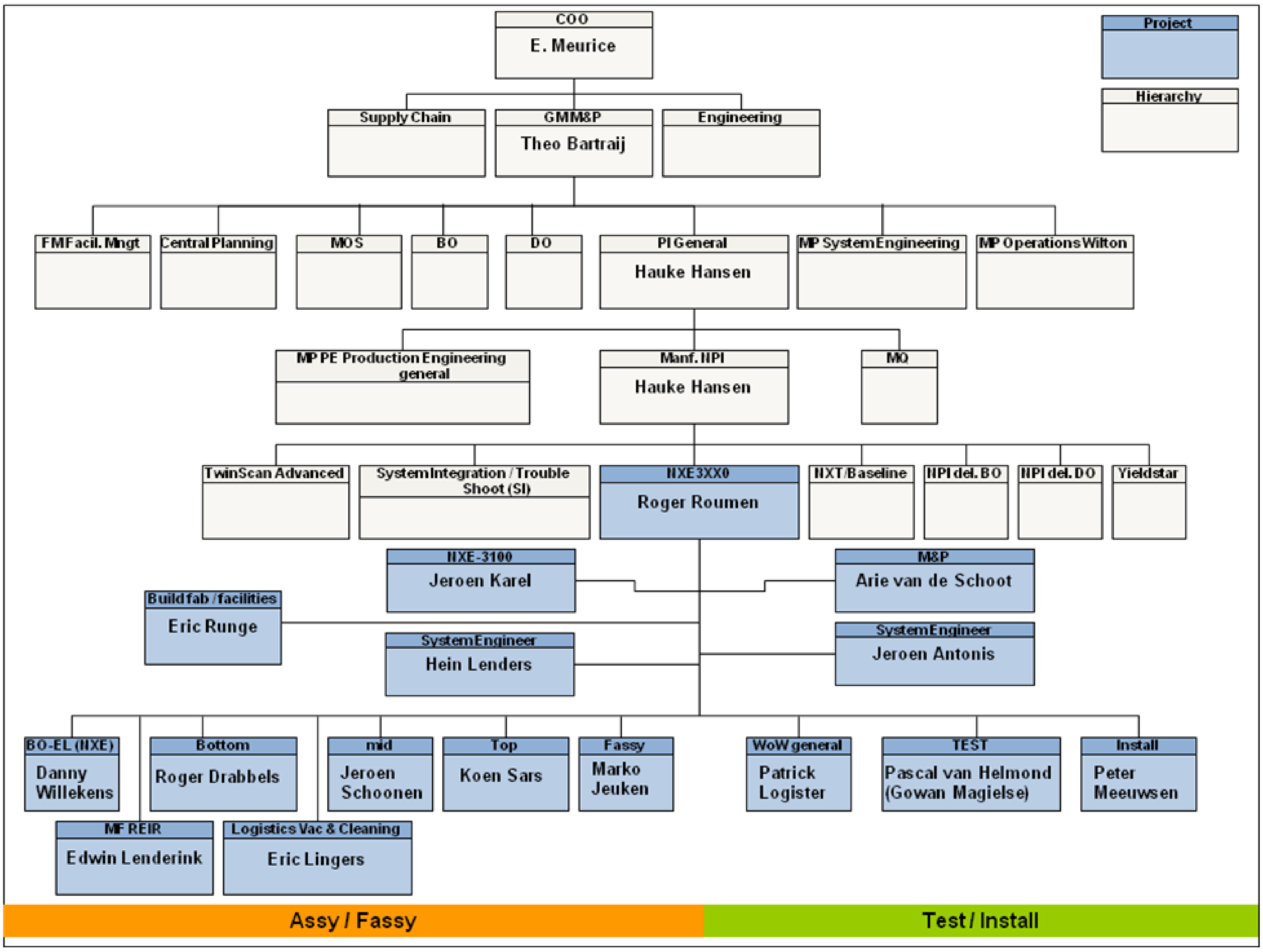

Figure 3: MP organisation

Chapter 2: Research assignment

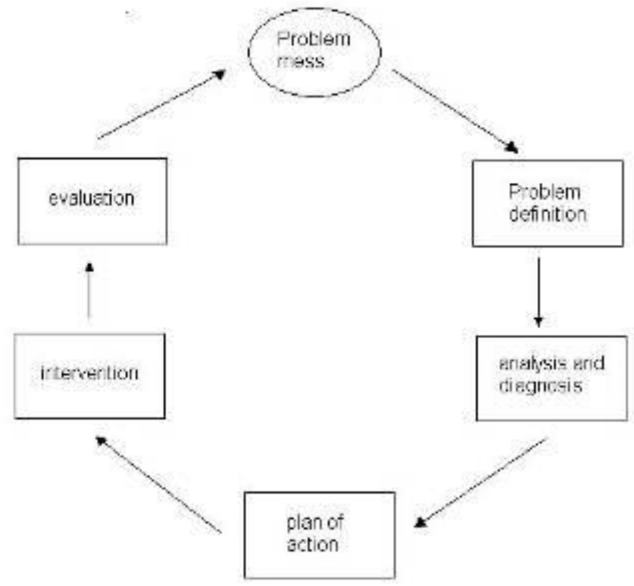

Figure 4: Regulative cycle

Van Aken et al [2] describe a method for working on business problems in which they use the framework of the regulative cycle of van Strien. (see figure 4) They claim that most assignments are stated in terms of a perceived problem. The first step that is to be taken is to evaluate the context of the problem, what they call the "problem mess". The evaluation might reveal the problem to be either a symptom of an underlying problem, a problem that is stated on the basis of unattainable norms or to be an unrealistic expectation of performances. Based on this initial analysis, an assignment may change in agreement with project stakeholders.

This chapter will first relate the research assignment as first proposed by ASML. Then the initial analyses will be described, followed by the final assignment that was agreed on by ASML- and TUe-stakeholders.

2.1 Initial assignment

The initial assignment was to evaluate the consequences of an organisation concept that was developed for the newest NXE type of machine. This machine is a radical innovation not only in technology, but also in the way it will be produced.

Prior machine types were first assembled (by assembly) into machine modules and then tested before they were handed on to a second department (final assembly) that further assembled these modules into a complete machine. These machines are then finally qualified or tested by a third organisational department (TEST) before dismantling and shipment to the customer takes place. The difference for the NXE type machines is that modules are assembled into three super modules, which are then separately qualified before these are put together into a complete machine. Building these super modules is still done by final assembly, but qualifying these modules is done by the assemblers of modules.

The reason behind this change in the production was that the cycle time or the time from start production to finish, of a machine was increasing with each generation and was on the point of being so long that it is no longer affordable to continue in this way. Also the reason behind introducing a new way of organizing this production was that this was thought to increase the learning capacity of the organisation by having assemblers see the result of their work in action or fail in the test phase of a complete machine. This way the feedback loop of errors is more direct and effective.

This was thought to be important because - besides having long cycle times - there is also the problem that these cycle times are very variable and unpredictable. When modules or machines fail to work properly, the cause of this failure can be hard to determine because of the large complexity involved. The time it takes to diagnose the correct cause is unpredictable and can sometimes take quite long. It is often a direct result of the knowledge and experience a person has with a specific module / machine. The "problem time" (B-time) proportion of the total production time (cycle-time) varies with the number of machines that have been build of a specific type, but can sometimes be as large as 6/7 of total cycle-time.

Since the underlying problem of the initial assignment was the variable cycle-times of machines, the initial orientation and problem mess analysis was concentrated on the underlying cause(s) of the variability of cycle-times.

2.2 Analyses: method description

It is recommended by van Aken et al [2], to use multiple data gathering methods during the orientation period. This is most likely to give an unbiased impression and moreover increases the amount of information that can be gathered, whereby it is more likely to uncover all relevant causes.

The first method that was used, was to carry out interviews with problem stakeholders. Around 20 interviews were carried out through the entire organisation with all personnel that could possibly have influence on decreasing B-time..

The second method was observing people in their daily routine in order to get a better understanding of the issues they face and the subtleties of their work routine. To this end, personnel in different functional positions have been accompanied for one day and asked for their normal routine tasks and meetings.

The last method that was used was studying (work) documents that were used in the organisation. These include database data, presentations and prior reports of similar and related studies, but also work reports that are used by first line management and machine mechanics.

The result of this analysis is described below.

2.3 Analysis: results

A number of causes were found through the initial orientation and analyses. These were categorized into four broad categories.

2.3.1 Causes: Company specific circumstances

The first set of causes are known at ASML and explains why B-time or “problem solving time” will always be present to some degree in its production process. This is due to the specific technological and environmental circumstances ASML faces.

Innovation has been the primary driver of market share growth and profitability. This has meant that all the machinetypes that are developed and produced are on the frontier of applied science. By definition then a large set of the problems that surface during construction of these machines are new and unknown. These problems need to be understood before a solution can be thought of, which is a knowledge intensive, haphazardness and sometimes time consuming process. These machines have also become more and more complex over the years to the extent that it is impossible for one person to exactly understand how a complete machine works. Moreover there are dependencies between modules so that solutions in one part of the machine can lead to possible new problems in other parts. It takes time and experience with a specific type of machine to develop it to the point that most problems have been engineered out of the design. Because of the large complexity of machines, new problems keep surfacing during production. It takes a certain amount of experience in building a certain machines type before most of the problems are known and they no longer constitute a large and variable part of the construction time. The constant pressure on better and faster machines however usually prevents the production department to get to this phase. New machine types are introduced by Development & Engineering and the learning and solving problems for Manufacturing & Planning starts over again with each successive type.

2.3.2 Causes: Product development

The second set of causes resides in the new product development processes. There is a large emphasis on being first mover in terms of being able to get the smallest line width. Almost 2500 people work at ASML on challenging the problems that are involved in realizing this. These people do both fundamental research into new theoretical ways of accomplishing this as well as applied development of these theories into a machine design. They are typically very highly educated and enjoy challenging these problems and translating this into designs and machines that actually work. D&E is responsible for the first prototype machines and then hands over responsibility of production to M&P. Designers then usually move on to the next type. These machines are typically optimized in design to function properly. The next step would be to design for manufacturability. This has a very low priority however at D&E. Usually the experienced and senior engineers move on and only a skeleton crew of mostly new people (who are said to be able to learn from older machines) take over. The consequence is that machines are only to a small extent improved after the initial prototypes. Of course the effort is there but due to the unfamiliarity and the limited resources on D&E’s part, design for manufacturing could be improved upon.

2.3.3 Causes: Production handover for volume production

The third set of problems relate to the organisational divide between D&E and M&P. After production of the first couple of prototypes, the release for volume takes place. Protoypes are build by senior production mechanics picked from M&P's "best" who are assisted by very knowledgeable D&E and production engineering personnel. After release for volume M&P personnel has to take over and D&E leaves. Production engineers and senior production personnel usually stay, but production volumes increase and new inexperienced mechanics are included. This transition then causes a lot of dilution in knowledge. Ideally production instructions and storing problem-cause data should help in this transition, but this is usually not a high priority. The information that is written down, is written from a more knowledgeable background and is not always well understood by new mechanics. The effect of this problem can be seen in an initial small spike in cycle-times after transfers.

2.3.4 Causes: M&P internally

The last set of problems is located in M&P internally. All previous causes were external for M&P and are either difficult to change or indirectly the result of management priorities. Another set of causes can be found in M&P.

A high degree of specialization is present at the factory. Production of machines is split up among many groups of mechanics, so problems are not always the result of a mechanics own mistakes. They can also be the result of previous production steps. It is difficult to trace back these mistakes because of the large complexity of the machines and the number of people working on it. This makes it difficult to learn from mistakes for the future. The introduction of working in shifts decreases total cycle-time (16 hours of work instead of 8 hours), but also decreases the feelings of responsibility and ownership of work. In combination this decreases the ability to systematically improve production.

This is set off by the introduction of work instructions and specialized problem solvers. Work instructions in principal decreases mistakes through standardization of work and problem solvers have the ability to routinely solve problems, learn from them and thus to solve problems faster. Work instructions are written by different specialists, split up by competences however and problem solvers are split up in to different hierarchies of problem escalation as well as competences. This has resulted in the spread of knowledge and responsibilities over a large number of people in M&P, which means that it is difficult to determine the correct set of engineering changes and way of working even when systematic causes are found.

So problem-cause relationships are difficult to find and when these are found it is difficult to translate these into engineering changes. This is furthermore aggregated by the large management emphasis on output. Machines are expensive to have on stock and customers want their ordered machines on time. So when a delay occurs the emphasis is logically on a solution so that production can continue. This however also comes at a cost of systematic improvement.

2.4 Final assignment

A large part of the above described causes are inherent to ASML or cannot easily be solved. The last set of causes is M&P internally but is also a result of uncontrollable factors such as the complexity of machines and the small volumes that are produced.

The initial assignment was to evaluate the consequence of an organisation change for the production of the newest NXE type machines. The change would allow different assy personnel to learn from mistakes by experiencing and solving the problems that occur in a later production stage – in the qualification of the "super" modules. The idea was to have personnel from the different assy modules to test and qualify the super module. This would have the effect of increased learning from both interaction with personnel from different assy's and seeing the interaction their own module has with other modules. Less cycle-time was further expected because experts of different modules could together more easily diagnose the cause of a problem and propose a solution. These and other hypothesized effects can be found in figure 5.

In the orientation period however it became clear that the interaction would only partly take place. The qualification phases of the super modules do not require the expertise of different assy personnel. In the case of the Main Body Mid Module (MBMM) it would only make sense to have mid module assy personnel. For the Main Body Bottom Module (MBBM) only waferstage personnel is required for the most part and only for a small part is metroframe personnel needed. The Main Body Top Module is built in Winston (USA) and would only require personnel from there. The interaction effect then is only partly there. Furthermore, it appeared that building and testing modules are different kinds of work and was going to be done by different groups of employees. Thereby also decreasing the expected learning effect.

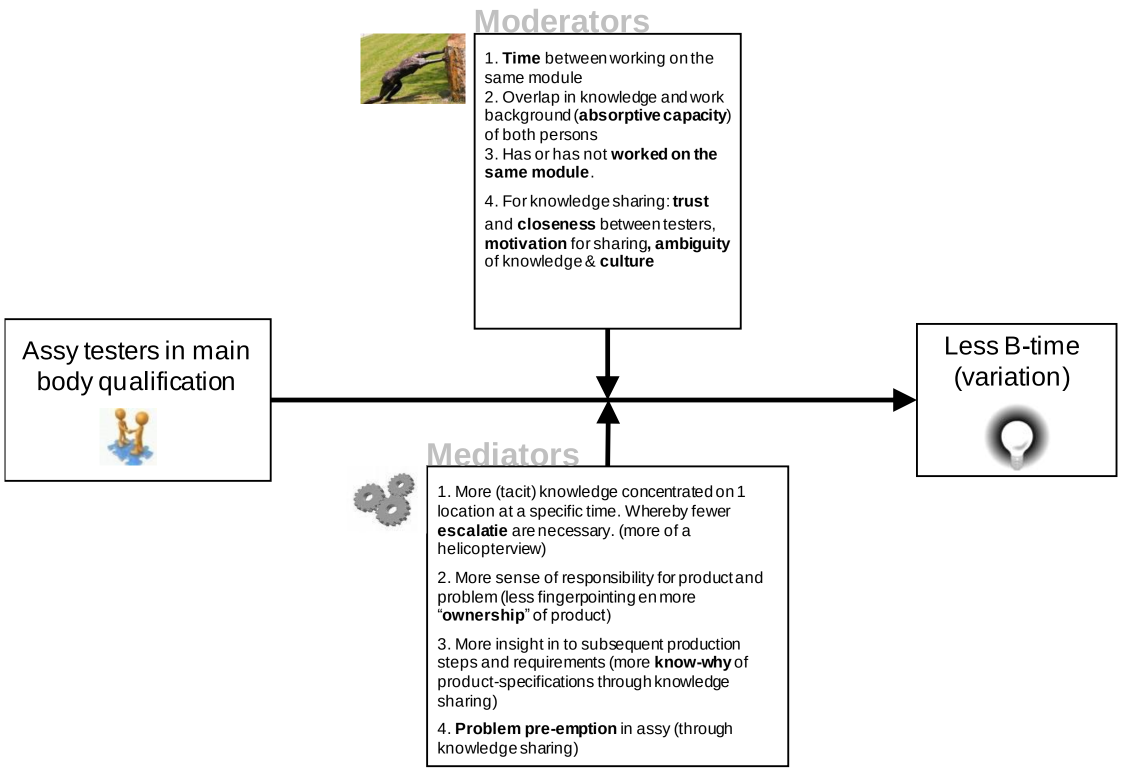

Figure 5: Expected effects organisation change

In cooperation with ASML stakeholders the assignment was consequently changed to evaluating a number of other organisation forms for the NXE type machines. This research will serve as a recommendation for the NXE3300 and following (NXE3XX0) type machines (volume situation) as opposed to the current NXE3100 type machine in which the choice for the above described organisation form is already taken.

The following assignment was agreed upon:

- Design a new organisation structure for the NXE volume production and compare it with existing alternatives.

- Investigate what conditions need to be satisfied for the new organisation structure to work.

- Investigate what - if any - gains in B-time variation reduction can reasonably be assumed.

The rest of the report will document the reasoning and results of this assignment. In the next chapter an explanation of the current production organisation will be given. It will also relate the fundamental differences between Twinscan and EUV technology machines. The next chapter will describe a number of organisation structures that have been designed using literature and company experience. Chapter 5 will describe the criteria that were used to evaluate the organisations. Chapter 6 will then evaluate the three organizations using these criteria. Chapter 7 will use part of these criteria as input for a simulation that is used to further evaluate the three organizations in a quantitative fashion. Chapter 8 then finally relates the important conclusions and recommendations of this project.

Chapter 3 Analyses current production organisation

In this chapter the production- and organisation structure of the current machine type, the Twinscan, will be described. This will then be contradicted with the new NXE production structure. The important differences will be highlighted. As an introduction to these sections however, first a typical ASML machine will be described. This will serve as a background for the production situation.

This chapter serves as an introduction to ASML's production situation and organisation structure. Readers who are already familiar with this, are advised to skip this chapter and go on to the next chapter.

3.1 Machines

ASML machines have - over time - consisted of a reasonable stable set of modules. Integrated circuits are built on wafers. These wafers enter the machine in the wafer handler part of the system. Here they are stored and collected by the wafer handler when ready for imaging. The wafer handler pre-aligns the wafer and moves it on to one of the wafer stages. Two wafer stages are present in the machine. While one wafer stage is under the laser, being processed, the other wafer stage is scanned for irregularities and position. When the wafer is finished processing, the wafer stages swap and a new wafer is loaded and scanned while the other undergoes processing. Imaging takes place with a laser that is shot through a reticle and then reduced in size by a large column of optical lenses. This process is essentially a reversed "picture taking", in which a blueprint (the reticle) is projected multiple times on a wafer. Different reticles can be placed in front of the laser by a reticle handler. This ensures that the machine can image multiple types of blueprints. The entire machine requires power and a diverse set of gasses and liquids to operate. These are supplied by cabins that are placed around (at ASML) or beneath (at the customer) of the system.

In summary, the large modules a typical machine consists of are a wafer stage and handler, a lens, reticle stage and handler, a laser, cabinets, a frame and numerous smaller supporting parts that these modules rely on to operate.

3.2 Twinscan production situation

The Twinscan type machine is ASMLs current "volume" machine. The Twinscan type was introduced approximately 10 years ago as a replacement of the PAS system. This system was radically new in the sense that it used 2 wafer stages which doubled the amount of wafers that could be processed by continuously having one wafer stage under the laser. Over the years new versions of the Twinscan have been launched. These new types varied in the amount of new technology that was incorporated, but these were always incremental and built on the old design. The increased technological complexity that was required, has resulted in very specific competences per system module. Machine design has been divided in these competences, but machine construction has been divided in these competences as well. The construction time (cycle-time) of machines has increased over consecutive machine types as well, because of the increased complexity that was involved. Because the repetition of tasks needs to be high for understanding and learning purposes, this has resulted in a very fragmented manufacturing organisation.

The production situation of the Twinscan will be described in two sections. First the assembly process of modules into a functioning machine will be described. Then, the M&P organisation position structure (the organigram) will be shown and explained, for as far as is relevant for this study.

3.2.1 Production steps

Modules are assembled from parts that are supplied by a large number of suppliers. As it is ASML's policy to outsource as many parts of machines to suppliers, only highly critical assembly steps in the early stages of construction is done at ASML itself. Parts that arrive at ASML have been assembled as far as possible, but are still relatively small.

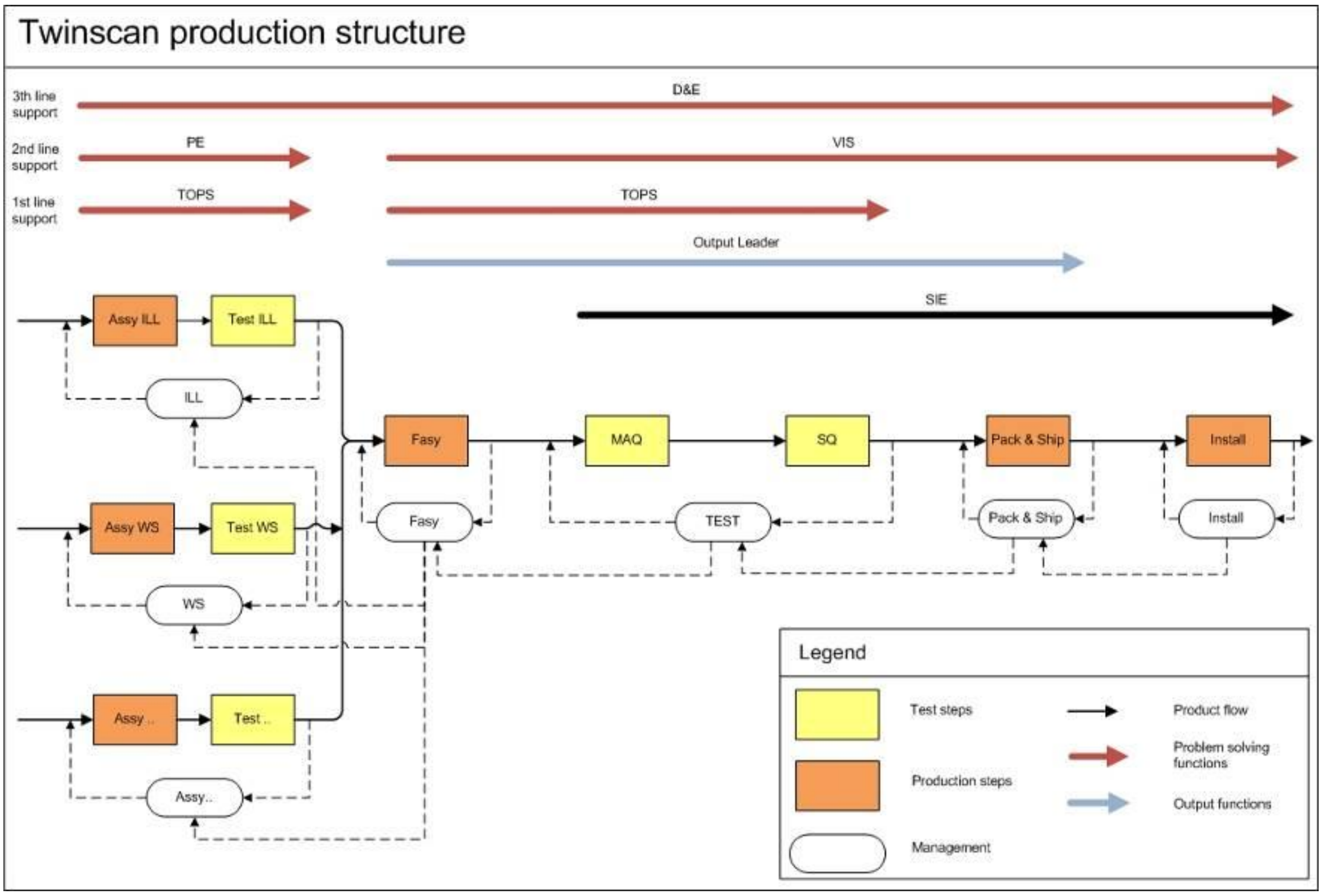

Figure 6: Twinscan production structure

The production of Twinscan systems is represented in the figure 6 above.

ASML's production steps are essentially a number of assembly steps and a number of test and adjustment steps. Parts are assembled at functionally specialized work centers that assemble modules from parts. This work is done in clean rooms, since the presence of dust can cause problems for the proper functioning of a machine. These modules are then tested on a test rig to make sure they function properly. This work is done by a different set of operators then those that assemble them, because the work involves the running of software tests and interpreting the results that are generated by these tests. In case of an invalid value (and thus a problem / issue), the test-rig tester needs to have a good understanding of the functioning of a module to be able to diagnose the cause and resolve the issue. When these issues cannot be resolved, a first line support can be called. This is TOPS. These are present in the clean room and can help the tester with resolving issues. If the TOPS-er is not able to solve an issue within a certain time frame, he can consult a second line of support; a production engineer (PE). Production engineers are people who design the production process (assembly steps) in case of a new product and write work instructions for assembly operators. They typically have a good understanding of the technical details of a module and through this larger knowledge base are able to handle the more difficult problems. If they in turn are not able to solve an issue, they can consult D&E. After the modules have been assembled and tested, they are then assembled into a machine by final assembly (fasy). This is done in cabins where the necessary facilities for an operating machine are present. Modules are assembled into a complete machine and are then initialized. Initialization is the phase where power is first put on the machine and a check is carried out if all parts of the machine get the required power and other utilities. Modules will also communicate with each other in this phase. The next step is the testing and aligning of each module to others. These tests are similar to the tests that are carried out on a test rig and this step is thus essentially done twice. The advantage of using a test rig is that all problems that are caused by a test rig (essentially an unfinished machine) are better known so causes can be found more easily. This phase is carried out by testers together with a system install engineer (SIE-er). The SIE-er will work on one and the same machine from this time on, until it is installed at the customer site and is fully functional. This way SIE-ers are able to learn about tests that are carried out at the customer site as well and to recognize machine specific problems, that have also occurred during construction. When the MAQ (Module Adjustment Qualification) test phase is done the final test phase starts. During this phase, the machine is tested with actual wafers and reticles and should be fully functional when successfully completed. The following step is breaking down the machine again in large parts and packaging for transport. The final part is building and qualifying (testing) the machine again at the customer site.

Most M&P personnel work in shifts. This enables a longer total production time per week on modules and machines and so should reduce machine cycle-time. Working in shifts does not help in solving problems however, as mentioned before. The mostly mental work of diagnosing a problem can only partly be passed from one operator to the other through a written or oral transfer. Some rework is essentially always present and depends on the quality of the transfer. Operators are also scheduled to work on different modules or machines from day to day or week to week, which does not help in operator commitment and sense of responsibility towards their work.

The factory is also going through an implementation phase of lean manufacturing. Lean has been implemented and incorporates a number of best practices such as keeping a clean and organized work place and cutting out all non value adding operations, etc. Assemblers use a computer with SAP with work instructions written by PE-ers. They can follow the instructions step by step and need to close and open instructions when they are finished and start a new one. Flow is the next step for M&P and includes the working in takts in the factory. All production steps have been divided into takts of 1 working day. Takts consist of the time a task should normally take (A-time) and a predicted problem time (B-time).

3.2.2 Functions

Production of machines is hierarchically separated in build operations (BO) and delivery operations (DO). The rationale behind this is the long production time of multiple weeks. Both departments furthermore face different challenges. Build operations needs to synchronize the delivery of numerous parts from suppliers and needs to qualify incoming parts and communicate rejects. Building the separate modules is also very complex work that requires a high degree of specialization. Delivery operations faces the challenge of customer demand and is consequently more focused on getting machines out on time. Furthermore, many problems that result from assembly errors are found in this phase, resulting in a very variable cycle-time which is a challenge in itself.

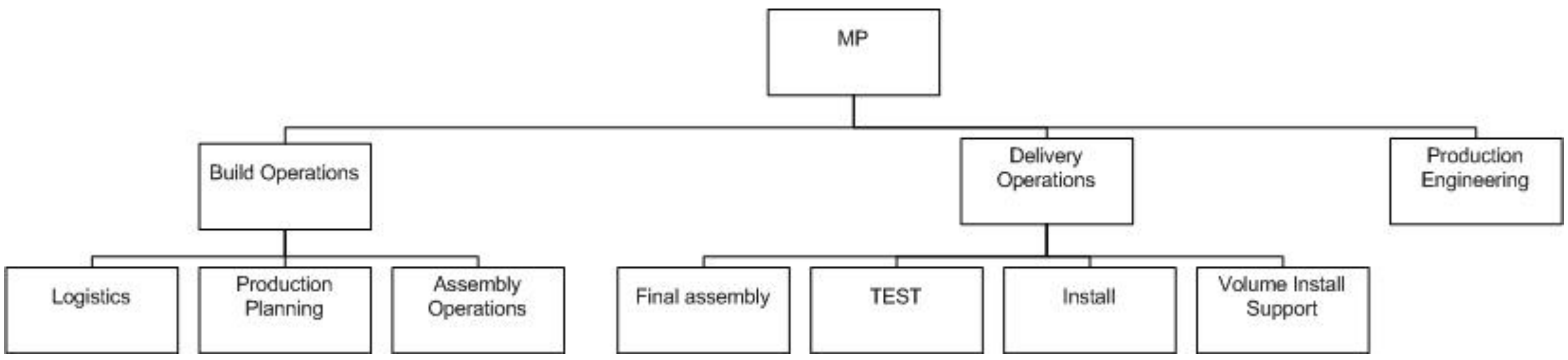

Figure 7: Organigram production

Only functions that are directly related to workfloor operations have been depicted in the organigram. 2 Assembly group leaders are responsible to the build operations manager. (in “assembly operations”) These in turn have a number of team leaders that report to them. Team leaders have a team of operators that carry out actual assembly or test work.

A Team leader is assisted by a material handler (from “Logistics”), who works on the floor and is responsible for ordering material (parts) from the ASML warehouse. He is further assisted by a production planner (from “Production Planning”), who takes care of operator scheduling over a time period of 1 to 2 weeks and of the ordering of material at suppliers for planned production. A production engineer is further operationally and hierarchically responsible to a team leader and functionally to a PE team leader. Last is a material quality inspector who is responsible for vendor related quality issues. Test rig related operations are usually carried out by specific testers who also report to a team leader. In some work centers however the test rig tests are carried out by the same persons who have built the module. In other cases, operators rotate through test rig and building tasks.

For delivery operations a similar construction is present. Final assembly, test and install have Group leaders and Team leaders responsible for output. Volume install support is responsible for assisting these groups when problems are encountered. Team leaders are also known as competence leaders who determine together with output leaders what machines have priority.

3.3 NXE production situation

This part will relate the differences between the NXE and Twinscan on several aspects. First the differences between Twinscan- and NXE-type machines is highlighted. Then the differences in the physical production of these types will be described. Finally the difference in production organisation is explained.

3.3.1 Differences between Twinscan & NXE

New ASML machines need to be able to produce ever smaller line width of integrated circuits. For this purpose the NXE uses a new kind of laser. This laser generates extreme ultra violet (EUV) light, which operates on a smaller wave length and is thus able to project smaller line widths. EUV light however, is very easily absorbed by any particles that float in its path. Because of this, large parts of the machine are now vacuum chambers. Vacuum requires much more solid parts which has resulted in a machine that is significantly larger than was previously standard. The traditional lenses that were used in ASML systems to project the reticle on the wafer also absorb this EUV light, so mirrors are used for this purpose instead. These mirrors and all other parts that are used inside the vacuum chambers need to be extremely clean in order to project the reticle image correctly. Any contamination of these parts will cause potential large delays in production time when these vacuum chambers are first depressurized. So a very high working discipline is demanded from machine builders. Another difference between Twinscan and EUV machines is the number of new gasses that are needed. This requires new and extra safety measures and will also require extra training from personnel. The increased size of EUV machines and the new gasses that it needs, has also required new production facilities.

3.3.2 Production steps

The entire production time (cycle time) and total product costs for the NXE are unprecedentedly high and have forced ASML to make adjustments in the design of the production processes and the machine design.

First, to decrease WIP costs, the number of modules that need to be built by ASML has been decreased. The NXE has 5 work centers in Veldhoven and 2 in Wilton (USA). These include waferstage, REIR, baseframe, metroframe, midframe, reticle stage and reticle handler. The production of the reticle stage and handler is carried out in Wilton (USA). The source (laser) is further outsourced to Cymer, who will assemble and install this at ASML. A graphical representation of this process can be found in figure 8.

For a further decrease in WIP costs, the NXE machine is also designed with a potential future “drop-shipment” in mind. This means that larger parts of the production process (assembly of Main Body Modules) can possibly be performed in parallel, which saves work in process and thus work capital, by decreasing total machine cycle-time. The NXE will need to be much more optimized for this to work and so this will not be done for the first and second generation machines (NXE3100 and NXE3300). Separate test phases of Main Body Modules (called MAQ – Module Adjustment Qualification) however *will* be carried out and this constitutes a difference with regular Twinscan production where these tests are carried out only after the entire machine is assembled.

The high contamination risk related above requires high discipline of production personnel. It also means that all tools that are needed for assembly, need to be extremely clean. This is achieved through a “buddy” system, where all assembly tasks are always performed by 2 persons. One person will perform the assembly task while his buddy will clean tools and materials.

Because of the high contamination risk, a number of vacuum qualification steps are added in the production process. Vacuum qualification will determine whether parts are contaminated and need to be cleaned. A balance has to be found between time lost in these extra production steps and time saved by not having problems later on, when the machine malfunctions because of these contaminations. In case of a contamination issue, causes are most easily found when the parts are still small, so a number of these checks are designed in to the production of smaller assembly parts. A separate vacuum work center will perform these functions for other work centers by using what is essentially a large kettle that can be depressurized and has a number of sensors to measure the number of particles inside.

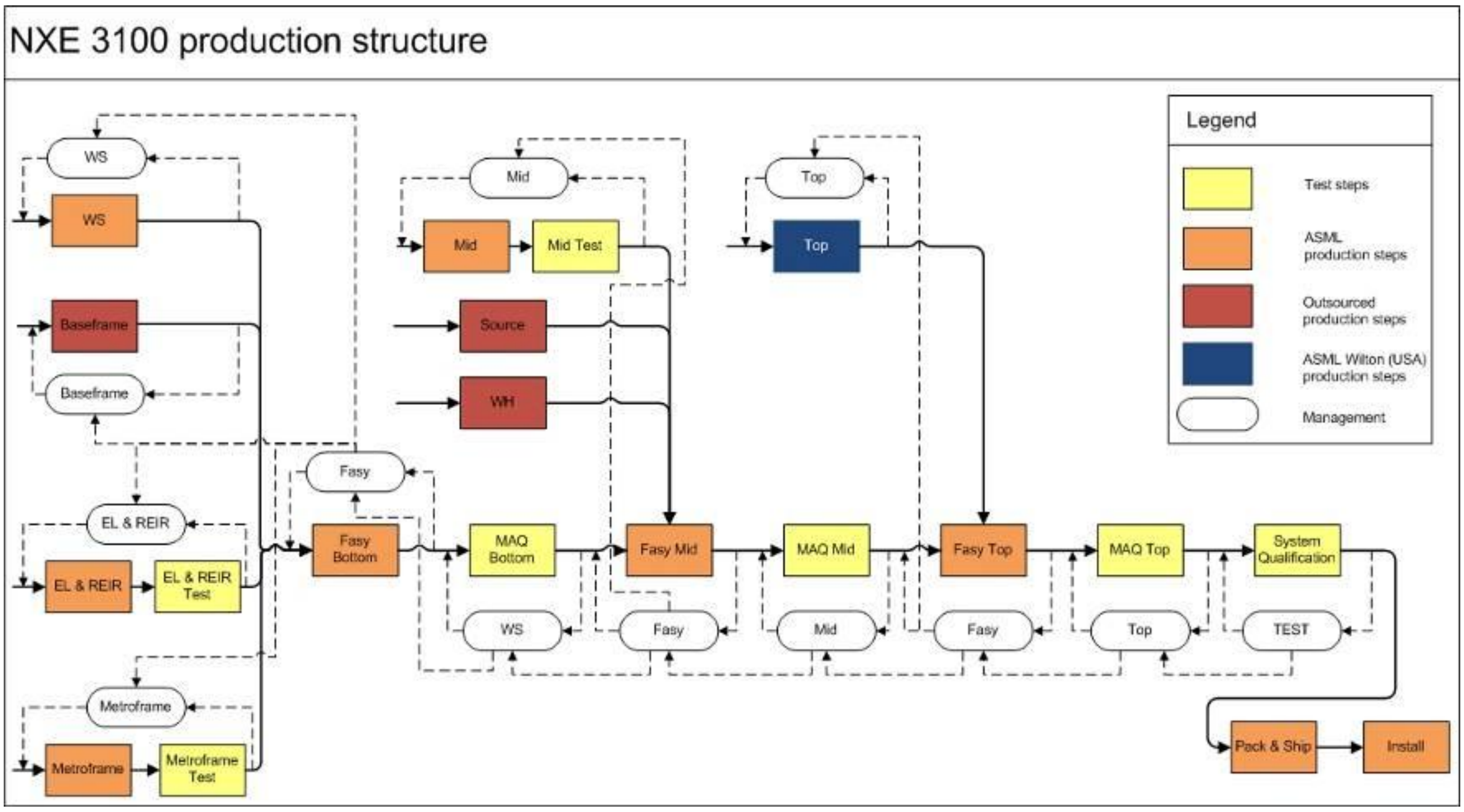

Figure 8: NXE production structure

3.3.3 Functions

Production of the first NXE3100 machine has recently started. Because this is a new product, D&E is still closely involved. PE-ers also are building the machine together with some operators on the sideline, who can learn from watching PE-ers. Functional positions are similar however to volume production with the exception of the absence of a VIS or TOPS to escalate to. Problems are solved by PE-ers and D&E-personnel themselves, since they are already most knowledgeable.

Since only a small number of NXE3100's are going to be build and since these are still only prototypes and pilots, the whole assembly process is also still essentially experimental. For this reason management is a hybrid structure of project and operational management. TL's are responsible for output as well as for technical changes that influence the production process. NXE3300 production will resemble the Twinscan volume situation. As the NXE evolves into a more mature phase, its production will also need to conform to volume organisation structure.

3.4 Project approach

The part of this report will go in to the details of the search for a good organisation for NXE volume production. For this end first a number of organisations will be presented in chapter 4. Then a number of criteria that can be used for the evaluation of these organisations will be presented in chapter 5. A number of these criteria are qualitative in nature and as such, they say something about how each organisation "scores" on that criteria relatively to each other. The organisations will be evaluated on the qualitative criteria in chapter 6. In order to get a feeling for how important each criteria is for ASML and to get a feeling for the efficiency with which each organisation utilizes its manpower resources, a simulation is used. The qualitative criteria will serve as an input for this simulation. The extent to which these criteria deviate per organisation is estimated on ASML experience and common sense, but the sensitivity of this estimation is also investigated. The simulation will be discussed in chapter 7. Finally the results of the simulation and the recommendations that can be derived, are discussed in chapter 8.

Chapter 4 Organisations

This chapter will describe the three organisations that are considered in this project. For this purpose, first the literature on organisation structuring will be examined. Then some ASML specific considerations will be discussed. These considerations will act as constraints on the organisation designs. Finally, the three organisation designs will be introduced.

4.1 Literature

Most research on organisation structuring has been done in the period of 1990 to 2000. Not many articles on this subject have been written since then. Consequently, information on this subject is best found in books where research findings and main conclusions have been summarized. Four books [3, 10, 11, 17] have been used in this project as a basis for understanding the considerations that are important for evaluating and designing organisations. The important concepts and considerations in these books that are relevant for ASML will be summarized very shortly below.

Organisation structuring literature is in agreement that the core of designing an organisation is a careful balancing between trade-offs. Basically the trade off is that of determining who cooperates with whom and by that, what kind of specialization employees and organisation departments will eventually obtain. Organising employees to their functional tasks allows for a larger specialisation and efficiency in their respective jobs, but causes a lack of focus on the processes that run through a company. Van Aken [3] mentions in this respect that there is a "tradeoff between increasing specialisation and an increasing cost of organisational coordination".

Most authors use a 2 step iterative approach to the design of organisations. First the hierarchical "bricks" of the organisation need to be formed, which constitute the hierarchical structure. This is done by separating the daily activities in an organisation in to individual tasks and then bundling these into sets of tasks that can be performed by employees or organisational departments. Important considerations here is in the extent to which specialisation and coordination is balanced, as mentioned above. The grouping of functions in groups or departments should be done as much as possible to employees who have a reciprocal relationship with each other (i.e. long and intense interaction). Serial interaction also benefits from grouping (output of one employee is input for the next) while pooled interdependence (people performing the same kind of tasks independently) is the weakest argument for grouping. Tasks can also be categorized to their operational, tactical or strategic nature. Strategic and tactical tasks should be placed respectively at the top and middle management level of hierarchy. Managers should also be restrained as much as possible to these strategic and tactical matters, while ideally the operational tasks continue at their day-to-day activities without requiring too much direct interference by managers. Although steering, motivating and monitoring are part of managers job, an organisation benefits from managers who have time to perform their tactical and strategic tasks. When determining the hierarchical distribution of tasks, the scope and span of control should also be considered. The scope is the depth to which a managers influence can reach in a certain organisation and the span is number of direct subordinates he can reasonably be assumed to take responsibility for. These are practical limits to a managers effectiveness and thus should be treated as boundary constraints. When tasks have been delegated to specific functions, the responsibilities and authority should also be given to these employees so to be enable them to actually carry out those functions. This distribution of responsibilities and authority should preferably be of a clear and unambiguous nature.

When the distribution of tasks has been completed and the hierarchical structure of the organisation is finished, the procedural aspect or "mortar" of the organisation can be designed. To a large extent this develops naturally and is actually difficult to "design" for a manager, but it can be influenced. (to a large degree also by the structure that is designed) A distribution of tasks always induces uncertainty in an organisation of one or another kind because of the interdependencies of individual functions. This uncertainty is also influenced by the environment of an organisation. (high degree of change and/or complexity) These uncertainties need to be mitigated by coordination between functions and departments, which is usually done by procedural methods. Power, influence, formalisation, standardisation, communication (e.g. information streams) and formal education are all examples of this.

4.2 Considerations for the ASML NXE production organisation

The focus in this report was mainly on the design of an organisation structure as opposed to the design of the procedural element, because these tend to form more naturally and because this would be more of an in depth activity. This is less useful for ASML because of the large changes that are still likely to happen to the production structure of NXE's in the coming years. The degree to which procedural elements or - put differently - how much relative coordination need each organisation requires, will however be evaluated in this study.

For the design of an organisation, a number of constraints by management and by the nature of production needed to be considered.

<u>1 Knowledge specialisation</u>
Knowledge needs to be concentrated and specialised at ASML, because a lessened degree of knowledge specialisation will lead to insufficient problem solving capacity. For this reason a separate specialist organisation is run that can be called upon as backup for testers, that are highly specialized in problem solving. The sometime rapidly changing construction standards are further specialised in the form of production engineers. A lot of operator and tester training would be required to keep up otherwise and training of new employees would require even more time. Moreover it would probably result in a significantly larger portion of mistakes which would result in longer problem time.

<u>2 Assembly of machines has to be divided in to different specialised sections</u>
Assembly of machines must be divided in to different groups for the same reason as stated above. Moreover, the total assembly time of a machine is relatively long and so the total work content would be to large for employees. A subdivision of assembly work thus needs to take place, the only question is how this division should take place.

<u>3 Specialisation leads to increased coordination and communication problems</u>
As can be expected in an environment with a high degree of specialisation, coordination between different specialists is difficult due to language barriers and the fragmented nature of the organisation. Especially in those areas that requires coordination over a number of different specialists – such as formulation and prioritization of engineering changes - it can be a challenge to do this effectively. Ferdows argues that a reciprocal interdependency is beneficial for cooperation between specialists. [6] An organisation design can also be more or less conducive for cooperation between desired specialists.

Together these constraints mean that any NXE organisation has to have the specific functions of PE, VIS/TOPS, TS and different groups of assemblers/testers. The task of designing organisations then essentially becomes a task of rearranging tasks, responsibilities and authority over different production tasks. With different rearrangements come specific advantages and disadvantages. These disadvantages can be investigated by using a number of criteria, which will be done in subsequent chapters.

4.3 Organisation structures

Three organisations are evaluated in this project. Of these three, two organisations are logical continuations of existing organisations and one is a new organisation. All three organisations will be introduced and described below.

<u>Organisation 1</u>
The first organisation is a continuation of the Twinscan production organisation, but "translated" to the NXE production structure. An innovative graphical representation is used for describing these organisations. This is not an officially used format, but was nevertheless used because it immediately exposes the specific differences in a clearer way then the traditional organisation chart does. These traditional organisation chart are still given however. Take note however that this structure will change with an increase in the size of the organisation, given that the span and scope of control are constraints in this respect.

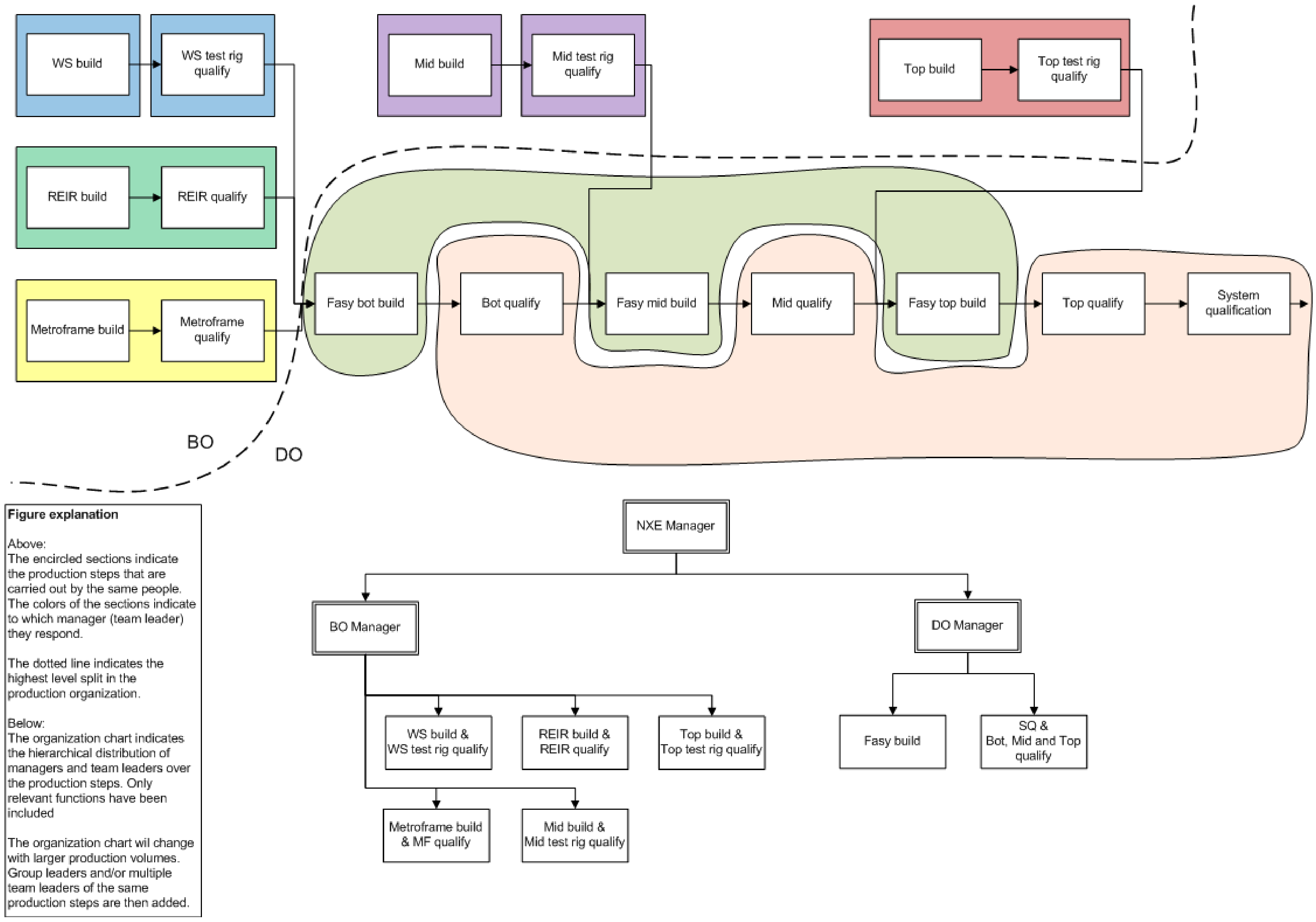

Figure 9

As can be seen in the figure above, the assembly of machines is still carried out by individual work centers with team leaders, who respond to one BO (Build Operations) group leader. Final assembly is also neatly divided between assemblers and testers with each having specific team leaders, who respond to a DO (Delivery Operations) team leader. The difference in production structure between the NXE and Twinscan, however causes the clear transfer of modules between both group leaders to blur a bit. In the Twinscan production this transfer takes place neatly at the start of final assembly, thereby making it more clear where responsibilities start and stop. For the NXE organisation however there are 2 more modules that are introduced in final assembly during the process. Output responsibility is thus endangered, because a delay in mid for example, can cause DO to be too late, while the MID work center is really to blame. This interaction could be a possible problem.

<u>Organisation 2</u>

An opportunity of the new NXE production structure however, is the possibility to test modules on the machine it is going to be used on. Test rigs are currently used, but this suffers from reproducibility and repeatability problems in that errors that come up at the test rigs sometimes which do not come up during MAQ and SQ phases and vice versa. The time between these similar kinds of tests (on test rig and on machines) is much larger for the Twinscans. This introduces the possibility for increased learning by having the same group of people perform both module test rig testing and machine (MAQ or bottom, mid, top qualify) testing stages. As explained in chapter 2, this would potentially decrease the number of problems ASML has in its production process and would thus be a great benefit. This lead to a new organisation structure for the NXE3100 production. This can be seen in figure 10 below.

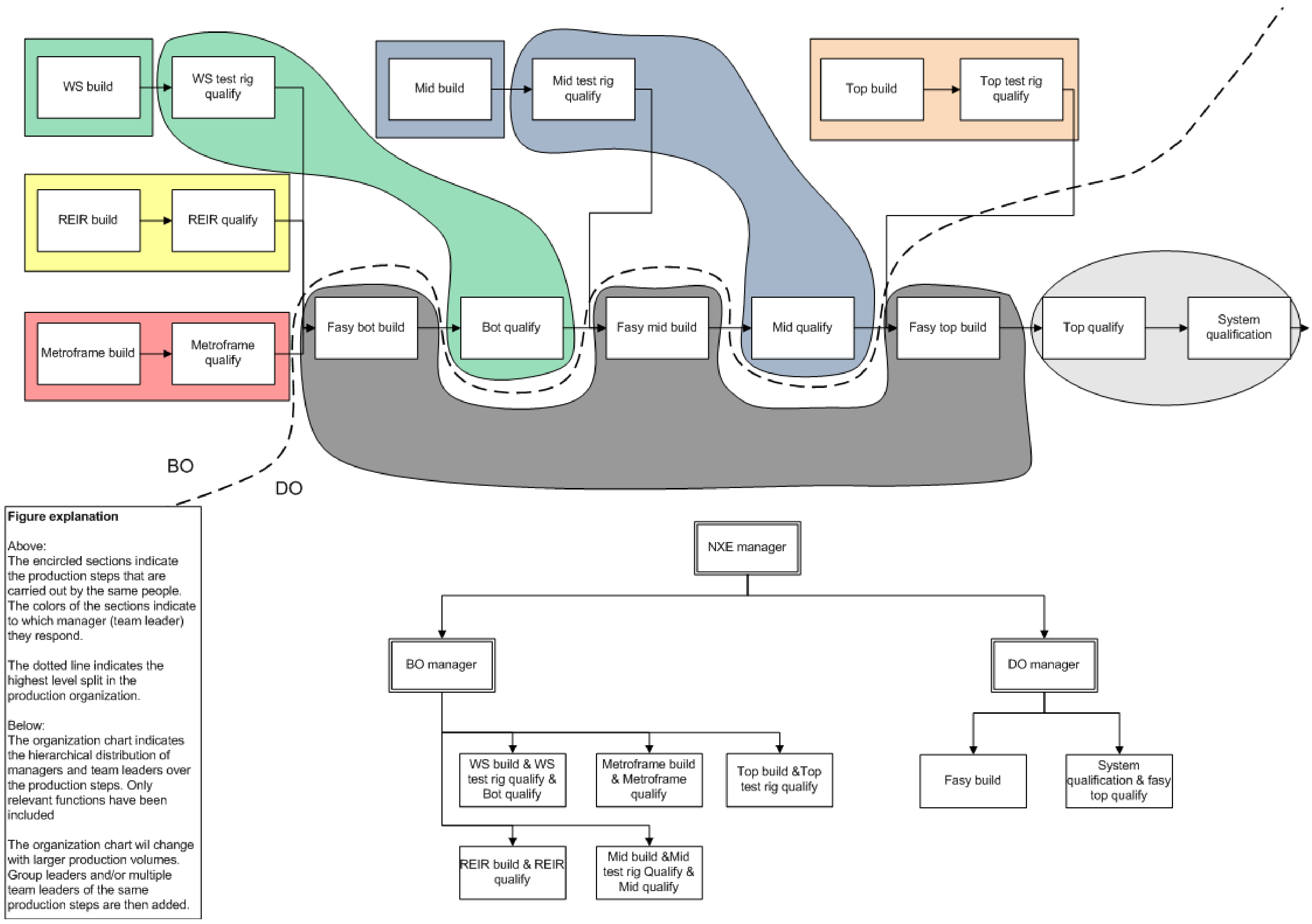

Figure 10

In this structure, the waferstage (WS) testers and MID testers are also allocated to the former DO MAQ test phases. As can be seen however this also leads to a more diffuse authority and responsibility distribution. DO no longer has full control over the machine, instead responsibility for machine progress is alternatively handed over between BO and DO. This is less of a problem as long as production volumes are small, because having group leaders can still be avoided. Total span of control still allows for the NXE manager to have all team leaders respond directly to him. As production volumes increase however this will become more and more of a problem. Because of this problem a third organisation was conceived of.

<u>Organisation 3</u>

Figure 11 represents organisation 3. In this organisation the principle of functional specialisation has been carried out to a further degree, by having module assemblers also perform final assembly tasks. This enables a clearer responsibility and authority distribution between group leaders, by again having two clear transaction moments where a machine is transferred between two groups.

Another benefit is the increased capacity flexibility that is achieved in the bottom build department, by having all assemblers being able to conduct the final assembly bottom build. Given ASMLs large variations in cycle time, the monthly work load per function can also change quite a lot. More assemblers and testers then are actually needed are hired because of this, with a low capacity utilization as a result. By having more work allocation flexibility however, peaks in one work center can be mitigated by using someone from another work center. This works as a buffer on the amount of overcapacity that is needed and might thus potentially make the organisation more efficient. A problem with this organisation that might decrease this efficiency however, is the fasy top build function. This is a relatively short production step that does require 4 persons to operate. Especially for low volumes this will decrease the efficiency of this organisation. Which effect is stronger is difficult to say and will have to be determined by the simulation that is used latter on in this project.

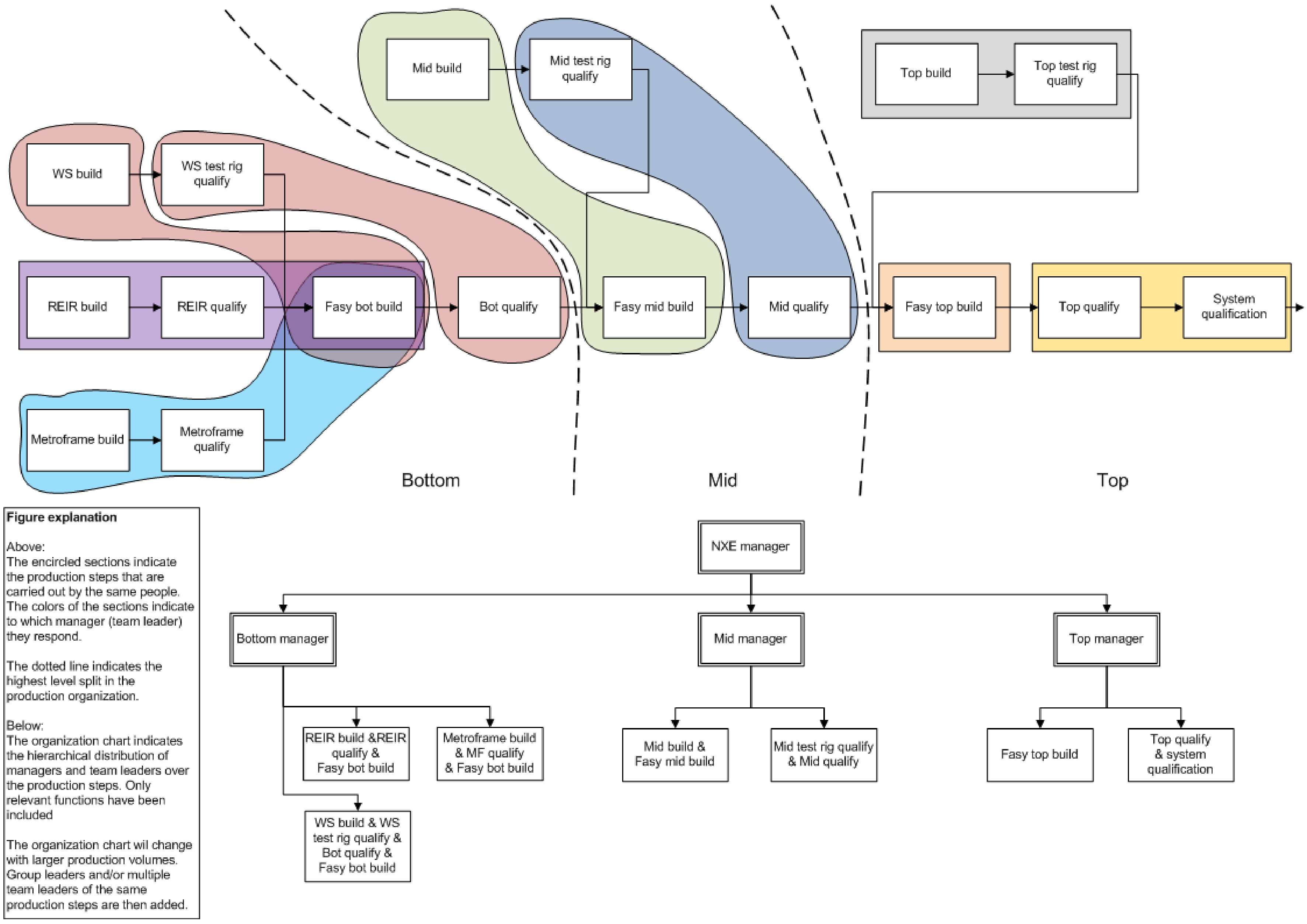

Figure 11

Another problem with this organisation is the fact that it is very function focused. As mentioned before in the description of organisation structure literature, a trade off exists between a focus on function and a focus on process. As the process side is less represented here than in the traditional ASML production organisation (i.e. Twinscan production) it is feared that the "output focus" of this organisation is jeopardized. A change with respect to the Twinscan production however is the production volume. Total production of NXE machines is even in the high demand scenario a small fraction of the normal Twinscan production. Total production volume at any given time would be a much smaller number then was the case for Twinscan. Output focus thus could be much more easily be guaranteed by the NXE manager. (since he is the only one who has total control of the production process) As also mentioned above however, manager focus should be as much as possible on strategic and tactical issues, so this operational task is undesirable.

Chapter 5 Criteria

In the last chapter the 3 organisations have been introduced. In this chapter the criteria on which these organisations have been compared will be discussed. As also mentioned before, there is not much contemporary literature on organisation structuring. Most research seems to have been conducted during the 90s. The 4 authors that were used in the preceding chapter have also written about important considerations when evaluating organisations. These must be considered in the design of organisations, but they can also be used as criteria for evaluating organisations. Although the processes for doing so differ between authors, they do all provide a list of what these criteria are. These criteria are similar in many respects, but also differ in many ways. These differences are due to their own interpretations and opinions. Most authors also concentrate on the structure of large international corporations. Although the underlying theory is similar, the criteria are not always relevant for a small, single location production organisation. Therefore the criteria of each author was summarized and compared with each other. Where there was overlap the criteria have been spilt up, so that eventually all the criteria of different authors could be grouped into specific categories. These categories then were judged on relevance for ASMLs case, which resulted in a shorter list of relevant criteria for ASML. This process can be read in appendix IX. This chapter will continue from the list of relevant criteria to describe the operationalisation of these criteria. Not all criteria are specific enough to be able to measure them. Because a quantitative comparison was desired, by means of a simulation, these qualitative criteria will be given a more concrete definition that can subsequently be used in the next chapter for comparing the different organisations.

5.1 Operationalising the criteria

Operationalising the criteria required an understanding of the working of ASMLs production. To be able to judge how different organisations might influence process improvement (the learning curve) for instance, it was necessary to understand how the cycle time was actually reduced in reality over time. Interviews were carried out for this purpose, but some things were very difficult to convey in a conversation. Consequently some days of working in the production organisation were spent, where a better and more realistic understanding of the production was gained. This understanding was used in combination with literature to come to a set of drivers for every criteria. These sets of drivers can be used to evaluate the different organisations in a more objective fashion in the next chapter.

5.1.1 Productivity

Productivity can be defined as a ratio of output for a particular system and its input [1]. The inputs for ASML´s machine production are materials and employees. The number of materials is equal for each production organisation. The time they remain in the production organisation, i.e. the work in process level, does vary with different organisations. For this reason the material costs are included via a discounted netto present cash flow calculation. The number of employees for a given output can also vary depending on the worker flexibility that is possible, because of the large process variability given in ASML´s production situation. This process variability means that worker capacity demand can vary strongly as well and necessitates (some) worker overcapacity to cope with high capacity demand time intervals. This worker flexibility is enhanced to some degree at ASML via the use of the hours bank and the use of occasional flexible shifts. The hours bank allows workers to build up future free time when they have to work overtime during busy times. The number of hours that can be saved are limited. The maximum hours of overwork is given by union and company negotiations. The flexible shifts option can improve capacity flexibility even more, because management can determine workers working schedule and adapt these within short time intervals. These measures are similar for all organisation structures however, so they do not need to be considered in this criteria. The extent to which workers can be allocated to different production tasks however is also an important factor for worker flexibility [5]. This does change with different organisational structures, by the extent to which workers can perform different production tasks. So less specialization for assemblers and testers contributes to a larger degree of flexibility and will decrease overall worker costs.

Implications:

The productivity criteria will be measured by the number of resources that are required on average to produce one machine. The standard productivity criteria is usually defined in the form of number of products per time unit. Given the fact that the number of machines that are going to be produced are given in the form of three demand scenario's (to be described later), this definition of productivity is not usefull here. As a consequence a definition that is more closely related to the traditional efficiency concept will be used here. Efficiency is usually stated as a measure of how much resources it costs to produce a certain quantity of products. As stated in appendix IX, the original criteria of efficiency was broken up in three specific criteria for ASML. Namely, productivity, process improvement and coordination need. Productivity here will thus be the criteria that will measure this efficiency in number of resources required per machine for each machine. This will be a quantitative number which requires a quantitative method to obtain. This method will be a simulation, as will later be described.

Productvitiy will then be described by the following formulea.

$Y_{productivity}$ = resources / machines

Where,
Resources are the organisation specific resources, which are:

number of assemblers and testers (€)
the discounted direct material cost (€)
hiring cost of personnel (€)

5.1.2 Process Improvement

Repeating similar activities enables personnel to learn on the job and to improve their way of working in such a way as to be more efficient. This phenomena has been noticed by early industrial engineers and has consequently been the subject of studies for a long time. The same learning effect is not only visible on a personal level, but is also present on organisation and industry level. The mechanics behind this effect are largely similar for all levels but also include other more advanced mechanics on a higher levels.

Learning curves in organisations are generally thought of to be the result of 4 different ways of learning [7]: individual learning, collective learning, incremental innovation of machines and tools and increasing returns to scale. Collective learning is the learning to work together efficiently (which is generally dominant in assembly operations), incremental innovation of machines and tools are mostly engineering changes for producibility at ASML. Engineering changes are a big cycle time reducer for ASML. Increasing returns to scale is probably less significant considering low production volumes. Fioretti further emphasizes that there is a tradeoff between too many and too few engineering changes. Too many will disturb operations to much, and too few leaves cycle time unnecessarily high. Reagens et al [16], did some further research into collective learning and found that it consisted of learning to work together efficiently, but also of knowing who knows what within a group. These are general observations, so it is useful to look at ASML's specific situation.

A distinction that has to be made for ASML, is the difference between the two production activities at machine construction. Machines are both assembled and tested during construction and these activities are not similar in a number of ways. Testing requires a large amount of know-why of a machine and thus also a larger amount of knowledge background. VIS, TOPS and testers need a lot of knowledge of the internal workings of a machine in order to hypothesize possible causes of problems. The learning effect with this group of people is not so much dependant on the number of times a particular test has been run but more on the number of problems that have been encountered and solved on a particular test. Assembling a machine from parts on the other hand requires more know-how of assembling tasks and is thus more dependent on experience with any particular task. The learning curve in this case depends more on the number of repetitions of a particular activity. The distinction between know-how (knowing how to operate a certain set of tasks) and know-why (knowing why to do them in that particular fashion) has been made in literature [13] and is particular useful here.

Know-how is acquired by repetition. Know-how learning is done by performing a task, interpreting the result and using this knowledge to change a particular activity in a task in order to improve efficiency of the process or quality of the outcome. For ASML however this feedback loop is not always situated in 1 person, because the activity of performing a task and evaluating the outcome is done by different persons. (e.g. assembly and test rig or final assembly and system qualification) Standards are set in the form of work instruction by PE-ers but these also are not directly involved in the production process. So for the right kind of know-how to evolve, good communication is necessary between operators, PE-ers and Testers. This is facilitated in an organisation where this feedback loop is enclosed in the same person or if not possible, at least in the same organisation group. Enclosing this in the same organisation group raises awareness of this effect for managers and focuses attention and priority on it. Managers furthermore have more discretion over this process when it is inside their scope of control as when they have to rely on inter group coordination mechanisms to achieve this. This can be illustrated by Hoopes et al, 1999 case study [9]. He investigated the causes of communication problems between different experts in new product development, that lead to costly problems later on in the process. This can be interpreted at ASML for example, as passing on product knowledge via the machine log between fasy and test. He found that time pressure and unfamiliarity with each other were the most common causes of a costly mistake. Time pressure can be lessened by a manager through emphasizing the importance of this process and unfamiliarity is obviously also less of a factor when both are part of the same organisational group.

The know-why that is important for testers and support is acquired by individuals via a number of different means. Reagens et al 2005, [16] as mentioned above found that the rate of learning was influenced by individual learning, learning to work together and learning who knows what. Specialization and grouping of specialists in one organisation group, is thus important for these production tasks. Especially in a fast changing production environment where machine designs change rapidly it is recommended to have as much specialization as possible [6], while simultaneously keeping these specialists connected so they know where to find specialized knowledge. (i.e. know who to consult)

Hatch and Mowery [8] however found that in knowledge intensive, short product lifecycle and high tech companies (in their case semi-conductor industry), learning in organisations was highly dependent on engineering capacity applied to problems. Translating to ASML, this means that engineering changes for producibility or for enhanced problem diagnosing could have a very large impact. A production organisation that is capable of formulating and prioritizing the right kind of requirements or even engineering changes, is thus able to “learn” or decrease cycle-times more rapidly. This would require more of an overall view of the machine and the production process. This means less specialization or at least a coordination mechanism (separate organisational group) that monitors these requirements. In ASML’s case however the design of machines at DE and the introduction of engineering changes is also done by specialized teams that focus on only parts of the machine, with only some coordinating functions between modules. So it is not useful to have many `generalists` on production’s side. Instead generalists on module level could be more of an even counterpart to DE. Learning on module level is now done on separate levels by PE-ers, operators and support. Combined, their experience and knowledge would enable better formulation and prioritization of engineering change requests. Especially for the NXE, where complexity is in capsulated in the Main Body Modules and interfaces between MBM´s are kept as simple as possible. Translating to organisational implications, this means that organisations that have PE, operators and VIS in close proximity and relationship to each other, are better able to formulate and prioritize these engineering changes.

Implications:

The process improvement criteria will be measured by the learning curves of assembly and test. The dependencies of this measure are given by the following formula:

$Y_{process\ improvement} = f(Y_{assembly} + Y_{test})$

Where,

$Y_{assembly}$ = f(learning curve assembly)

Y_{test} = f(learning curve test)

and,

learning curve assembly = f(repeating frequency of production activities, degree of feedback between qualification and building operations)

learning curve test = f(number of known problem-solution combinations with testers and their ability to find these at peers, degree to which an organisation is conducive for good formulation and prioritization of engineering changes)

5.1.3 Coordination Need

Coordination between people is essentially a cost factor in organisations. Specialization of groups leads to efficiency and quality improvements on tasks. At the same time, specialization leads to an increased division of production tasks and an increased need to synchronize these activities in content and timing. This takes coordination between the groups that perform these allocated tasks. The more specialization and division in an organisation, the more coordination is needed. The relationship between the amount of specialization and the amount of coordination depends on the coordination mechanisms that must be used. Typically this depends on the type of dependencies that exists between groups in the primary process [3, 11].

The distinction is made – in order of low to high dependency - between serial, parallel or pooled and reciprocal dependency. Serial dependency is a one way dependency of an operator that requires input from an operator upstream. Parallel or pooled dependency is the dependency of different tasks that require the same resources (tools, people, machines, etc). Reciprocal dependency is the dependency that is present when two or more tasks require frequent interaction in order to be completed.

It is recommended to capture most of the large dependencies inside an organisational group and to use coordination mechanisms for the remaining weaker dependencies between organisational groups. Depending on the remaining inter group dependencies, stronger or weaker coordination mechanisms can be used. Weaker coordination mechanisms are generally preferred where possible, because they have the lowest impact on the organisation and thus are least costly. Van Aken, Keuning's and Jägers [3, 10, 11] all describe the same coordination mechanisms, but use different frameworks to present them. Van Aken's framework will be used here, because it is the most clear to comprehend and describe.

Van Aken, 1994 [3] mentions that direct coordination between organisational groups is always preferable, because it takes the least amount of resource time. When this is not possible due to the complexity of the matter or because of conflict, other coordination mechanisms need to be used. He makes a distinction between these kinds of coordination by using two general attributes of relationships. A relationship is either based on power or on influence and is at the same time also either direct or indirect. With these two attributes, four different kinds of relationships can be made. These are displayed in table 3.

Table 1

	Direct	Indirect
Power	1 Directing	3 Regulating
Influence	2 Inducing	4 Conditioning

Directing relationships are based on direct power. This is the most common means of coordinating activities between organisational groups, which is also known as hierarchical coordination. When inter group coordination is needed, this can be escalated in the hierarchical line until this reaches an appropriate level where two managers can agree on a course of action. This is then fed back to the lower level. The functions that use this kind of coordination are hierarchical line managers, i.e. team leaders, group leaders and their managers. This kind of coordination is best used in case of conflict situations. (e.g. late delivery of modules) It is also usually the preferred and first method of coordination. Other coordination mechanisms are usually used when managers can no longer make quality decisions because of work overload. This direct coordination mechanism is the main mechanism that changes with different organisations. Both the level to which must be escalated and the number of product handovers between organisational groups changes here. The higher the level of escalation and the more product handovers, the more coordination between groups (i.e. managers) is necessary. This ultimately determines how expensive this coordination mechanism is.

Inducing relationships is usually the next favorable coordination mechanism to use. These are usually supporting organisation groups such as staff functions that can be consulted by management or by the floor directly to assist in decision making. They have no direct power to influence the primary process, but since managers rely on their expertise, they usually do have considerable indirect power. At ASML, MOS is an example of this function. Support organisations that coordinate activities independently of management involvement are also included in this coordination mechanism. For ASML this includes for example manufacturing logistics, production planning, VIS and facility management. This kind of coordination is best used when decision taking requires a lot of expertise, mundane support work and/or complex data interpreting. Of all these coordination mechanisms only the amount of support work is relevant for this investigation. The amount of coordination between MOS and the production floor for example will not change considerably, since their work content is unrelated with the way production is organized. The supporting functions of manufacturing logistics and facility management do not change considerably either because their work is also unrelated to the production organisation. The supporting organisations production planning and problem support (VIS, TOPS) however are influenced by the production organisation. The task variety or specialization of assemblers and testers for example determines the extent to which they are able to solve problems within their work domain. With less specialization they will probably require more problem support. Production planning furthermore also plans production capacity on the short term and will thus need to coordinate with multiple organisation groups when worker flexibility is present.

Regulating relationships are found in the form of regulations, rules, standards and/or instructions. Since this is a very static form of coordination (expensive to change), it is best used in stable situations where change happens only slowly over time. Standardization or formalization can be a part of organisation culture and be self-imposed or it can be superimposed by a separate organisation, as is the case at ASML’s production engineering. Because ASML’s situation is not stable at all, this is a costly coordination mechanism. It requires constant adaptation of work instructions, but it is still desirable because it enables a number of things. First, a more stable quality output of operator work is achieved by standardization of work processes. Second, it also enables less costly labor because of lower education demands and lastly it enables a lessened vulnerability to the external economic situation. The last because production knowledge is retained in a separate organisation and is thus not lost in downturn situations. The consequences for PE of different production organisations are insignificant. PE- ers are specialized to specific machine modules and are coupled to the production process according to their specialism. The number of relationships for a PE-er with team leaders will still always be one. (only one team leader per PE-er) The number of PE-ers per team leader however does change with different organisations, but this is already acknowledged in the directing relationship above.

The last coordination mechanism is conditioning. This is the training of people and is also a form of standardization. Not of output but of means of achieving the output. Although training is done a lot at ASML, this is not just explicit training. The introduction of engineering changes and software updates by DE also requires implicit learning for support and PE. This coordination mechanism is unchanged with different production organisations.

Implications:

The coordination need criteria will be indicated by the number of product handovers and the extent to which problem support is needed. This is summarized in the following formula:

$Y_{\text{coordination need}}$ = f(coordination need primary process, coordination need of non primary process related functions)

Where,

coordination need primary process = f(number of product handovers between organisational groups (with increased cost of higher hierarchy escalation))

coordination need of non primary process related functions = f(need for problem support of operator due to large or small task variety, coordination need of production planning)

5.1.4 Controllability

The controllability of the primary process is an important issue at ASML that is difficult to achieve. Although the reason for this is mainly because of the high complexity and innovativeness of the machines that are produced, there are some aspects that are also organisation dependent. The main cause of the variability (or b-time) in the production process are material quality issues and technical issues. (B2 and B8) Material quality issues originate from upstream production processes or suppliers and are a consequence of workmanship errors or design errors. Problems from design errors can not be prevented on the short term, so it is a part of "process improvement". Workmanship errors can be the result from an inadequate understanding of what is the right execution of a particular activity. There are also other causes of workmanship errors, but this is one that can be influenced by the type of organisational structure. An inadequate understanding for instance can be decreased by the amount of feedback assemblers receive from the results of their work (by which they can improve the quality of their work). Specialization of particular production tasks (lower task variety) might also decrease the number of workmanship errors, but this relationship is not clear because a better, more comprehensive understanding of his work's impact on other parts of the machine might also decrease the number of workmanship errors. (although requiring the opposite: a larger task variety) Since this relationship is ambiguous, it will be ignored.

Workmanship errors translate into problems at the test phases of production. Testers (and problem support) need to diagnose and solve these problems. The timeliness with which this happens is a factor in the controllability. The diagnose time at test production steps is dependent on the knowledge of testers and VIS-ers. This does not only depend on the knowledge of individual testers and VIS-ers but also on their ability to find and leverage peer knowledge [16]. The actual implementation of a solution is usually insignificant time wise. Specialization in these test production steps would be beneficial for the familiarity with specific problems. The specialization however should not compromise their ability to have a comprehensive understanding of the solutions and their impact. The familiarity with a test rig and the specific module or machine they are testing is also influential for the diagnose time.

Implications:

The controllability criteria can be measured by the number of problems multiplied with the time it takes to diagnose and solve the problem. The calculation of this measure is given by the following formula:

$Y_{Controllability}$ = variation of cycle time = f(number of problems,variation of problem time)

Where,
number of problems = "workmanship" of upstream production = f(feedback of work)

variation(problem time) = diagnosing time of problems = f(specialisation of test work, number of known problem-solution combinations by testers and their ability to find these at peers, familiarity with other factors (test rig, specific module/machine)

5.1.5 Quality Management

Quality management is usually defined as the ability to produce a constant high quality product. The term high quality is ultimately defined in the eyes of the customer. For a customer there are two aspects to the quality of a product. First a product has to satisfy a particular need a customer experiences. The correct definition of the quality of a product for a company should be the extent to which a product fulfills that need. Second, when this need is filled, the time period a product is able to satisfy this need is also important. This is the reliability of a product. For both aspects there are a lot of techniques in literature for improving these. These are not organisational in nature however and - in ASML's case - are also largely dependent on engineering changes, i.e. D&E's responsibility. So the determination of what is quality is mostly done outside the production organisation. This results in quality standards, to which the production organisation has to comply. The ability of an organisation to comply with quality standards ones defined, does depend to some degree on its structure.

The ability to comply with standards was also important in the criteria "controllability". As can be read above, the variability of its processes is mainly due to quality issues. (i.e. the machine or module not working) To prevent these same aspects from being measured twice, this criteria will focus mainly on the supplier material quality aspect. So the ability to discover quality issues that are the result of material quality issues from suppliers. This ability depends mainly on the familiarity of employees with quality standards. This in turn will depend on the number of materials that are part of their production tasks. The number of materials is given per production task. The number of production tasks per organisational department however does change with each organisational structure. The ability to recognize materials that do not comply with quality standards is probably related with the number of materials one has to use in its function. With more specialization, someone has fewer incoming materials with which to familiarize oneself, and thus will recognize defective or nonconforming parts more easily.

Implications:

Only part of the quality domain will be used in this quality management criteria. Specifically only the supplier material quality aspect is defined here.

$Y_{\text{Quality mangament}}$ = recognition of incoming material's quality = f(familiarity personnel with quality standards of material)

Where,
familiarity personnel with quality standards of material = f(number of materials needed per function)

5.1.6 Work satisfaction

The quality of labor indicates the extent to which an organisation is able to satisfy employee's need. It is an employee's perspective on their work content and work environment. This criteria is not only important from an employee's perspective however. It is also an indication of work involvement, employee motivation and positive contribution to company goals. Quality of labor is also an important driver of the amount of sick leave among employees. There is a lot of literature on employee motivation and performance that could be relevant here. However most of this literature focuses on specific processes, methods and personal characteristics that are determinants for motivation and performance. These determinants are usually only sideways connected to the specific organisational structure and so are not really relevant here.

De Sitter (2000) [17] does investigate the organisational structure as a determinant for labor quality. He argues that there are two indicators of quality of labor, stress and estrangement. Stress is the phenomenon of being unable to perform as desired. This is a result of how many possibilities for solving problems someone has and the amount of problems someone receives from his surroundings. If his ability to solve problems is lower than the number of problems he receives, he will experience stress. Estrangement is the phenomenon of no longer caring for ones work. Although someone might be able to solve problems and comply with what is expected of him, he does not really care for his job and will no longer creatively "think along" to solve structural problems and improve efficiency, etc.

These two phenomenon's are explained with the help of two concepts. The internal and external problem solving capacity. Internal problem solving capacity is the ability of an employee to solve interface problems with other employee's within their own means and methods of work. It can best be described as the ability to change ones methods of working in order to be able to comply with work output norms. External problem solving capacity is the ability of an employee to solve these same interface problems in coordination/communication with other employees. Usually with changing the norms in such a way that the other is still able to comply with his own output norms. An interface is defined here as a relationship with another person within the organisation, with whom one has to deal in order to carry out ones job. These interface problems are in itself a result of the organisational structure, since this defines the number of interfaces. A situation with high specialization and a short cyclical work content means there are many interfaces within a production organisation. At the same time it also means that employees have less internal coordination, because they have fewer possibilities for adaptation within their own short cyclical task responsibility. For example, when someone receives work that is not according to the agreed upon norms, or if one is dependent on other supporting functions (such as work preparation or material supply) and these do not deliver according to agreed upon norms, they need to somehow bring these inputs in agreement with the output that they are supposed to deliver. Of course every organisation will have many of these interfaces. The specific characteristics of these interfaces do vary with organisational structures. For example, there can be many interfaces one has to align or the interfaces can be constantly changing over time or the manner in which information is transferred between interfaces can constantly change. This changeability of interfaces is mostly due to a changing production environment. (changing products, market demand, changing production means, etc)

The relation between internal-, external problem solving capability and stress and estrangement is summarized below in table 4.

Table 2

		Internal problem solving capacity	
		High	Low
External problem solving capacity	High	Stress and estrangement risk low	Stress and estrangement risk low (unlikely situation)
	Low	Stress risk low Estrangement risk high	Stress risk high Estrangement risk high

Translating this to organisational designs, this means that organisational structures that have more possibilities to communicate with the production steps right before or right after their own, will have more possibilities to work out their individual problems with each other. (and thus have a high external problem solving capacity) The lower in the hierarchical line these product handover interfaces are situated, the better employees and managers can coordinate and solve problems among each other. Moreover, organisational structures that have less specialization or perform more production tasks per function, will have more internal problem solving capacity. Increasing task variety and span of control of team leaders will thus increase the internal problem solving capacity of employees. As can be seen in table 4, both internal and external problem solving capacity is desirable for low stress and estrangement.

Implications:

The quality of labor criteria will be measured by a qualitative weighing of options. The scoring of this criterion will be based upon the determinants described above which is summarized by the following formula:

$Y_{\text{Work Satisfaction}}$ = **f(span of control team leader**, **worker specialization (task variety)**, **number of product handover interfaces** (with as few higher hierarchy level handovers)**)**

5.1.7 Scalability

The scalability of the production organisation is a specific organisation criteria for ASML, because of the large swings in product demand. The resulting change in production volume will have consequences for the organisation size. The sudden volume changes can be cushioned by a number of measures, some of which have been mentioned before. The specialization in problem solving and the standardization of work through work instructions can be thought of here. These however do not change with different organisations. Different organisations have impact in a number of ways.

A distinction can be made between expansion of the organisation and contraction. With rising product demand, the organisation has difficulty to increase production because of capacity shortage. New production personnel is hired but they require training so they will not contribute to output at first. Training time depends on the work that is to be performed. The personnel that is hired and fired are mostly operators (assemblers) and testers. Problem support and production engineers are usually retained because they have most of the product and production knowledge and expertise. Moreover, their training time is the longest and also consists of mostly tacit knowledge only acquired through experience. The training time of operators and testers depends on the depth and breadth of their work. The work breadth is the number of tasks that personnel is required to learn and know for their function. This does depend on the organisational form that is chosen because these do vary in the way functions are defined. The work depth depends on the amount of knowledge that is required per production task. This however does not depend on different organisational forms, since this is defined by machine design and production design both independent of organisational forms. With a decrease in machine demand, the organisation has to let some personnel go. The problem that this present is in this case the loss of production knowledge. This problem decreases as the number of people in the organisation that have the same function increases. In other words, with more persons doing a particular job, the amount of knowledge loss of that particular production task is lessened when one of those persons leaves.

In both upturn and downturn then, the vulnerability depends on the amount of specialization in the organisation. More specialization is desired in order to be able to expand more rapidly. Less specialization is desired for a decreased vulnerability to knowledge loss. These contradict each other. Ease of expansion however is most important for ASML and the amount of knowledge loss is already limited by other factors, so should be less of a problem. The degree of worker function specialization will then be taken as an indicator of the extent to which ASML can expand its production activities.

Implications:

The scalability criteria will be measured by a qualitative weighing of options. The scoring of this criteria will be based upon the degree of worker function specialization as is summarized in the following formula:

$Y_{Scalability}$ = **f(degree of worker function specialization)**

5.2 Summary of the criteria

Table 3

<table>
<tr><th></th><th colspan="2">Criteria</th><th>Definition</th><th>Operationalisation</th></tr>
<tr><td rowspan="6">Literature</td><td rowspan="3">Efficiency</td><td>1. Productivity</td><td>The number of machines ASML can produce per given time unit with the same resources.</td><td>$Y_{productivity}$ = resources / machines
Where resources are the organisation specific resources, which are:
number of assemblers and testers (€)
the discounted direct material cost (€)
hiring cost of personnel (€)</td></tr>
<tr><td>2. Process improvement</td><td>The extent to which the organisation structure enables internal efficiency process improvement.</td><td>$Y_{process\ improvement} = f(Y_{assembly} + Y_{test})$
Where,
$Y_{assembly}$ = f(learning curve assembly)
Y_{test} = f(learning curve test)
- learning curve assembly = f(repeating frequency of production activities, degree of feedback between qualification and building operations)
- learning curve test = f(number of known problem-solution combinations with testers and their ability to find these at peers, degree to which an organisation is conducive for good formulation and prioritization of engineering changes)</td></tr>
<tr><td>3. Coordination need</td><td>The amount of coordination that is required between organisational departments in order to carry out their tasks.</td><td>$Y_{coordination\ need}$ = f(coordination need primary process, coordination need of non primary process related functions)
Where,
- coordination need primary process = f(number of product handovers between organisational groups (with increased cost of higher hierarchy escalation))
- coordination need of non primary process related functions = f(need for problem support of operator due to large or small task variety, coordination need of production planning)</td></tr>
<tr><td colspan="2">4. Controllability</td><td>The extent to which an organisation is able to deliver its service / product in a constant and timely manner.</td><td>$Y_{Controllability}$ = variation of cycle time = f(number of problems,variation of problem time)
Where,
- number of problems = “workmanship” of upstream production = f(feedback of work)
- variation(problem time) = diagnosing time of problems = f(specialisation of test work, number of known problem-solution combinations by testers and their ability to find these at peers, familiarity with other factors (test rig, specific module/machine)</td></tr>
<tr><td colspan="2">5. Quality management</td><td>The extent to which an organisation is able to produce a constant high quality product / service.</td><td>$Y_{Quality\ managament}$ = recognition of incoming material’s quality = f(familiarity personnel with quality standards of material)
Where,
familiarity personnel with quality standards of material = f(number of materials needed per function)</td></tr>
<tr><td colspan="2">6. Work satisfaction</td><td>The extent to which an organisation is able to satisfy employee’s needs.</td><td>$Y_{Work\ Satisfaction}$ = f(span of control team leader, worker specialization (task variety), number of product handover interfaces (with as few higher hierarchy level handovers))</td></tr>
<tr><td>ASML</td><td colspan="2">7. Scalability</td><td>The speed and ease with which an organisation is able to expand and contract in a certain time frame with a minimum of problems.</td><td>$Y_{Scalability}$ = f(degree of worker function specialization)</td></tr>
</table>

Chapter 6 Evaluation of the organisations

Evaluation will take place both in a qualitative and a quantitative fashion. For the qualitative evaluation, the organisation structure literature – as discussed in the previous chapter - will be used, while for the quantitative evaluation a simulation model will be built and used. The criteria process improvement, coordination need, controllability and scalability will be used as inputs for this simulation. The criteria productivity and controllability will be the results of this simulation. The criteria quality management and work satisfaction in contrast will be evaluated in a qualitative manner. This process is illustrated in figure 12.

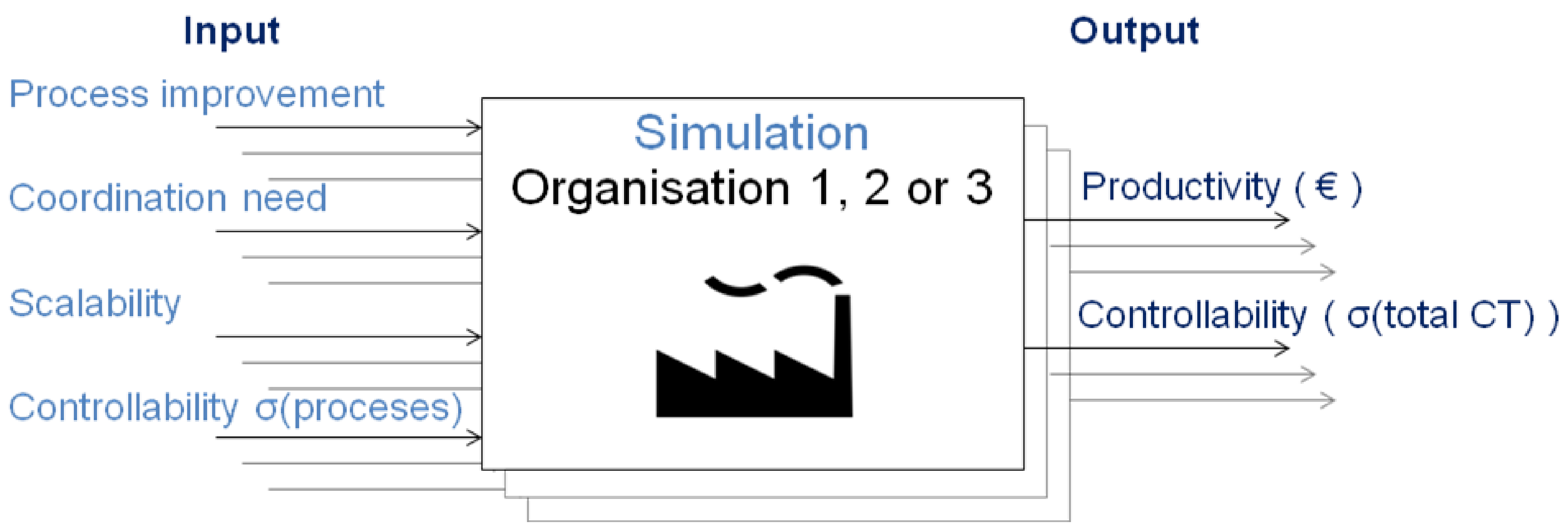

Figure 12

The evaluation of each organisations impact on the criteria per organisation and the translation of this evaluation to the simulation, will be discussed below. During this discussion the organisations will be refered to as organisation 1, 2 and 3. For a detailed description of these organisations, the reader is refered back to chapter 4. Organisation 1 is the translation of the organisation that ASML has used for the production of Twinscan to the production of NXE machines. Organisation 2 is the organisation that is currently used for the production of NXE3100 machines and organisation 3 is the newly designed organisation. For convenience's sake, the organisations are repeated in figure 13.

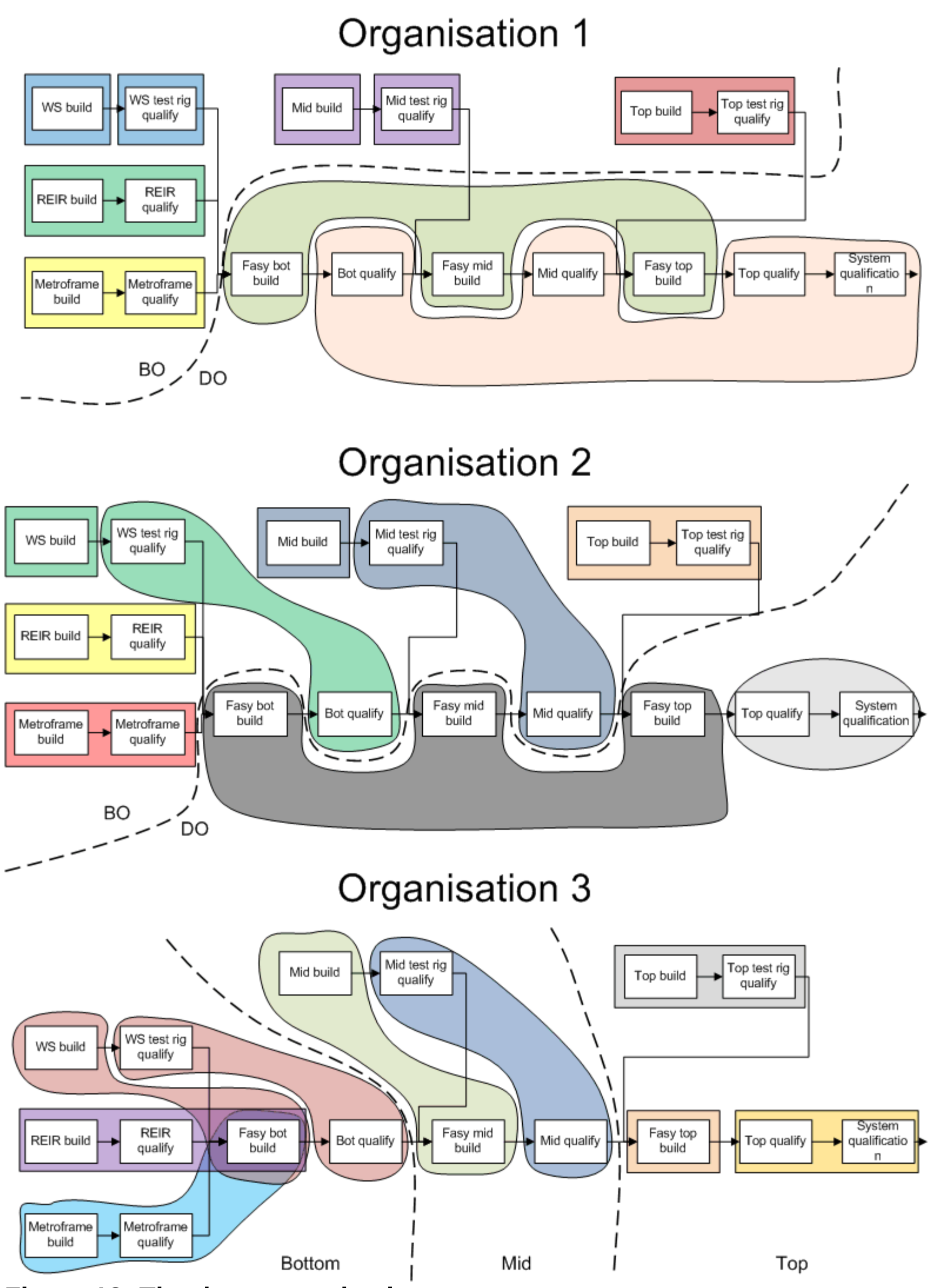

Figure 13: The three organisations

6.1 Process improvement

Process improvement relates the ability of an organisation to change its production processes in an advantageous way. This ability is seen at ASML in the learning curve that every machine type goes through. Analyses of historical data provides evidence that a relatively stable 84% learning curve applies to all historical ASML machines. (appendix I) Because of the large variability in cycle-time of machines, the actual realized cycle times might deviate extensively from this learning curve, but the 84% learning is generally broadly used and accepted at ASML. The 84% means that with every doubling of the number of machines that are produced, the total cycle time of machines drops with 16% of the previous cycle time.

As detailed in the previous chapter, the extent to which the production organisation at ASML is capable of following this learning curve depends on 4 factors.

Repeating frequency of production activities

The repeating frequency of production activities depends on the size of the work content of every function. Organisation 3 scores lowest on this because almost every function encompasses 2 or more work blocks. Organisation 2 scores best because the fasy qualify steps (MAQ) are performed by assy test rig personnel (which is essentially the same work content), which means the system qualification testers only have to do the top qualification step and the system qualification. This leaves organisation 1 in the middle since it is a mix of relatively large (fassy, SQ) and small (assy) workcontent.

Feedback between assembly and test operations

Feedback between assembly and test operations depends on the extent to which the pairs assembly operations and their subsequent test operations are interlinked. Although communication between people does not always depend on organisational structure, it is a close approximation. Furthermore because the only variables that are changed in this project is the organisation (i.e. all personal, unofficial relational ties remain unchanged) it is justified to use the organisational structure as a proxy for the amount of feedback between persons performing related tasks. Strong organisational ties here are assumed between employees of the same team. (under the same team leader) Weak organisational ties are assumed to exist between employees of different teams and even weaker organisational ties are assumed between employees of different groups. (i.e. with different group leaders)

Organisation 1 scores worst on this criteria, through the existence of a hard boundary between assy and fasy work in the sense that they belong to two different group leaders. Organisation 2 scores better because the MAQ (bot, mid and top qualify) phases are performed by assy personnel, thus ensuring feedback to assy assemblers. Organisation 3 scores best, because a similar effect takes place as in organisation 2, with the added effect of feedback between fasy assembly stages and MAQ test phases, through these activities being in the same group.

Knowledge of problem-solution combinations

Knowledge of problem-solution combinations is acquired by testers through experience or from their fellow colleagues when they know who to ask. This depends on the frequency with which they encounter the same problem, which in turn depends on the size of their workcontent. Given this reasoning, organisation 1 scores worst on this aspect, given that it has the largest number of test activities lumped together under the same function. Organisation 2 and 3 might seemingly have more workcontent for their assy test personnel (since they also need to do the MAQ phases), but these test activities are actually almost identically, so their actual work content is not much larger. Given these reasonings, organisation 2 and 3 both score equally better on this aspect compared to organisation 1.

Engineering changes formulation

This aspect is probably one of the most important for process improvement over the long run. The ability to formulate the right engineering changes for D&E is a major structural contributor to long run cycle time reducement. As argued in the preceding chapter, an organisation that has production engineers, production personnel and problem support working in close proximity and cooperation has the best chance of formulating and prioritizing the right kind of engineering changes and will consequently learn faster and proceed through the learning curve in a quicker pace. The most obvious choice with regard to this aspect is organisation 3. The organisation is clustered around the Main Body Modules and smaller modules. This is similar to the way D&E is organised. This will facilitate easier communication between these groups since they have a shared understanding of their specific work content. Organisation 1 is next best with regards to this aspect. The separation between assy and fasy is also quite conducive for a good communication between D&E and the production organisation. Organisation 2 is probably worst situated with respect to this aspect, because of its “split” nature. Group leaders are alternatively responsible for a machine in the fasy stage which is bad for communication and does not facilitate an overall machine perspective or Main Body module perspective. This perspective however is needed in order to be able to formulate and prioritize coherent engineering changes.

Conclusion

The scoring of the different organisations on the different aspects of process improvement is summarized in table 6.

Table 4

		Organisaton 1	Organisation 2	Organisation 3
Process improvement		0%	5%	10%
Learning curve assembly	Repeating frequency of production activities	o	+	-
	Feedback between assembly and test operations	-	o	+
Learning curve test	Knowledge of problem-solution combinations	o	+	+

The translation of this qualitative scoring to the simulation is done by modeling a learning curve for each individual production step (a process in Arena). With each machine or module that passes through the process, the average cycle time of the next machine/module will decrease according to a learning curve formulae. Since organisation 1 resembles the prior production organisations, it is assumed to also have a learning curve of 84%. Organisation 2 and 3 are then thought to perform 5% and 10% better respectively. 5% better, comes down to 83,2% decrease every doubling of the number of machines. (0,84 - (1-0,84)*5% = 0,832) And 10% better comes down to a 82,4% decrease.

6.2 Coordination need

Coordination need relates to the extent to which an organisation will require more or less coordination between employees. As described in chapter 5, coordination need in the production organisation of ASML depends on a number of factors. First is the frequency with which resolvement of problems or conflicts needs to take place by managers. Second, is the extent to which more or less support personnel is needed. Third and last is the complexity of production planners' job.

Hierarchical coordination need

The extent to which problems need to be resolved by escalation of problems to managers determines the work pressure of management and the extent to which they are able to focus on long term improvement and goals as opposed to short term "fire-fighting". Coordination between employees is ideally kept on the lowest possible level where the most effective communication and resolvement can take place. In ASML's production organisation this effective coordination can take place between members of the same team. If problems or conflicts between teams occur, these need to be resolved by the respective team leaders. When problems or conflicts between different groups occur, these need to be resolved by group leaders. Teams and groups need to coordinate work with each other where a module or machine is transferred from one group to the other. There are 14 module and machine transfers in the production of NXE machines. At every transfer, a conflict or problem can possibly occur. The extent to which these problems need to be escalated in the hierarchy (to team leaders or group leaders or not at all when they can be resolved by members of the same team) determines to a large extent the operational hierarchical work load. The number of transfers on each level then is an indication of the operational hierarchical work load, this can be found in table 7.

Table 5

Organisation →	**1**	**2**	**3**
level 1 - within a team	5	5	4
level 2 - between teams	5	1	8
level 3 - between groups	4	8	2

As can be seen, organisation 2 has most product transfers on a group level and thus has the highest hierarchical coordination need. Organisation 1 has half these and organisation 3 has only 2, which makes organisation 3 score highest.

Need for problem support

Another aspect of the coordination need is the need for support personnel. Due to the complexity of machines it can sometimes be hard for testers to determine the correct source of a problem. For this purpose support personnel like VIS (Volume Install Support) and TOPSers can be needed for assistance. The degree to which these persons are needed depends on the knowledge testers posses of possible problems. This depends on a number of things but with respect to the effect of different organisations on this aspect, the largest influence can probably be found in the task variety each test function has. This differs per organisation as can be seen in figure 13, where organisation 2 and 3 have a relatively small task set per function in comparison to organisation 1. Organisation 1 has 3 different test functions; (top test, REIR test and MF test are not included here because they don't change between organisations or are relatively unimportant) WS-test, MID-test and fasy-test. Fasy test specifically has a very broad set of tests they need to perform. (Bottom, mid and top MAQ as well as SQ) Organisation 2 and 3 have WS testers and MID testers perform the bottom and mid MAQ phases respectively and have the "fasy"-testers only do the SQ test phase. What is more, the bottom and mid MAQ phases are largely similar to their test rig tests, so this does not constitute a large increase in work content. This makes organisations 2 and 3 score higher on this aspect then organisation 1.

Need for production planners

The last aspect of coordination need is the number of production planners are required for a smooth day to day operation of production. This depends largely on the complexity of the organisation. Production planners are responsible for the day to day planning of operators and testers. This becomes more challenging when these employees can perform more tasks, because there are more possibilities. Even though this extra flexibility is desired it will require extra production planners.

The largest flexibility occurs at organisation 3 where both operators and testers can be scheduled to more then one production task. Organisation 3 then will probably require relatively more production planners then organisation 1 and 2. Organisation 2 has the second largest flexibility, because testers can work on both module qualifications as on MAQ phases. Organisation 2 also requires production planners to cooperate more with production planners of different groups given the interlaced nature of fasy. Organisation 1 then requires the least amount of production planners.

Conclusion

The scoring of the different organisations on the different aspects of coordination need is summarized in table 8.

Table 6

		Organisation 1	Organisation 2	Organisation 3
Coordination need				
coordination need prim	Nr of product handovers	o	-	+
coordination need sec	Need for problem support	-	o	o
	Production planning	+	o	-

The translation of this qualitative scoring to the simulation is done by using ratio's for the required number of team leaders, group leaders, support and production planners and the number of testers and operators. These ratio's have been based on the current Twinscan situation. For example, the span of control of one team leader is expected to be 11 operators or testers in organisation 3 because relatively more product transfers occur between team leaders in comparison to organisation 1 and 2. These organisations consequently have a larger span of control. Other ratio's have been determined on similar reasoning's that can be deduced from the above described argumentation. The ratio's that have been used in the simulation can be seen in table 9.

Table 7

Organisation	1	2	3
operators/TL	12	13	11
TL/GL	6	5	7
testers/VIS	1,89	2	2
tl/pp	2	1,8	1,6

6.3 Controllability

Controllability relates to the problem of having highly variable production processes. This is due to the large machine complexity and the difficult issue resolvement which this causes. This adds cycle-time to the production process but more important it also introduces a lot of variability, meaning that it is difficult to estimate the time a machine will be ready. This variability is mainly due to the unpredictability of issue resolvement time. As argued before in chapter 5, the number of issues and the time it takes to resolve these, depend on the quality and quantity of feedback assemblers receive, the specialisation of test work, the number of known problem-solution combinations by testers and lastly testers' familiarity with test rig and specific modules/machines.

Feedback of workers

The feedback assemblers receive from testers about the quality of their work depends on the hierarchical structure of the organisation. Employees in the same team are more likely to talk and criticize each other (constructively) then employees from different teams. Employees from different groups in turn again, are less likely to communicate then employees from different teams. When this logic is applied to the organisations, organisation 1 has no feedback from final assembly to module assembly. Some feedback can be expected in the final assembly between MAQ test phases and final assembly. Organisation 2, on the other hand, does have very direct feedback between MAQ test phases and test rig test phases. (since these are by the same groups) Feedback in the final assembly phase however will be bad given the highly interlaced nature, where every machine transfer is between group leaders. However since most issues are assumed to originate from assembly of modules (given that most complexity is inside modules as opposed to between modules), organisation 2 scores higher than organisation. Organisation 3 scores highest on this aspect because it motivates most communication between assembly and test teams of the same main body module. Taking the mid module for example, this module is first assembled and then tested by testers. Assemblers are then given the module back to install it on a machine and is then again passed on to the same testers. This kind of intensive cooperation is most likely to lead to good feedback. Feedback between main modules on the other hand is worst for this organisation, but given the fact that the design of the machines is also focused on main body modules, this kind of feedback is thought to be least important.

Diagnosing time of issues

The specialisation of test work, the number of known problem-solution combinations by testers and the testers' familiarity with test rig and specific modules/machines, all determine the diagnosing time of problems. Where feedback of workers aims at reducing the number of problems/issues, these factors determine the ability to solve issues as fast as possible.

All three factors are influenced by the fact that testers perform both module qualification and MAQ phases in organisation 2 and 3 which does not occur in organisation 1. This means that organisations 2 and 3 are both equally well suited for diagnosing problem causes as fast as possible and that organisation 1 will perform worse on this aspect.

Conclusion

The scoring of the different organisations on the different aspects of controllability is summarized in table 10.

Table 8

		Organisation 1	Organisation 2	Organisation 3
Controllability				
Workmanship of upstream production	Feedback of work	-	o	+
Diagnosing time of problems	Specialisation of test work	-	+	+
	Number of known problem-solutions	-	+	+
	Familiarity with other factors	-	+	+

The translation of this qualitative scoring to the simulation is done by adjusting the variability of production steps. A-time (actual assembly of test time) and B-time (trouble time) are usually assumed in the production of machines to relate in a 1:1 ratio for assembly work and 1:4 ratio for test work. (this seems justified by historical data, see appendix II) Since not much variability will exist in the A-time, most of the variability is in the B-time. Typical variability is weibull distributed at ASML (see appendix II) The differences in variability due to organisational characteristics as discussed above, is translated in to different weibull distributions for each organisation. The mean and standard deviations of these distributions can be found below in table 11.

Table 9

	Organisation 1		Organisation 2		Organisation 3	
	Assembly	Test	Assembly	Test	Assembly	Test
Average	3,00	1,00	2,85	0.95	2.70	0.90
Standard deviation	5,52	1,84	5,25	1,75	4,97	1,66

The magnitude of the differences between the organisations are determined on a qualitative estimate. There is no data available by which this could quantitatively be determined. There are no real life experiments and historical changes in organisations have always been accompanied by many other changes as well whereby organisation specific effects cannot be separated by other effects.

6.4 Scalability

The scalability of an organisation is determined by the speed and ease with which an organisation can scale up or down its size to accommodate production volume changes. As argued above in chapter 5, this is determined largely by the extent of specialization in an organisation. A large degree of specialization helps in scaling up an organisation, because the average training time is relatively small. It is counterproductive however for scaling down, because a large amount of specialization means that relatively more knowledge will leave the organisation with each “specialist” that leaves. Given the production forecasts of ASML for the NXE machines this latter will not be much of a problem however, since a year on year increase in the number of machines (and thus in employees) is expected in every demand scenario. (see appendix III)

The amount of specialization is worst in organisation 3 as can be seen in figure 13. Assemblers have multiple production stages they need to learn to perform, which means these functions have a relatively long training time. The test functions however have less overall training time, because the module qualification and MAQ test phases are similar and only have to be learned once. The reverse is true for organisation 1, where assemblers require relatively less training time, but testers have relatively more training time. Organisation 2 then has best of both, whereas organisation 1 and 3 both have 1 advantage and 1 disadvantage. The maximum training time (of all functions), the total training time and the average training time are measures of how well an organisation scores on this criteria. The calculation and the training time per function can be seen in table 12. The training times per function are based on their workcontent and based on historical training times for Twinscan production functions. As the actual training times for NXE employees is not known yet, these numbers are not accurate. The relative function training times should be accurate for comparison purposes, since they are based on the predicted training time per production step. (e.g. the REIR assemblers training time consists of the work block REIR build and bottom build for organisation 3, which comes to 0,3 + 0,5 = 0,7 years) The training time per production step on which these training times per function are based can be found in appendix IV.

Table 10

Organisation 1	Training times (years)	**Organisation 2**	Training times (years)	**Organisation 3**	Training times (years)
WS build	0,5	WS build	0,5	WS build + fasy bot	0,9
WS test rig	0,5	WS test rig + bot MAQ	0,6	WS test rig + bot MAQ	0,6
REIR build	0,3	REIR build	0,3	REIR build + fasy bot	0,7
MF build	0,5	MF build	0,5	MF build + fasy bot	0,9
MID build	1,0	MID build	1,0	MID build + fasy mid	1,2
MID test rig	0,3	MID test rig + mid MAQ	0,4	MID test rig + mid MAQ	0,4
Fasy bot+mid&top	0,7	Fasy bot+mid&top	0,7	Top fasy + top MAQ+SQ	1,3
Bot + mid + top MAQ + SQ	2,2	Top MAQ + SQ	1,2	SIE	1,5
SIE	1,5	SIE	1,5		
Sum of training time	7,5		6,7		7,5
Maximum training time	2,2		1,5		1,5
Average training time	0,8		0,7		0,9

As can be seen organisation 2 scores best on all measures. Organisation 1 and 3 have the same total training time, which indicates the advantages and disadvantages of the organisations nullify each other. Organisation 1 has a longer maximum training time however because fasy testers need to learn bottom-, middle-, top MAQ phases and SQ, which is not necessary in organisation 3 (and 2). The average training time however is larger for organisation 3 then it is for organisation 1. So nothing really conclusive can be said about how organisation 1 and 3 compare. Organisation 2 however scores highest on all three measures and thus scores best on this criteria.

Conclusion

The scoring of the different organisations on the different aspects of scalability is summarized in table 13.

Table 11

	Organisation 1	Organisation 2	Organisation 3
Scalability			
Specialization	o	+	o

The qualitative scoring on this criteria has been translated in to the simulation by assuming that new personnel is not productive for the duration of this training time while still costing ASML wages. For this purpose the training times in table 13 have been multiplied by an average cost figure. (which can be found in the simulation assumptions in appendix IV) Because in reality these new employees have to be trained on the job by experienced employees, there is a limit to how many new employees can be trained at any given time. It appeared however that with the given demand forecasts, this will not be an issue. Consequently this aspect has not been incorporated in the simulation.

6.5 Quality management

Quality management is very similar for ASML to the controllability criteria as discussed in chapter 5. This is because every quality issue results in extra cycle time and is thus a part of controllability. The aspect of quality management that is evaluated here is the ability of assemblers to immediately recognize quality issues in their incoming material. Only assemblers are considered here because testers are not able to judge this immediately. (their entire work in fact is to judge this, so by definition they can only judge the quality of their input material when they are finished) As discussed in chapter 5, the ability of assemblers to judge the quality of their input materials depends on the number of incoming materials per function, with the reasoning that more materials will compromise the ability of assemblers to distinguish good and bad quality. The number of incoming materials in turn depends on the work content per function.

The first thing that can be noticed is that there is no difference between organisation 1 and 2 with respect to this aspect, since assemblers have similar functions in these 2 organisations. Organisation 3 however does have a different task distribution for assemblers. Assemblers have a broader task variety in this organisation, since they do not only assemble modules but need to build Main Body modules as well. The group that performs fasy in organisation 1 and 2 has a very broad task variety, and the absence of this group in organisation 3 does weigh in its favor. The broadened task variety of module assemblers however is more important because mistakes there are more difficult to find. The number of functions that have a broader task variety is also much larger for organisation 1 and 2. Organisation 3, thus scores highest on this criteria, while organisation 1 and 2 are a close second.

Conclusion

The scoring is summarized in table 14.

Table 12

	Organisation 1	Organisation 2	Organisation 3
Quality management			
Number of materials needed / function	o	o	-

The effects of quality management have not been incorporated in the simulation. This is due to the already mentioned overlap between controllability and quality management. The important consequences of quality issues have already been modeled in the variability of production steps. The scoring on this criteria is then just a qualitative indication.

6.6 *Work satisfaction*

Work satisfaction of employees is important for low work stress and estrangement, as argued in chapter 5. Work stress is caused by not having the means or liberties to cope with problems within one's own domain. Estrangement is the effect of not caring for ones job because not enough interaction with other individuals is required for solving problems. The determinants of estrangement and stress can be found in table 15. The discussion of these determinants can be found in chapter 5 under work satisfaction. An example of estrangement is Fords famous low cyclical assembly line. Although experienced employees usually had enough internal problem solving capacity to cope with their work pressure. (enough time to perform their job in the required time) Their short cyclical work required no interaction with other employees and consequently they had no means of changing the norms of their input and output requirements (no influence on how the assembly line was designed). This led to high estrangement. (so high in fact that every employee stayed on average only half a year at the factory. Of course, Ford compensated by offering twice the hourly wages competitors offered)

Table 13

		Internal problem solving capacity	
		High	Low
External problem solving capacity	High	Stress and estrangement risk low	Stress and estrangement risk low (unlikely situation)
	Low	Stress risk low Estrangement risk high	Stress risk high Estrangement risk high

The production process does not change dramatically with different organisations, but there are some aspects that influence stress and estrangement. These have been argued to be the span of control of team leaders, the amount of employee specialisation and the nature of the product handover interfaces. (whether these are situated on a low or high level)

Span of control team leaders

The span of control influences the time he has available for addressing employees problems and giving them personnel attention. Of course other factors such as their personal attitudes and management style has a much larger impact, but these do not change with organisations. As determined in table x at the discussion of the coordination need, organisation 3 has the smallest span of control, followed by organisation 1 and organisation 2 having the largest relative span of control. These span of controls however were based on the coordination need of team leaders, so it is not sure that the smaller span of control of organisation 3 will also lead to more personal attention.

Worker specialisation

The inverse argumentation of quality management applies here. Where it is a plus for the recognition of incoming material quality to have a small task variety, it is a negative for worker satisfaction. The internal problem solving capacity is increased with a larger workcontent and increased work cycle, because there are more possibilities to develop and apply one's own means and methods. Organisation 3 then scores highest here, because the work content is on average the highest. Organisation 1 and 2 again score equally below organisation 3.

Product handover interfaces

The nature of the product handover interfaces has already been discussed above and can be found in table 7. The nature of handover interfaces influences work satisfaction through increasing the external problem solving capacity. With more handovers situated on lower levels it becomes easier for employees to coordinate directly with each other, which is a positive for managers as well as employees. The possibilities for solving problems between assemblers and testers directly thus increase.

Conclusion

The scoring on work satisfaction has been summarized in table 16.

Table 14

	Organisation 1	Organisation 2	Organisation 3
6 Work satisfaction			
Span of control team leader	o	-	+
Worker specialization (task variety)	o	o	+
Product handover interfaces	-	o	+

Just as with quality control, work satisfaction is not incorporated in the simulation. The effects of work satisfaction are difficult to quantify and will probably not have a very large effect since the production is not completely different. In [17], de Sitter gives some examples of how a different production structure influenced quite significant results with regards to work satisfaction. In these examples however the changes were quite dramatic and constituted changes in the production structure (from production line assembly to cell based manufacturing) with subsequent logical changes in the organisation structure. The effects of the organisation on work satisfaction is possibly only small in ASMLs case.

6.7 Conclusion

The effects of the different criteria are summarized in table 17.

Table 15

		Organisation 1	Organisation 2	Organisation 3
1 Productivity				
2 Process improvement				
Learning curve assembly	Repeating frequency of production activities	o	+	-
	Feedback between assembly and test operations	-	o	+
Learning curve test	Knowledge of problem-solution combinations	o	+	+
	Engineering changes formulation	o	-	+
3 Coordination need				
coordination need prim	Nr of product handovers	o	-	+
coordination need sec	Need for problem support	-	o	o
	Production planning	+	o	-
4 Controllability				
Workmanship of upstream production	Feedback of work	-	o	+
Diagnosing time of problems	Specialisation of test work	-	+	+
	Number of known problem-solutions	-	+	+
	Familiarity with other factors	-	+	+
5 Quality management				
	Number of materials needed / function	o	o	-
6 Work satisfaction				
	Span of control team leader	o	-	+
	Worker specialization (task variety)	o	o	+
	Product handover interfaces	-	o	+
7 Scalability				
	Specialization	o	+	o

As can be seen organisation 3 seems to come out best on average and organisation 1 the worst. Organisation 2 lies somewhere in between. The significance of these criteria however ultimately need to be related to financial figures. Coordination need for example might be worse for organisation 2, but if the extra cost of support personnel and support are insignificant in relation to the advantage it offers on the scalability criteria, it might still be a better choice. For this reason the simulation was used. The simulation and its results will be discussed in the next chapter.

Chapter 7 Simulation

The use of a simulation for evaluating organisations in a quantitative manner is a unique feature in the field of organisational design. Simulation was chosen in this project because of a number of reasons. The first reason was that it allows for different situations to easily be considered. Experimentation with and evaluation of alternatives becomes easier by using simulation.

It is also useful in situations where real time experimentation is to costly, time consuming or dangerous. In this case it is both too costly and time consuming. The choice for one alternative, naturally foregoes the implementation and experience of others, so the advantage of natural experimentation is not possible. Simulation can show “what if” scenarios and might point to small changes that would have otherwise been overlooked.

Another reason is that simulation gives the possibility to weigh the importance of different criteria. While general literature criteria can be used to qualitatively score different organisations, the magnitude of different effects is thereby often either assumed equal over different criteria or is left for managers to evaluate on a “gut” feeling. By using simulation the magnitude of different effects can be quantified, which might in some cases lead to a revaluation of the alternatives.

A disadvantage of using simulation for choosing between organisation structures, is the high aggregate level of modeling that is required. An extensive model would take a long time to build and would be highly vulnerable to changes in the production process which are still expected in ASMLs case. An appropriate higher level was chosen, which unfortunately also leaves out quite some elements that might be important. Another consequence of this higher level modeling is that a lot of simplifying assumptions needed to be made about costs and processes. So while the cost of for example one FTE differs across functions for the purpose of this simulation they are equalized to one number. The quantitative results therefore need to be interpretated with care, because the results might differ substantively from eventual realized results. The results also need to be interpretated with care because a number of aspects have not been included in the simulation that will certainly have a large impact on actual performance. These aspects have been left out because they do not influence the choice between different organisations even though they will have a large impact on the eventual NXE production organisation performance. As stated by Law and Kelton [14]: “A simulation practitioner must determine what aspects of a complex real-world system actually need to be incorporated into the simulation model and at what level of detail, and what aspects can safely be ignored.” The results however will usually still resemble reality. Because of the high aggregation level in modeling in this case, this might not always be the case here. For example, the simplifying assumption that the CRP process (the choice of when to hire and fire new personnel) is perfect in the simulation is not justified. The effect of shortages in manpower on bottom line performance, for example have previously been quite large and have “cost” ASML a number of foregone sales. Modeling a CRP process would have taken extra time and would only have introduced extra variability. This variability would have added to the realism of the simulation, but it would have distracted from the goal of the simulation. So, while the actual numbers might not always resemble reality, for the purpose of evaluating different alternatives the model is thought to be adequate.

This chapter will first describe the process of modeling the production process of NXE machines. It will then continue to describe the model as it was implemented in the simulation. The most important assumptions that were used in this process will also be described. The next part will describe and discuss the simulation results. The conclusions that can be derived from the simulation will be described in the final part.

7.1 Base Model

The base model has been based on conversations with production engineers and team leaders. The production models used by ASML are typically quite detailed, so for the purpose of this project, production steps have been lumped together where possible. The model has also been modified where certain changes between the production of NXE3100 and NXE3300 are expected to occur. For instance for the production NXE3300 machines, it is assumed test rigs for testing the MID and Waferstage modules will be available, which are not yet available for the NXE3100 production. Where these changes were assumed, the expected cycle time and resource requirements have been discussed with responsible engineers and assumptions were based on these discussions.

The production process as it was modeled for this simulations’ purposed can be seen in figure 14.

The figure depicts the number of persons required at a certain production step, the length of the production step and the sequence in which they are required to be executed. The work centers that the production steps are assigned to are depicted in the rectangles that surround the production steps. The distribution of production steps to type of employee is depicted by the color of the arrows. Yellow arrows are testers, while grey arrows are assemblers/operators. Some of the production steps have no arrows which means these steps are either executed by another company (in the case of the source), do not require any person to execute (as for example in the case of curing) or are not taken in to consideration in the simulation because they are outside project scope. (as in the case of pre-pack and pack) The indicated time of production steps is always A-time. The distinction is made between A and B-time at ASML. B-time is defined as “problem time” which is a mark up on A-time. Typical mark ups that are used at ASML is a factor 1 of A-time for assembly steps and a factor 3 for test phases. Since the production of NXE machines has only recently started, these cycle times are still subject to change.

7.2 Simulation model

The simulation program that was used is Arena from Rockwell Automation. This is a visual simulation program that can be used in many different scenarios and for different purposes. It is also often used for production process simulation. This program was chosen mainly because of familiarity reasons and because it was thought to have enough flexibility possibilities to be able to model some specific ASML circumstances.

It’s most basic building blocks consist of processes that can be lined up in parallel or sequential, with an entity generator at the start and an entity “sink” at the end. Entities originate at the entity generator and travel through these processes, splitting up and waiting for each other where necessary, until they reach the sink, where they are removed from the simulation and their data is stored. These entities (machines) can be generated according to a random process or on a user defined schedule. The time each processes takes can be programmed to be the result of a function and can be both constant or stochastic. Resource types (employees and material) can be allocated to the processes, which means that the simulation can keep track of how many resources are needed per entity (machine) or overall (for the whole factory).

The model in figure 11 was transcribed in to Arena. The arena model can be seen in figure 15.

CT's are A-time

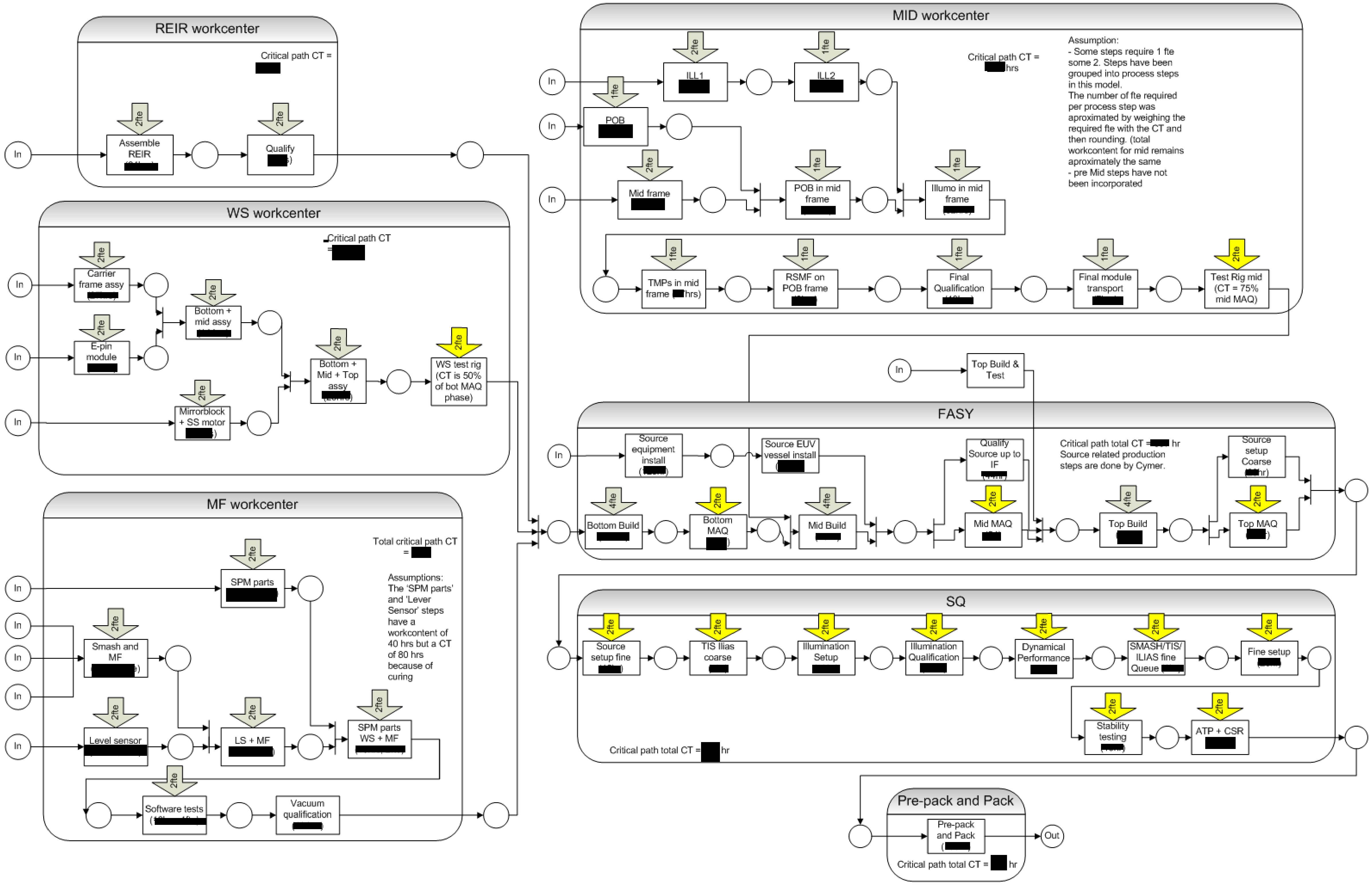

Figure 14

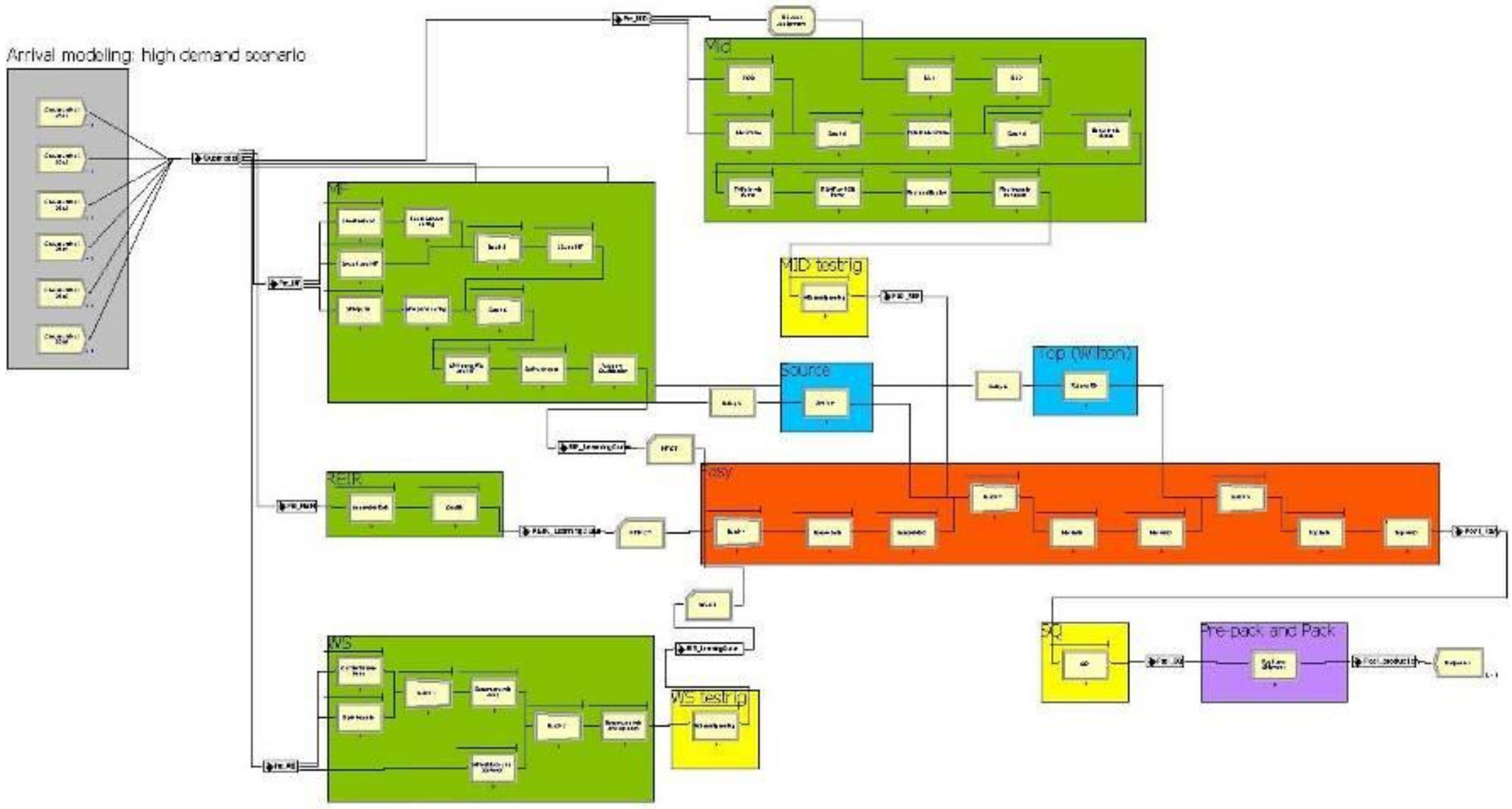

Figure 15

The way the different input criteria were incorporated in the simulation has already been discussed shortly in the preceding chapter. This will shortly be repeated and extended here. As a side note, it must be noted here that the magnitude of the input criteria effects per organisation have only been estimated on qualitative assessment. This is because in most cases it can be quite difficult to measure the criteria in reality, because the data is not available. When it is available, there are many other variables that can influence the measures. The controlling variable – the organisation structure - moreover has been more or less constant since the start of Twinscan production, which makes it virtually impossible to estimate the magnitude of the criteria effects for each organisation on a quantitave, historical basis. As compensation, an orthogonal factorial expirement has been carried out to determine the effects of the different input parameters on the output parameters. This sensitivity analysis can be used to determine the relative importance of the estimations and to extrapolate aproximately how larger or smaller differences per organisation with respect to certain input parameters, might influence results.

The input and output factors can be seen in figure 16.

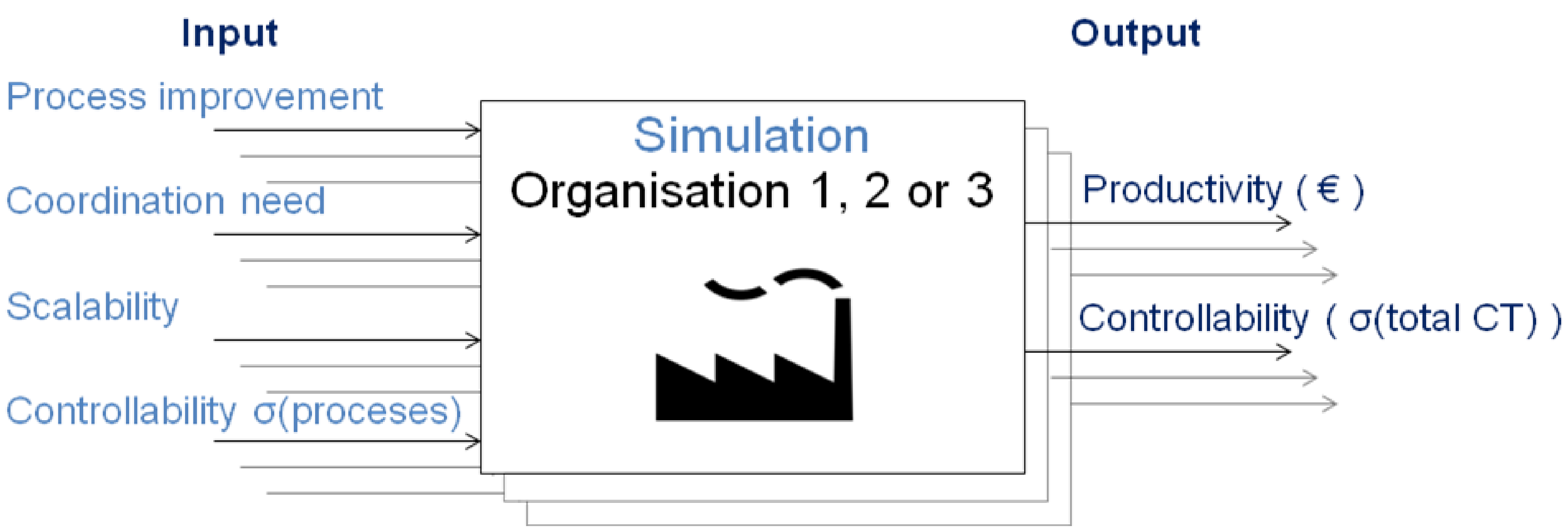

Figure 16

7.3 Assumptions

By translating the production model to the arena model, a number of assumptions needed to be made. These can be found in appendix V. The most important ones will be discussed below.

<u>Assumption 1: Workforce hiring and firing is perfect & no resource shortages</u>

The hiring and firing of employees is usually done via a monthly CRP process at ASML that involves a number of meetings between marketing and production to determine the expected demand and the corresponding required number of personnel. While this process could have been modeled, it would have required extra effort while it would not have added to the purpose of the simulation. Moreover it would have added extra variability to the results that is really not desirable. Consequently the CRP process was assumed to be perfect and hires personnel exactly on time (with respect to training time). Because training times are relatively long and because of the absence of a downturn in the production forecasts, there is also no firing in the CRP process. This means that relatively more testers and assemblers (and thus also support personnel) will be hired in comparison with reality. For example in case of a short spike in the requirement of REIR assemblers, the number of assemblers will be adapted upwards, but when this spike is over the number of assemblers will not be adjusted downwards afterwards. In reality these spikes might have been avoided through working overtime or temporarily changing the shift structure. As a result the number of employees will likely be on the higher side than what is to be expected.

Assumption 2: A-time : B-time ratios of 1:1 and 1:3 for assembly and test production steps

As explained before A:B time ratios are used at ASML to estimate the cycle times of new machines. Normally this is assumed to be 1:1 for assembly phases and 1:3 for test phases. This figure seems to be justified historically. (see appendix II) This ratio was then consequently used for organisation 1, since this resembles the current production structure most closely. Small adjustments were made for organisation 2 and 3, as can be read previously in this chapter.

Assumption 3: 96 production hours per week (smart shift)

ASML uses a number of shifts for the production of its machines, which can be changed when required, depending on work pressure. This ultimately determines how many hours a week are worked on a machine. Modeling of this aspect was attempted in Arena, but ultimately was not accomplished. Consequently one shift structure was used in the simulation and no shift flexibility was present in the model. NXE machines are relatively expensive even for ASML terms and the carrying costs (WIP) are expected to be a large part of machine costs. The shorter the total time between material purchasing and receiving customer payment, the less this cost will be. Consequently it can be assumed quite safely that the shift which minimizes this total time will be chosen most often. (under restriction to union demands) This is the smart shift structure, which is a double shift during week days (16 hrs a day) and a single shift in the weekends. (8 hours a day on Saturday and Sunday) This totals 96 hours per week. With 52 weeks a year, this totals 4992 available work hours per year.

Assumption 4: 60 000 € per employee per year

Employees salary at ASML depends on their function, experience and some other variables. Exactly modeling these factors would add to reality, but would probably not significantly alter simulation results. Consequently an average of 60 000 € was assumed for each employee.

Assumption 5: Internal Rate of Return = 11%

ASML uses an internal rate of return of 11% for evaluating investment projects. Since the carrying cost of WIP at ASML is so large it should be seen as a part of machine cost price. Since total average WIP investment depends on the average cycle time and this in turn depends on the organization that is chosen, the carrying cost should be measured. Since the investment in WIP could also be used for other investment opportunities, this WIP is weighed at the same 11% that is used for other investment opportunities. [18]

7.4 Results

For the comparison of the 3 organisation s, 9 different scenario's were run. Each organisation was simulated on a high middle and low demand scenario (see appendix III). Each scenario was run a 100 times, whereby the statistical significance of the results could be improved. 90% Confidence interval where calculated to determine the statistical significance of the numbers and the safety with which conclusions can be drawn. A 2 sample paired T-test was conducted on each possible pair of organisations, to determine their differences and the statistical significance of these differences. These results can be found in appendix VI. To insure that the results that are obtained from this simulation are correct a verification and validation of the results was also carried out. This can be found in appendix VIII. The most important conclusions will be related below.

7.4.1 Organisation comparison

Simulation results compose of a number of variables. These are either cost components or cycle-time related. (as indicated in figure 16) Cycle time results are straightforward in that it consists of the average cycle times of machines per year. These are quite simple to compare. The cost element (which ultimately determines the factory productivity) consists of a number of elements. First is the **personnel costs** an organisation has. This includes both direct personnel - that assembles and tests machines - as well as support staff - which consists of production planners, group leaders, team leaders and VIS/TOPS. A second component of the costs is the **holding costs** of machine. This constitutes the carrying cost of the material cost in the factory. The material price is a large part of machine costs, but this does not vary with organisations. The carrying cost of this material investment however does depend on the average time a machine spends in the factory. (thus the cycle time) The third and last cost component is the **hiring cost** of personnel. The cost components considered here are not exhaustive of all costs that are incurred with the production of machines, but they are the cost components that are expected to change with different organisation structures.

With respect to cycle time it appears that it is very much a case of what is put in the simulation is also what comes out. As argued previously organisation 3 and 2 will have a better cycle time and less variability. Unsurprisingly this also shows in the results of the simulation, see figure 17. The organisation with the lowest average cycle time is taken as a bottom and the other organisations are compared on a relative deviation basis. As can be seen, organisation 3 always performs better, although the difference declines with higher demand scenario's. This is due to the learning curve effect. With more machines ultimately being made in a high scenario's the learning curves end up pretty close to each other. (the largest decreases in cycle time can be seen in the early stages of production) This means that there are more machines in each simulation that have a relative small difference, which brings the averages closer to each other.

The results with respect to the costs are more diverse. The same representation is chosen as with the cycle time. The best organisation is chosen as a baseline to which the other organisations have been related. Again organisation 3 scores better, but only in the middle and high demand scenario's. Organisation 2 is slightly better in the low demand scenario. Organisation 1 is relative more expensive in high demand scenarios then in low demand, but nevertheless is clearly the worst option of the three. The differences per demand scenario can be explained with a closer examination of the cost components in each demand scenario. This can be seen in figure 19 and 20. (cost figures on the y-axes have been normalized for confidentiality reasons in these figures)

In these graphs the total cost of an organisation over 6 years is presented, which is subdivided by cost drivers. As can be seen, organisation 3 is the least expensive organisation in the high demand scenario, but it no longer is in the low demand scenario which is consistent with figure 18. The main advantage of organisation 3 comes from having lower holding costs. The actual resource flexibility advantages that were expected in chapter 4 have thus not weighed up to the inefficiency of having one specific group for top fasy. A special experiment was carried out where only the organisation resource effect was evaluated, the results

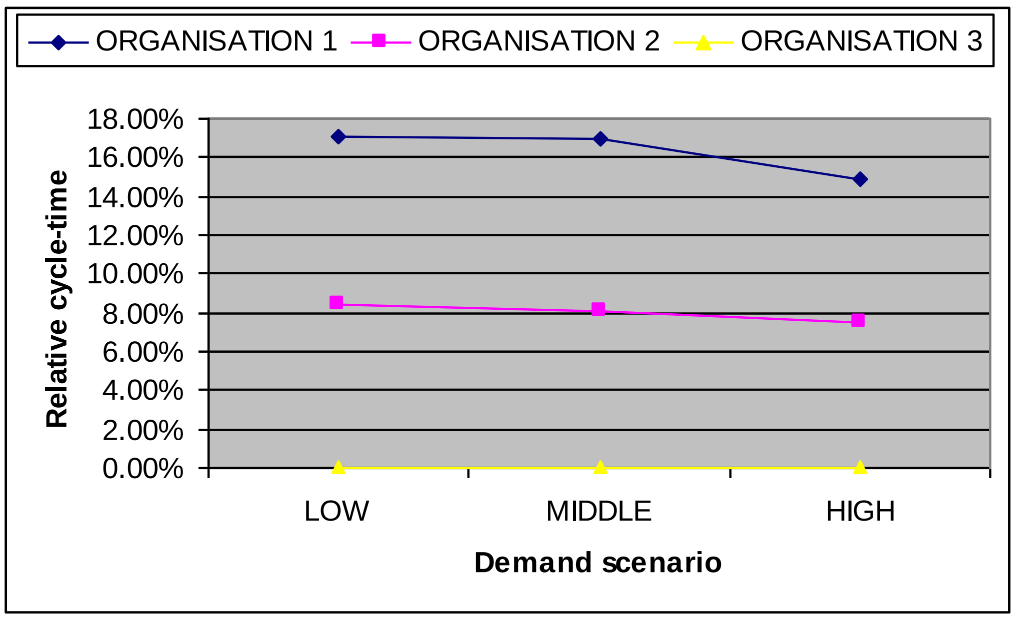

Figure 17

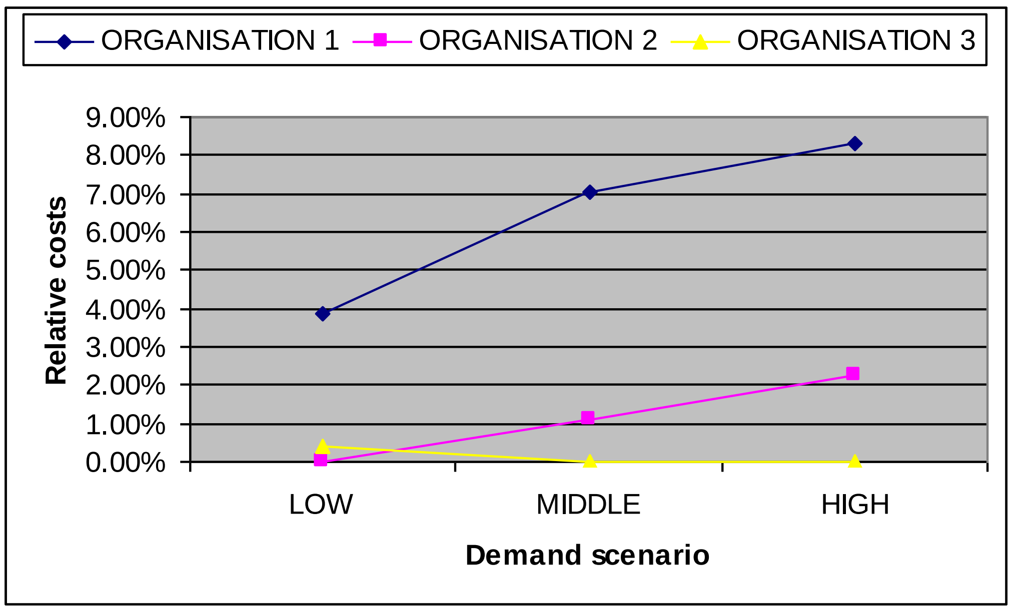

Figure 18

of which can be seen figure 21. As can be seen organisation 3 uses personnel resources less efficiently then organisation 1 and 2. Admittedly this was carried out in a low demand scenario's where these inefficiencies are especially large. In a low demand scenario this inefficiency is extra large and combined with a relatively smaller advantage in holding cost (because
there are fewer total machines produced) this leads to organisation 3 having slightly higher costs.

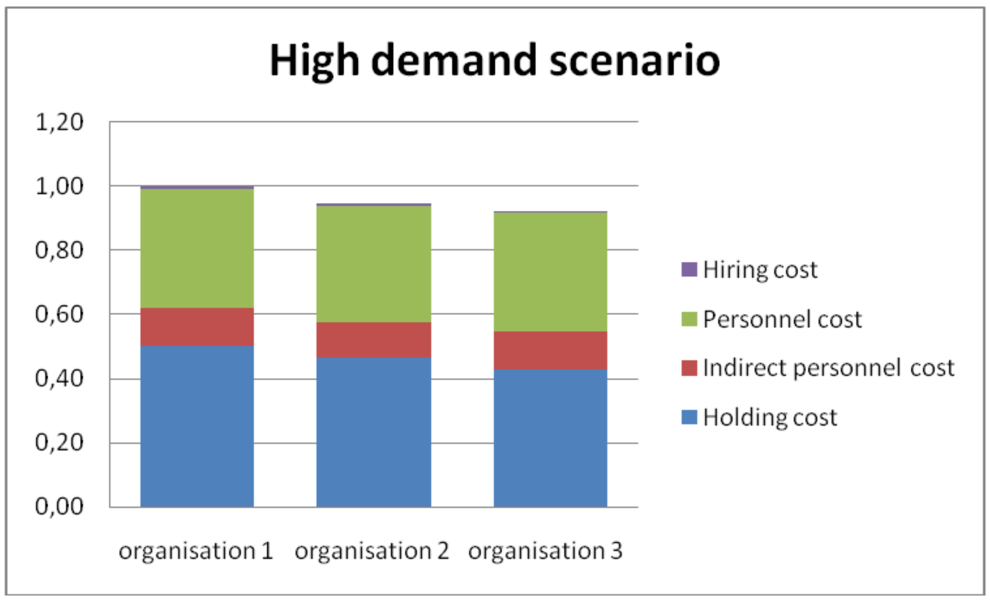

Figure 19

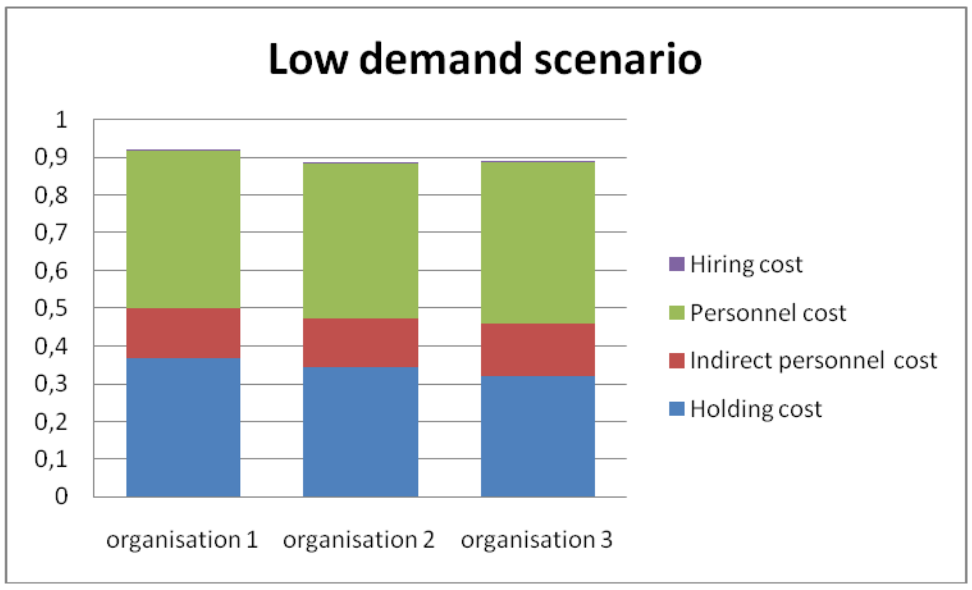

Figure 20

7.4.2 Sensitivity analysis

Because the analysis of the input parameters (i.e. the input criteria) is based on a subjective valuation, an sensitivity analysis was carried out to determine the extent to which results depend on the individual input parameters. This was done by an orthogonal factorial analysis that is often used in experiment design for quality purposes [4]. It enables a smaller amount of runs to be used to obtain the same results as can be obtained from a full factorial analysis. This is done by a setting of the parameters in such a way that every parameter is ultimately balanced out to every other parameter. An example of the orthogonal array that was used and an explanation of the way it used can be read in appendix VII.

Nine scenarios were run and examined for both cost and cycle time effects. The input parameters (coordination need, controllability, scalability and process improvement) were varied over 10% deviations from an average. (see for more explanation appendix VII) The resulting changes in the output parameters are also given in deviations from the average. The results from the sensitivity analysis towards the average cycle time can be seen in figure 22.

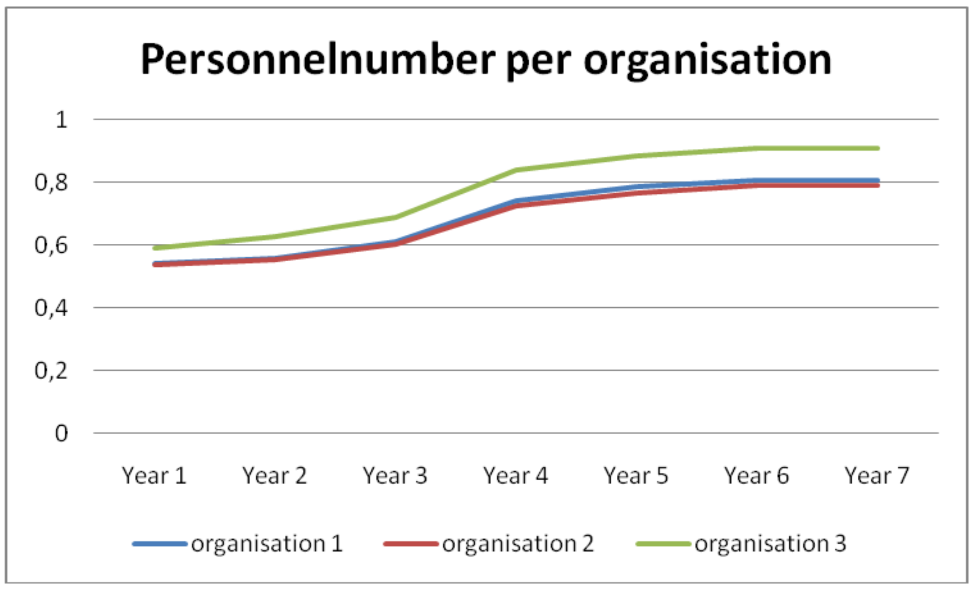

Figure 21

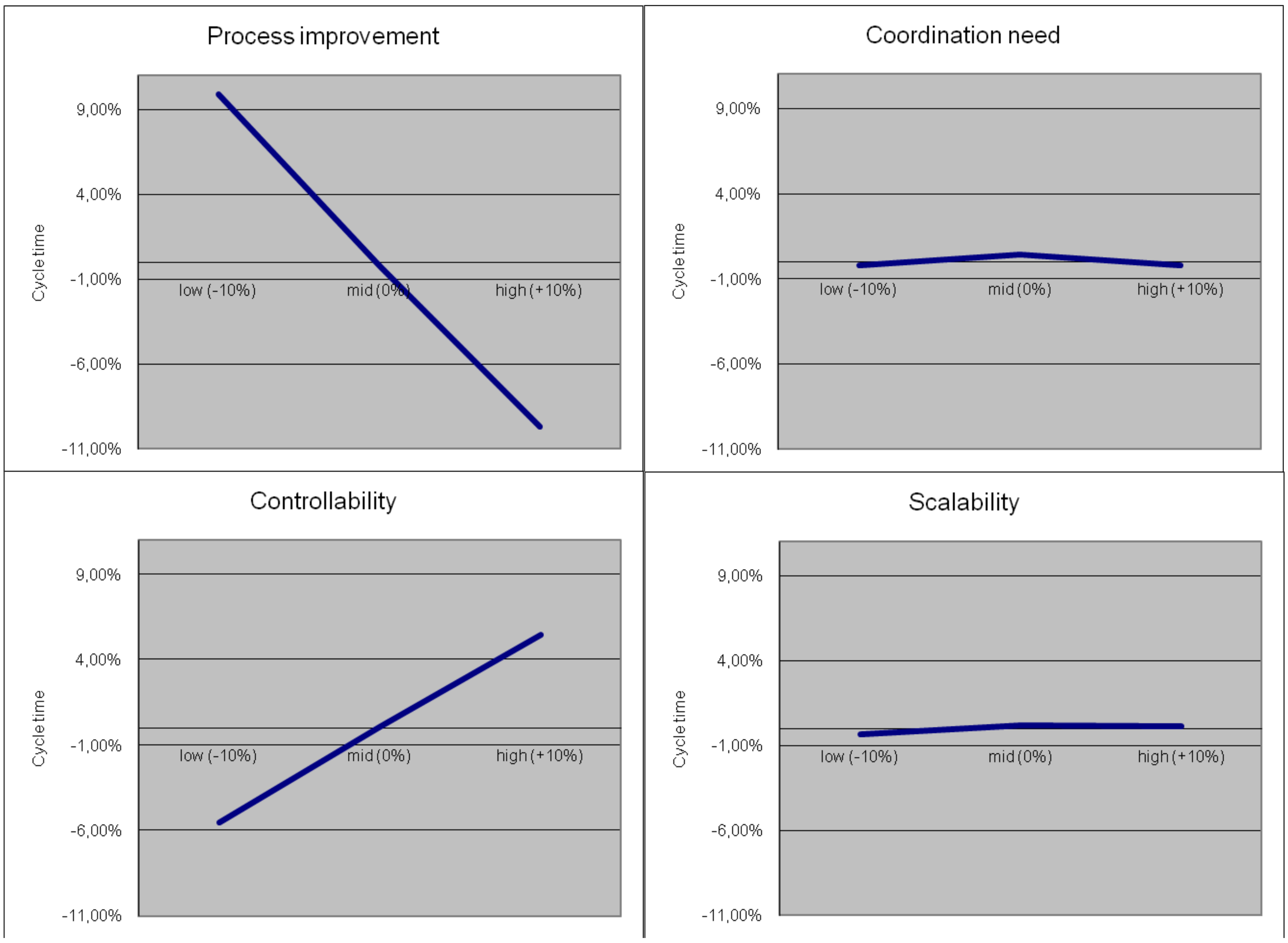

Figure 22

As can be seen, the parameters process improvement and controllability have the largest impacts on the cycle time. Coordination need and scalability are both parameters that relate to the costs, and as such have no effect on the cycle time. Surprisingly, process improvement has the largest influence on the average cycle time. Although it can be expected to have a large effect the -10% and +10% deviation results in almost 10% deviations in the average cycle time as well. Surprising because a -10% effect is only a reduction from 84% to 82,4% in the learning curve.

The same sensitivity analysis with regards to the costs can be seen in figure 23. In this figure process improvement and controllability are again seen to be dominant in importance. Cycle time translates in to costs via the holding costs that vary with shorter or longer average cycle times. These orthogonal experiments were conducted in a middle demand scenario's which is of importance - as can be seen above - because this influences the relative proportion of total costs, the holding costs constitute. Given that the learning curve differences are larger with minus and plus 10 deviations then in the original simulations it could be expected that it would also dominate in the costs aspects. Also remarkable is the scalability influence on costs. At least some effect was expected, since this determines the total hiring costs. Given the small proportion of total costs however, this influence should only be very small. The last parameter controllability also has a very strong effect on the costs. Again also via the holding cost effect, because with a decreased test time (due to a decrease in the variability) there is also less total average cycle time.

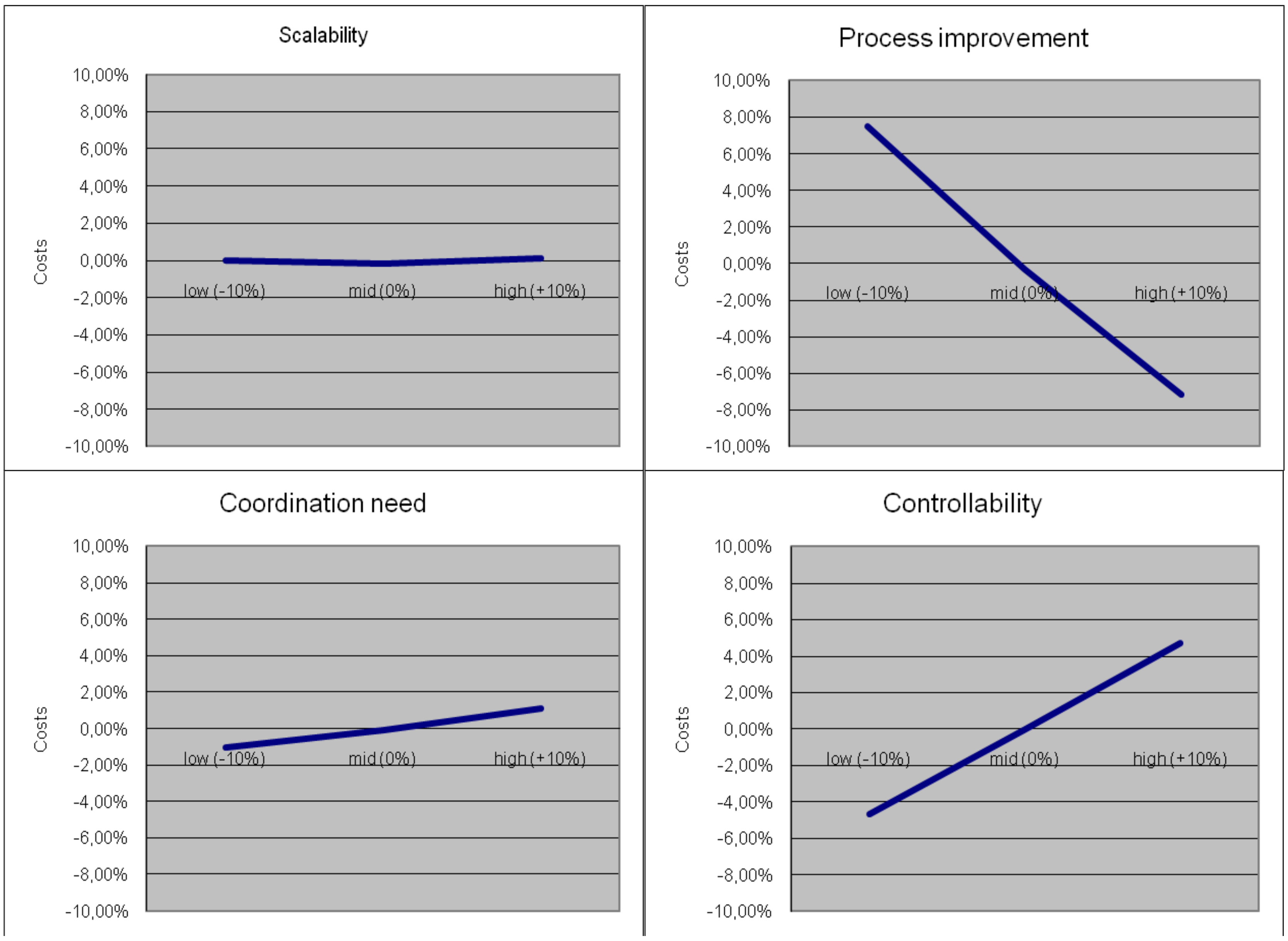
Scalability
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
-2,00%
-4,00%
-6,00%
-8,00%
-10,00%
Costs
low (-10%)
mid (0%)
high (+10%)
Process improvement
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
-2,00%
-4,00%
-6,00%
-8,00%
-10,00%
Costs
low (-10%)
mid (0%)
high (+10%)
Coordination need
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
-2,00%
-4,00%
-6,00%
-8,00%
-10,00%
Costs
low (-10%)
mid (0%)
high (+10%)
Controllability
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
-2,00%
-4,00%
-6,00%
-8,00%
-10,00%
Costs
low (-10%)
mid (0%)
high (+10%)

Figure 23

Chapter 8 Conclusions and recommendations

A number of things can be concluded from the preceding chapters. Both qualitative and quantitative results can be used to derive these conclusions. These conclusions naturally lead to a number of recommendations that will also be related in the final section of this report.

8.1 Conclusions

<u>Organisation 3 performs best on learning curve and controllability criteria</u>

Organisation 3 performs best on cycle time and cost aspects in almost all simulation scenario's. However as also mentioned in the simulation chapter, this is mostly a result of what is put in to the simulation is also what can be expected as output. The discussion consequently has to be focused on the argumentation that this organisation is best situated for learning and for decreasing B-time. (the process improvement and controllability criteria) This argumentation is formulated in detail in chapter 6, but will come down to the belief that organisation 3 facilitates functional concentration, whereby both assembler and tester learning and skill is increased. This organisation structure moreover also enables a better formulation and prioritization of engineering changes towards D&E, which is ultimately the most important source for cycle time reduction. These effects results in a faster learning curve and less problem time at ASML.

<u>Organisation 2 is most efficient with manpower resources</u>

Organisation 2 is more efficient with manpower resources then organisation 3. As can be seen in the simulation results however, these inefficiencies do not weigh up to the holding cost decreases that take place in organisation 3, due to smaller average cycle time. Organisation 3 was expected to be more efficient with resources due to the increased flexibility of personnel. However, because this effect failed it actually was more resource intensive than expected.

<u>The learning curve is an important aspect for ASMLs factory, that deserves active management attention</u>

From the sensitivity analysis of the simulation it can be concluded that the criteria process improvement, i.e. the learning curve, is an important consideration with respect to both costs and cycle time. The learning curve is mostly driven by engineering changes and this is perhaps why it is not actively managed by factory managers. Consequently, D&E is very dominant in determining these engineering changes (for the volume situation), while they will always have slightly different prioritization rules then production. A more active management stance towards this aspect can clearly be very beneficial, given that it can result in much larger decrease in the learning time then has been assumed in this study. It must be noted that this refers mainly to the volume situation of most products. This process is very actively managed for new products, but although most benefits can be gained in the early phase of the learning curve, potential benefits in the volume organisation are also significant.

This conclusion must not be taken in any way as a critique on the current processes and employees who are currently responsible for communicating engineering changes. Extra management attention can only lead to a higher prioritization and consequently more resources and more clearly defined processes. This also means that management attention needs to be available for strategic and tactical prioritization for this. Organisation 2 has more problems with respect to this factor then the other organisations, because it becomes very stressful for group leader managers when demand takes off. (as can be seen in table 7)

<u>Organisation 3 is to be recommended for the production of NXE machines</u>

Considering the above described conclusions, the general conclusion that can be derived from this project is that organisation 3 is best suited for the production of NXE type machines in a volume situation. The argumentation for this organisation is that it is best suited for organisational learning on both a long (learning curve) and short term (variability). As noticed in the sensitivity analysis, these two aspects are particular important for ASML from both a cost as cycle time perspective, and as such, is the most important consideration in the decision for a specific organisation.

8.2 Recommendations

8.2.1 ASML recommendations

Investigate the possibility of larger assembly workforce flexibility

The possibility of using one type of assembler for both assy and fasy is an assumption that was used for organisation 3. Although this was thought to be justified, it is possible that this might have consequences that are currently overseen. Argumentation is that the two do require different skills and attitudes. Where assy is the assemblage of smaller components into a module, fasy is really the assemblage of big blocks of finished modules in to an entire machine. Fasy consequently requires more teamwork and sometimes involves the appendage of larger modules to the machine by using large construction cranes. Assy in comparison is usual an individual task that sometimes requires very fine and precise maneuvering and requires more technical background knowledge then fasy does.

Investigate how engineering changes can be better formulated

In line with the reasoning of the last conclusion above, it deserves attention to investigate what kind of processes and extra means are beneficial for a better formulation and prioritization of engineering changes. Especially because this process requires input from multiple disciplines and functions, it is advised to investigate how management can actively facilitate this process.

Investigate how the weakness of a lack of output focus of organisation 2 and 3 might be decreased

As is already discussed in chapter 4, organisation 2 and 3 suffer from a lack of a clear focus on output. Where organisation 1 has one group leader that is responsible from the start of fasy to the delivery of the machine to the customer, this single point of responsibility is no longer present in organisations 2 and 3. Organisation 2 has a continued transfer of responsibility between BO and DO, which dilutes the output responsibility. Organisation 3 suffers from the same problems because the output pressure is only felt at the last phase of production. In ASMLs situation of large variations in cycle time it is especially important to have a single individual responsible for the output of particular machines, because delays easily remain undetected. Of course delays because of problems are inescapable, but delays that are caused by organisation parts not taking their responsibility are unacceptable.

8.2.2 Academic recommendations

More attention for organisation structuring

The first recommendation is based on the observation that academic attention for this part of organisation literature has declined significantly during the last decennia. Given the importance of the subject and the large practical usefulness that it could possibly provide, this is not justified. Although the main, important theoretical considerations have probably been found and explained, there is still room for a deepening of this knowledge for specific industries. As has been shown in this study, the importance of different criteria can be very company specific.

Development of industry specific organisational drivers per criteria

Literature seems to be very specifically oriented at the organisation of large corporations. Although theoretical concepts are applicable to other types of organisations, there are also differences. Especially the criteria that can be used in designing and evaluating organisations are different for different kinds of organisations. As it was necessary to deepen some of the criteria for the production organisation of ASML, it might also be interesting to develop new or more extensive criteria for other industries.

Usage of simulation and extension of simulation to include soft elements

The extension of criteria with more specific underlying drivers would be an useful extension of existing literature. In combination with industry specific criteria, this would enable the use of new tools with regards to organisation choice for practitioners. Especially the use of simulation can be beneficial for quantifying the importance of criteria and other consequences of different organisation variants.

The simulation that was used in this project is also still very high level and only includes measurable and first order effects that come first to mind. Possible interactions between criteria can be investigated and certain soft elements could be included for increased realism [15]. Especially work pressure effects and work psychology effects could be used to extend these simulations. A careful balance is needed in the level modeling. Too much detail will require too much effort, while too little risks leaving out important aspects. Research in to the underlying drivers of criteria for different industries will help in this regard.

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