MASTER

Accelerating the learning curve at ASML
an exploration of drivers

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Accelerating the Learning Curve at ASML: An Exploration of Drivers

by

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in partial fulfilment of the requirements for the degree of

Master of Science
in Innovation Management

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TUE. School of Industrial Engineering.

Series Master Theses Innovation Management

Subject headings: learning, learning curve, new product introduction, new product development speed
“There are two kinds of firms – the quick and the dead.”

Andy Grove, former president of Intel
Preface & Acknowledgements

This master thesis is a record of the research I carried out at ASML Netherlands BV in the period of January 2012 to July 2012. With the completion of this thesis I will receive a Master Degree in Innovation Management from the Eindhoven University of Technology.

This graduation project was a valuable experience for me as a future industrial engineer and therefore I would like to thank Fränk Zwaans for creating the opportunity to carry out this project in one of the most eye-catching Dutch technology multinationals.

In particular, I would like to thank my supervisors, Grardus Oosterhout and Sander Schepens. Grardus extended his role of supervisor to that of a coach, something I experienced as very educative and valuable. Furthermore, I would like to thank my colleagues of the former Business Engineering department for their cooperation and support.

I would also like to thank my university supervisors, Prof. Dr. Fred Langerak and Dr. Myriam Cloodt, for their feedback, advice and the instructive but pleasant discussions.

And last, but certainly not least, I would like to thank my parents, whom I can always count on, and who have always unconditionally supported me in every possible way throughout my studies.

Pim Polman

August 2012
Summary

Reason for this research
In ASML’s strive to supply customers with leading edge solutions, the technologies required to realize new generations of machines become more and more complex and capital intensive. For the next generation machine, the NXE, it has been calculated that more cycle time improvement during the production series is necessary than has been realized in current machines. Otherwise the total worth of the work in progress present in the factory will become too large compared to the turnover, which is a risk.

Research question
From the above follows the problem statement of this research: the planned reduction in cabin cycle time is not realized. This led to the following research question and sub questions to be answered in this thesis:

➢ How can the cabin cycle time learning curve be accelerated 5%?
   a. What are the drivers of the cabin cycle time?
   b. What are the quantified contributions of the drivers of the cabin cycle time?

Scope

- Product Platform: NXT
- Organizational unit: NPI
- Process phases: FASY-TEST-PREPACK

Conceptualization
Because of the intertwining of designing, engineering and manufacturing at ASML, cycle time is this thesis considered analogous to development time. Development time in turn is measure of development speed. This analogy of linking cycle time and development speed is required to make use of the extensive pool of academic literature on the acceleration of new product development processes. From the available literature on this topic the driver framework by Cankurtaran et al. (2012) has been selected as point of departure in the search of the drivers of ASML’s cycle time.
Methodology

Both qualitative and quantitative data have been gathered from 8 respondents that were selected by the principal, half of which with NPI and half with Volume backgrounds. The qualitative data has been gathered through the use of in–depth interviews. The quantitative data has been gathered in the form of 8 scaled score sheets and CT data from the company’s information system. The quantitative data was then used as input for a regression analysis. This analysis was used to make a prediction model that included the most important drivers of ASML’s cycle time.

Results

The model resulting from the regression analysis included one driver: speed emphasis (Equation A). This model can explain 22% of the observed variance in the amount of cycle time improvement, and thus has a modest prediction power. Increasing the emphasis on speed with one standard deviation will benefit the amount of cycle time improvement realized by approximately half (.49) a standard deviation.

\[ \Delta C T_i = \beta_i + \beta_i x_i + \varepsilon_i \]

Equation A: The integral model of cycle time improvement (i = machine number, units in weeks)

Besides the integral model, drivers have been reviewed that did not make it into the model due to sample size constraints. This is done in terms of partial correlations. Different drivers are found for the NPI and Volume phase (Tables A+B). Due to the possibility of shared explained variance, one should primarily look at the significance level: a smaller value indicates a more certain relationship with cycle time improvement.

<table>
<thead>
<tr>
<th>Driver</th>
<th>NPI (n = 16)</th>
<th>Volume (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed emphasis</td>
<td>0.039</td>
<td>-0.607</td>
</tr>
<tr>
<td>Team stability</td>
<td>0.053</td>
<td>-0.516</td>
</tr>
<tr>
<td>Organizational support</td>
<td>0.053</td>
<td>0.380</td>
</tr>
</tbody>
</table>

Table A + B: Overview of partial correlations for the NPI and Volume phases
Conclusions – To accelerate the learning curve it is necessary to do the right things at the right times by making use of windows of opportunity (WO). It is found that the learning curve can be divided into four of these windows, each displaying different cycle time improvement characteristics (Figure A). It was determined that windows 2 and 3 have priority. Based on the drivers found, appropriate actions for both windows of opportunity are provided in the form of recommendations.

Recommendations

- **WO 1–4** — Focus on speed by making shorter cycle times a concrete goal for the entire organization, from start to finish and from high to low (*speed emphasis*).
- **WO 2** — Use the same people for different product introductions; it is important to keep the people together that know how to play the game (*team stability*).
- **WO 3** — Emphasize standardization and formal process use, but match the level of detail with the innovative company culture (*standardization*).
## List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>ASSY</td>
<td>assembly</td>
</tr>
<tr>
<td>CT</td>
<td>cycle time</td>
</tr>
<tr>
<td>DN</td>
<td>disturbance notification</td>
</tr>
<tr>
<td>D&amp;E</td>
<td>development and engineering</td>
</tr>
<tr>
<td>EUV</td>
<td>extreme ultraviolet</td>
</tr>
<tr>
<td>EUR</td>
<td>euro</td>
</tr>
<tr>
<td>FASY</td>
<td>final assembly</td>
</tr>
<tr>
<td>FTE</td>
<td>full time employee</td>
</tr>
<tr>
<td>IC</td>
<td>integrated circuit</td>
</tr>
<tr>
<td>KPI</td>
<td>key performance indicator</td>
</tr>
<tr>
<td>LC</td>
<td>learning curve</td>
</tr>
<tr>
<td>M&amp;L</td>
<td>manufacturing and logistics</td>
</tr>
<tr>
<td>NPD</td>
<td>new product development</td>
</tr>
<tr>
<td>NPI</td>
<td>new product introduction</td>
</tr>
<tr>
<td>PGP</td>
<td>product generation process</td>
</tr>
<tr>
<td>PrePack</td>
<td>preparation and packaging</td>
</tr>
<tr>
<td>TEST</td>
<td>testing</td>
</tr>
<tr>
<td>WIP</td>
<td>work in progress</td>
</tr>
</tbody>
</table>
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1. **Introduction**

This chapter introduces both the company in which the thesis research takes place and the research itself.

1.1 **Company introduction**

This section provides a description of the company in which the research takes place, the way it is organized and what the importance of its products is for the market in which it operates.

1.1.1 **Company Biography**

Advanced Semiconductors Manufacturing Lithography (ASML) was founded in 1984. The company is the world’s leading provider of lithography systems for the semiconductor industry, manufacturing complex machines that are critical to the production of integrated circuits for microchips. ASML designs, develops, integrates, markets and services these advanced systems, which continue to help their customers to reduce the size and increase the functionality of microchips and consumer electronic equipment (ASML, 2012).

Lithography systems image circuit patterns on a thin disk of silicon, called the wafer. This results in hundreds of Integrated Circuits (ICs), also called chips. More defect-free chips allow more profit. Each new lithography development enables more chips to be packed onto a wafer and more functionality per chip. Making smaller chips results in three major improvements:
• Higher productivity for chipmakers and lower costs for consumers;
• Increased performance/processing power;
• Improved battery life of e.g. mobile equipment.

Headquartered in Veldhoven, the Netherlands, ASML operates globally, with activities in Europe, the United States and Asia. As of June 26, 2011, ASML employed 7,697 payroll and 2,159 temporary employees (measured in FTEs). ASML operates in 16 countries through over 55 sales and service locations. Customers include many of the major global semiconductor manufacturers like Samsung, Taiwan Semiconductor Manufacturing and Intel. The rising demand for smartphones, tablets and the latest super-thin personal computers is driving strong sales and new orders. ASML has a 75–80 percent market share. 2011 has been a record year for ASML with revenues of EUR5.65 billion and a net profit of EUR1.47 billion. Most of the revenues result from the sale of a relatively small number of lithography systems with prices of around EUR20–40 million. The mission of ASML is to provide a leading edge imaging solution to continuously improve its customer’s global competitiveness. To succeed in this mission, ASML believes that all its activities must stem from its core values: Quality, Integrity, Trust, Continuity, Excellence and Professionalism (ASML, 2011).
1.1.2 Organizational structure of ASML

ASML is organized in five main divisions: Product, Market, Operations, Corporate Support and Support (see Figure 2). This thesis project has been carried out at the Business Engineering department of the Manufacturing & Logistics sector of the Operations division. During the reorganization of April 2012, the Manufacturing & Logistics sector was divided into platform specific factories: ACE, Wilton, TWINSCAN and EUV. The latter two are located in Veldhoven.

![ASML's organizational chart as of May 2012](image)

1.1.3 ASML’s role in the semiconductor industry

Lithography systems image circuit patterns on a thin disk of silicon, called the wafer. This results in hundreds of Integrated Circuits (ICs) that are also called chips or semiconductors. Semiconductors contain numerous electrical pathways that are capable of connecting up to a billion transistors and other electronic components. These transistors store information on the semiconductors, either by holding an electrical charge or by holding little to no charge.
The process of manufacturing chips consists of many sequential steps, as can be seen in Figure 3. Photolithography (step 5: Exposure) is one of the most important steps in the manufacturing process of chips, as this is the moment where the multiple layers of circuit patterns on a chip are created. Each new lithography development enables more chips to be packed onto a wafer and more functionality per chip. More defect-free chips allow more profit, this means that there are three important performance indicators: imaging, overlay and productivity. These indicators determine the accuracy, performance when shifting between wafers and the amount of output. The expectations and demands in terms of these performance indicators from customers further up the chain are based on Moore’s Law. According to this law the number of transistors in an Integrated Circuit doubles each two years. ASML develops the tools required to follow this development.
1.2 Problem description & research question

This section introduces the problem experienced by ASML and how this is translated to a research question to be answered through this thesis.

1.2.1 Problem description

In its strive to supply customers with leading edge solutions, the technologies required by ASML to realize new generations of machines become more and more complex and capital intensive. For the next generation machine, the NXE, it has been calculated that more cycle time improvement during the production series is necessary than has been realized in current machines. Otherwise the total worth of the work in progress present in the factory will become too large compared to the turnover, which is a risk.

Figure 4: The KPIs influenced by the cycle time

Reducing the cycle time impacts not only the WIP but also a variety of other KPIs (see Figure 4). These KPIs illustrate that the speed of which the cycle time is a measure, is a very important construct. Recognizing the importance of the cycle time, ASML has started a project to look into the cycle time learning curve and establish improvement plans; this thesis was part of that project. This project, called CT Learning Curve Management, aimed to connect three concepts related to the learning curve: the learning curve, the business impact of the learning curve and the influence factors of the learning curve. The business impact of the learning curve had already been determined and resulted in an impact model that can calculate the performance on the KPIs of Figure 4 under a certain learning rate.
1.2.2 Research question

At ASML the cycle time is one of the most important KPIs and this makes it valid to delve deeper into what lies at the basis of the cycle time problems. To do so, a cause and effect tree (Appendix A) has been drafted based on eight interviews with the principal and various business engineers during the first weeks at ASML.

It proved there are two important streams of causes that prevent improvements in the cycle time: the large number of disruptions and the phenomena of ‘reinventing the wheel’. At ASML, historically the most attention has been given to the disruptions and much less to the learning and knowledge issues that underlie reinventing the wheel; so called barriers to learning (Ardichvili, 2008; Wiewiora et al., 2009).

The principal however is interested in getting a clear picture of what the drivers of the cycle time are, in a broader context than these two streams, and referred to the drivers as levers that can be used to actively manage the cycle time development. To simultaneously see how drivers relate to each other, as well as to the cycle time, the ultimate deliverable of this thesis is a model that quantitatively addresses these relations. This model can then be used to realize the target that was set based on the impact model: an acceleration of the learning curve of 5%.

The above led to appointing the following problem as the focus of this project:

The planned reduction in cabin cycle time is not realized.

To tackle this problem, ASML is interested in what underlies the dynamics in the cabin cycle time. This resulted in the following research question to be answered:

What are the drivers of the cabin cycle time?
When the drivers of the cabin cycle time are determined, this knowledge will be applied to create a model that quantifies the contribution of the various drivers. Hence, the associated research question covering the second part of this thesis was:

**What are the quantified contributions of the drivers of the cabin cycle time?**

Together the acquired knowledge and insights should then be used to answer the main research question:

**How can the cabin cycle time learning curve be accelerated 5%?**

### 1.2.3 Scope

To make sure the size of the project remained feasible in terms of the time available for the thesis project, the scope of this project had to be carefully considered. This section elaborates on these considerations.

- **Product Platform: NXT**

  ASML organizes business units around product platforms, as can be seen in Figure 2 where there are separate TWINSCAN and the EUV groups. This meant that in determining the scope the first choice was to select a product platform. There are two breakthrough product platforms that have been worked on in the last few years:

  - **NXT (TWINSCAN)** – Work on the NXT platform started as early as 2005, and the first pilots were started in 2008. The current NXT 2 is the successor of the NXT 1, of which more than 100 units have been produced.
- **NXE (EUV)** – The NXE is the newest product platform. Of the NXE:3100 6 units have been shipped. The NXE:3100 was a pre-production machine for the NXE:3300, of which the first pilots are being built at time of writing.

For the selection of a product platform, it was important that the NXE is very recent and relevant, as the findings of this research will primarily be used in the context of the NXE. However, the aim of this research was to make a quantified model which meant that the availability of system data was a prerequisite. This made the NXT the only viable option, simply due to the availability of data; for the NXE platform too little data was available. The required translation of the findings –from the NXT to the NXE– should prove no obstacle, according to the principal.

- **Organizational unit: NPI**

At ASML there are two separate organizational units responsible for the manufacturing of the machines. There is the NPI organization, that is responsible for building and testing the pilots, and there is the Volume organization, that takes over production when the product and process are stable enough to create the product in larger quantities. Though a focus on the NPI phase is not strictly in line with historic applications of the learning curve, that have mostly been in cases of standardized, large volume products (Yelle, 1979), there are sufficient reasons to primarily –but not exclusively– focus on the NPI phase:

- The cycle times of the NXT machines in the NPI phase, show far more spread around the plotted learning curve than those of the Volume phase (see figure 6). This leads one to assume that the underlying process in the Volume phase is better under control and thus offers less room for improvement.
• In the NPI phase there is still focus on continuous improvement, and thus it has the clearest NPD characteristics. For the Volume phase this is much less so. This continuous improvement can be recognized in the fact that in the NPI phase most structural issues are still solved, this is not the case for the Volume phase. This operational decision is however implicit.
• There is the common sense argument, that when one improves earlier in the process, there is a larger return over time than in case of an intervention later in the process. It also suits well with underlying intent of ASML: to achieve a stable and feasible cycle time as soon as possible.

- Processes: FASY–TEST–PREPACK
As will be explained in the chapter 2, there are three process phases that combined make up the cabin cycle time: FASY, TEST and PREPACK. This is a definition choice made by ASML. Since actual CT data is used in this project, these are also the process phases that are covered in this research. Appendix B contains an analysis of the production milestones, and a breakdown of the cycle time in durations of each phase.

1.2.4 Research introduction
This section describes the purpose and perspective of this thesis.

1.2.4.1 Research Purpose
There are three types of research purposes one can have when engaging in a thesis project. It is important to explicate which purpose is underlying this research project as each purpose has its own set of appropriate designs and methods:
• descriptive research, which aims to describe populations and phenomena;
• exploratory research, which aims to find relationships between phenomena;
• causal research, which aims to find cause-and-effect-relationships.

The purpose of this research is predominantly exploratory. Exploratory research is suitable to investigate relationships between variables or phenomena when little is known about these constructs and how they relate to each other (Van Aken et al., 2005). Typically, exploratory research results in hypotheses or conceptual models or frameworks that can then be investigated further with other types of research. In this project the goal was to come up with a quantified model, based on a limited data set, in a specific company setting, which justifies the choice to call the resulting model conceptual in nature, and the research as a whole exploratory.

1.2.4.2 Research Perspective
The thesis project was carried out from the perspective of the field of innovation management; the author and the supervisors of the Eindhoven University of Technology have a background in this field.

1.2.4.3 Research Approach
The approach that was used in this research consisted out of three phases. First the problem was validated. The purpose of this step was to ensure that the problem actually is a problem and not just a perception issue. After the validation of the problem, the actual exploration of the drivers of the cabin cycle time was carried out. After it had become clear what the drivers of the cycle time are, the third phase was combining these drivers into a model.
I: Validation of the Problem

The validation of the problem was carried out by ASML, as part of the integral project of which this thesis is part. Validation happened through comparing recent learning curves with historic learning curves and determining the business impact of different learning curves. Elements of this validation step are included in chapter 2.

II: Exploration of the Drivers

To determine what the drivers of the cycle time of ASML are, academic literature was used to establish a point of departure. This resulted in the literature review that accompanies the thesis (Polman, 2012). Literature findings were then compared to the practices of ASML.

III: Building a model

Besides a qualitative discussion of the drivers, also quantitative data has been gathered. In this last phase, this data was used to build a model of the drivers relevant for ASML and to validate the qualitative findings through statistical analyses.

1.3 Structure of the report

The structure of this report is as follows. Chapter 2 discusses the most important theoretical concepts that will be required to comprehend the remainder of this thesis. Chapter 3 discusses in detail the methods that were used in this research. Chapter 4 provides an overview of the results found. Chapter 5 starts with a discussion of the outcomes of chapter 4, and then continues with a number of conclusions and recommendations. Chapter 5 closes with a discussion of the limitations of the research and looks onwards to see new avenues of research, as follow ups or extensions of this research.
2. Conceptualization

This chapter is a summary of the literature review and validation phase. It must be noted however, that this chapter can only address the most relevant aspects, and even then in a condensed manner. For additional insights and backgrounds the reader is referred to the literature study that accompanies this thesis (Polman, 2012). Additionally, a list with the most commonly used abbreviations at ASML is included at the beginning of this report.

2.1 The Learning Curve

A learning curve graphically shows the development of a variable like the throughput time or cost per product over a series of products (see Figure 5). Below a typical formula for the calculation of the learning curve can be seen in Equation 1.

\[ Y = K \times X^{\log \theta / \log 2} \]

Every learning curve has a learning rate and a progress rate. Together these sum up to 100%. The progress rate is the percentage of decline in the variable of interest, each time the total number of produced items doubles, and the learning rate refers to the percentage that remains of the former value. For example, Figure 5 illustrates an 80% learning curve, this means the learning rate is 80% and the progress rate is 20%: the average time per unit declines with 20% each time the cumulative quantity doubles.
Historically, the learning rate of ASML has been \(\sim 85\%\) for new product platform introductions. This was not different for the learning curve of NXT product introduction (see Figure 6), for which an average learning rate of \(84\%\) was calculated. This figure was common knowledge at ASML, however during the CT Learning Curve project the NXT learning curve was reexamined. It was determined that the historic use of the standard formula could be improved by differentiating between segments of the learning curve. This approach resulted in a learning curve fit with a 75% segment and an 85% segment. Further experimentation at the beginning of this project also resulted in the discovery of flattening effects, which implied the existence of a third segment.

To create a sense of urgency for the CT LC project, the business impact was calculated for the KPIs of Figure 4. Due to confidentiality, no figures can be provided, but it suffices to state that making insightful that a sharper learning rate of just several percent could have resulted in the production of several additional machines (worth EUR40 million each), ensured managerial attention. Similar calculations underpinned the urgency to improve the learning curve of the NXE.
2.2 Cycle Time

Cycle time is a broad concept that is often also denoted by the more commonly used terms *throughput time* or *time to market*. ASML has defined a variety of cycle times, but in the context of this research only the cabin cycle time (CT) is relevant. The connection with the learning curve is found in the fact that it is plotted over the cabin cycle time of a machine series. The average size of a production series is around 30–100 machines. As can be seen in Figure 7, the cabin cycle time consists out of the throughput times of three underlying process phases:

- **FASY** – Final Assembly is the process of assembling completed modules into a machine.
- **TEST** – At TEST this machine is tested and calibrated.
- **Prepack/pack** – After the final test, the factory acceptance test, a machine is dismantled and packed during the Prepack/pack process and made ready to be shipped.

ASML does not produce any of the components itself; instead they completely rely on a network of suppliers. The components they supply are integrated into modules during the ASSY process, which precedes FASY.

---

**Figure 7: Cycle time definitions at ASML**
2.3 Drivers of cycle time

ASML uses a product generation process (PGP) that is consistent over different product lines (see Figure 8). After an initial feasibility analysis, two phases follow in which the new product is designed. These designs are then used to build a number of prototypes. After several prototypes a number of pilots follow through cooperation with the new product introduction (NPI) organization. After stabilization of the design and building process, the production of machines is transferred to the Volume organization.

![Diagram of Product Introduction and Product Generation Process (PGP - NPD) at ASML](image)

Because of the intertwining of designing, engineering and manufacturing at ASML, cycle time is considered analogous to development time in this thesis. Development time in turn is measure of development speed. This analogy of linking cycle time and development speed is required to make use of the extensive pool of academic literature on the acceleration of new product development processes. From the available literature on this topic the meta-analysis by Cankurtaran et al. (2012) has been selected as point of departure in the search for the drivers of ASML’s cycle time. Comparable studies have been considered as well – most notably Chen et al. (2010) – but the framework of Cankurtaran et al. (2012) was favored for two important reasons:
• Their analysis is more detailed and constructs are more clear and specific;
• Their analysis is based on a wider selection of articles stemming from a more thorough literature search, resulting in more trustworthy measures of effect size and cross situational consistency.

Cankurtaran et al. (2012) forward a framework with antecedents of high development speed. For semantic and conceptual reasons these antecedents are assumed drivers. Table 1 contains an overview of the drivers that were found significant by Cankurtaran et al. (2012), and an explanation of how each driver should be interpreted.

2.4 Two phases of the learning curve
Central to doing the right things is doing them at the right moment. To accommodate this timing issue, a differentiation between phases of the learning curve was needed. Eisenhardt and Tabrizi (1995) provide such a framework, through which the differentiation between phases was possible. They state there are two strategies an organization can follow in case of new product development projects:

• Experiential strategy – which revolves around rapid discovery and building knowledge and understanding to reduce the amount of uncertainty that comes forth from new technologies and products.
• Compression strategy – which is based on having a stable and predictable process that needs to become more efficient.

Because of the resemblance of these characteristics with ASML practice, and the links with both learning and the learning curve, the learning curve for the remainder of this thesis is considered to have two distinct and sequential phases: the first based on the characteristics of the experiential model, and the second based on the characteristics of the compression model.
<table>
<thead>
<tr>
<th>Driver</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardization</td>
<td>Degree to which the machines and processes are standardized</td>
</tr>
<tr>
<td>Formal process use</td>
<td>Degree to which formalized procedures are actually followed</td>
</tr>
<tr>
<td>Supplier involvement</td>
<td>Degree to which suppliers are actively involved in the process</td>
</tr>
<tr>
<td>Customer involvement</td>
<td>Degree to which customers are actively involved in the process</td>
</tr>
<tr>
<td>Goal effectiveness</td>
<td>Consists out of two aspects: the degree to which goals and priorities change frequently (i.e. goal stability) and the degree to which goals and priorities are clearly communicated (i.e. goal clarity)</td>
</tr>
<tr>
<td>Process concurrency</td>
<td>Degree to which work is done in parallel</td>
</tr>
<tr>
<td>Testing</td>
<td>Degree to which the product and its parts are tested</td>
</tr>
<tr>
<td>Cross functional team use</td>
<td>Degree to which teams consisting of employees with different functional backgrounds are used</td>
</tr>
<tr>
<td>Organizational integration</td>
<td>Degree to which there is mutual adaption between various departments</td>
</tr>
<tr>
<td>Teamwork quality</td>
<td>Degree to which team members work together in an effective way</td>
</tr>
<tr>
<td>Team stability</td>
<td>Degree to which the people on the team remain the same during the project</td>
</tr>
<tr>
<td>Team dedication &amp; commitment</td>
<td>Degree to which a person works on different tasks, machines or platforms simultaneously</td>
</tr>
<tr>
<td>Empowering management style</td>
<td>Degree to which an employee is allowed to take decisions or determine the content and order of their own work</td>
</tr>
<tr>
<td>Team leadership</td>
<td>Degree to which team leaders have the strength, expertise and influence to claim resources, hire and allocate people and steer the project</td>
</tr>
<tr>
<td>Marketing proficiency</td>
<td>Degree to which external info is collected and integrated early on in the project</td>
</tr>
<tr>
<td>Technical proficiency</td>
<td>Degree to which employees have the technical know how to carry out their work</td>
</tr>
<tr>
<td>Problem solving proficiency</td>
<td>Degree to which the firm is capable of finding &amp; solving problems in a timely manner</td>
</tr>
<tr>
<td>Team learning</td>
<td>Degree to which learning is present, facilitated, organized or otherwise emphasized</td>
</tr>
<tr>
<td>Availability of resources and facilities</td>
<td>Degree to which FTEs, money, tools etc. are sufficiently provided to carry out tasks</td>
</tr>
<tr>
<td>Organizational support</td>
<td>Degree to which high level managers are visible and actively engaged in the project</td>
</tr>
<tr>
<td>Project priority</td>
<td>Degree to which the project has priority over other projects</td>
</tr>
<tr>
<td>Speed emphasis</td>
<td>Degree to which a short cycle time is a priority</td>
</tr>
<tr>
<td>Company size</td>
<td>The size of the company measured in turnover or number of employees</td>
</tr>
<tr>
<td>Innovative firm climate</td>
<td>Degree to which the firm promotes and allows employees to engage in creative, out of the box activities, even if not directly related to the job</td>
</tr>
</tbody>
</table>

Table 1: Overview of drivers identified by Cankurtaran et al. (2012)
2.5 Hypothesis

After distinguishing the two phases of the learning curve, the drivers of Table 1 could now be allocated to their appropriate phase, based on the characteristics underlying each phase and based on suggestions about the order and hierarchy of the drivers from literature on new product development and change management. The resulting hypothesized allocation is found in Diagram 1, which forms the theoretical answer to the question of which drivers are relevant for accelerating the CT learning curve of ASML.

Diagram 1: Hypothesized allocation of cycle time drivers over the learning curve
3. Methodology

In this chapter the methodology that was used in this thesis project is delineated in detail. The choice of data gathering methods and the design choices made in applying these methods are a direct consequence of the type and intent of this thesis. Considering the explorative nature of this research, gathering and comparing both qualitative data and quantitative data helps to increase the trustworthiness of the findings. The methods used for both the collection and analysis of the data are outlined sequentially in the following sections.

3.1 Data gathering methods: choices & design

To collect the desired information on how ASML decreases its cycle time and what the drivers of ASML are, both qualitative and quantitative data gathering techniques have been used. The qualitative data has been gathered through the use of in-depth interviews that allow collecting first hand experiences from people within the organization. The quantitative data has been gathered in the form of scaled score sheets that needed to be filled in immediately after the interview, and CT data from the company’s information system. Below the data gathering methods and specific design choices for each method are discussed.

3.1.1 In–depth interviews

In–depth interviews – also known as semi–structured interviews – are often used in organizational science because of their usefulness in retrieving experiences or behaviors, opinions or values, feelings, factual knowledge, and personal background (Esterberg, 2002). Since much driver related information is not available as objective system data but resides in people’s heads, this type of information suits well with the kind of information the in–depth interview can retrieve. Another important and mainly practical reason to use in–depth interviews to gather the qualitative data, is found in its
flexibility that allows interviewers to pursue ideas and questions that spontaneously arise during the interview and that could not have been foreseen on beforehand. This possibility to delve deeper into the answers of the interviewee is one of the main advantages of the in–depth interview (Berg, 2009; Esterberg, 2002). This also allows the interviewer to play around with the order of the topics to keep the interview in a natural flow. Another important advantage of the in–depth interview is that it is based on personal contact and attention. This helps as people are more inclined to contribute when they are approached in a personal manner (Webber & Byrd, 2010), and allows respondents to explain their answers or ideas in greater detail, increasing the potential utility. Additionally, conducting interviews face–to–face allows researchers to record expressive or emotive nonverbal responses that indicate the importance of particular questions or topics for respondents. Seeing people’s reactions also may influence the researcher to probe further, ask additional questions or explain a question when the participant does not understand it. However, there are also a few disadvantages of in–depth interviews. Especially in terms of reliability there are issues related to bias stemming from interpretations of the answers given by respondents and the selection of the respondents. In addition to the issue of bias, the use of an in–depth interview and the subsequent analysis is time consuming and it often proves difficult to distill concrete constructs from the collection of answers.

3.1.1.1 Design choices in–depth interview

The in–depth interview is no ‘of the shelf’ method; it needs adaptation to the application setting to ensure a sound application (Webber & Byrd, 2010). In this section the most important design choices underlying the interviews are discussed:
Interview content: interview guide & question phrasing and ordering

An interview guide is a list of topics to be discussed during the interview and that helps the interviewer to focus on the topics at hand without being constrained to a particular format. This freedom helps to tailor the questions to the interview context and to the people being interviewed, for example by adapting the phrasing to the audience. The interview guide used in this research consisted out of a number of questions for each of the drivers and a number of insight questions (see appendix C). This setup intended to discuss for each driver of Table 1 how ASML covers that driver and whether the respondent could provide illustrative examples. After running through the list of drivers, the respondent was asked to select the drivers on which ASML puts the most emphasis and on which the least. Subsequently the respondents were asked whether they could name drivers in place at ASML that were not yet covered in Table 1. In line with what researchers recommend, easier and less threatening questions –like whether or not a driver is considered by ASML– have been asked first, while more advanced and sensitive questions –like where there is room for improvement– have been asked at the end of the interview (Berg, 2009; Esterberg, 2002). These last questions also required more familiarity with the naming and concepts introduced in the first part of the interview; saving them for the last part of the interview thus makes sense.

Interview setting

To make the respondents feel comfortable and get them willing to speak their mind, interviews were held at or close to the work place of each interviewee. All but one interview took place individually; in one interview two respondents were interviewed at the same time. This was a specific recommendation of the principal, motivated by the fact that one of the participants was relatively new in his current function. The individual setup was preferred over group interviews as it provided the interviewee the chance to speak more freely. Since all respondents were Dutch, the interview was carried out in the Dutch language.
Interview techniques used

Several scholars have provided tips that help to make sure the maximum return from the interview could be generated. In line with the recommendation of Berg (2009), the opening minutes of the interview were used for making small talk and outlining the research to the respondents prior to asking questions. Rubin and Rubin’s (1995) emphasis of the importance of demonstrating interest in the participants’ comments by using nonverbal cues, such as nodding and eye contact, and verbal cues and Esterberg’s (2002) focus on active listening, following up, and keeping the conversation going, have all been taking in account. Explicit attention has also been giving to reassuring the respondents that their experiences, thoughts, and feelings are of key importance, and that there is no “right” or “wrong” answer.

Data collection

During the interviews notes have been taken that were subsequently worked out into records covering all the topics discussed. This was done within 24 hours after the interview took place to ensure top of the mind recollection.

3.1.2 Score sheets

The quantitative data of this research has been collected partly from ASML’s information systems (i.e. the actual cycle times of the NXT machines corrected for D&E time and holidays) and a score sheet. On this score sheet each respondent was asked to rate the amount of focus on each driver at various points during the product introduction. This way the development of each driver over time could be made insightful, which is useful as the cycle time is influenced by multiple drivers at the same time. To better understand how that collection of drivers works together, it is important to know how each driver develops over time individually.
To make the development visible, participants were asked to attach scores between 1–10 to a number of machines equally spaced over the NXT series (i.e. #1, 15, 30, 45, 60 and 75) in which 1 is the lowest score and 10 the highest. This was done for each of the drivers of Table 1. The actual score sheet has been included as Appendix D, but for illustration purposes an exemplary scoring exercise is depicted in Figure 9.

<table>
<thead>
<tr>
<th>Machine #</th>
<th>1</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

The scale from 1–10 was used to give respondents maximum flexibility in scoring, while limiting the chances that several drivers would have similar, indistinguishable trend patterns. The machine numbers to rate over the series were picked to have enough data points to crudely determine the development of each driver while not asking the participants to rate too many machines.

3.1.3 Ethical considerations

Ethical issues come into play when the content of an interview or score sheet is private or can have consequences in terms of job security. In this research this was not an issue as the principal was involved in the selection of the participants based on their experience and difference in points of view and ideas. These are easy to attribute to a
certain participant, making it almost impossible to guarantee anonymity in such a small group of people. However, there is no reason to assume this should prove a problem and participants were informed on beforehand that their answers would be discussed with other stakeholders.

3.2 Sample size & respondent selection
The initial selection of the participants for the in-depth interviews followed from a consultation of the principal and resulted in the selection of the 9 participants with extensive ASML experience. Two respondents were interviewed together, making the total number of interviews 8. The same participants that took part in the in-depth interviews were also asked to fill in the above mentioned score sheet, resulting in 8 score sheets. In the selection of the respondents it was ensured that there were an equal number of people from NPI and Volume, making that the two organizational units were equally represented. Since the 8 score sheets each contained scores for 6 cases, the total number of cases is 48 (N=48).

3.3 Feedback from the pilot interviews
The first two interviews functioned as pilots to check the feasibility and adequateness of the interview and the score sheet. It proved that several changes needed to be made to increase the time efficiency of the interview and the clarity of the score sheets.

The first important change was the decision to send the score sheet after the interview and thus no longer fill it in during the interview. The respondents hence had to fill in the sheet without supervision or additional explanation in case of confusion, a method that left room for higher levels of interpretation bias but that did save considerable amounts of time. Moreover, it provided respondents the opportunity to take all the time they needed to complete the sheet, potentially benefitting the accuracy of the answers.
provided. To cope with interpretation bias, a separate manual was distributed containing instructions on how to fill in the sheet and an explanation of how the sheets would be used in this research (see Appendix E).

The second important change was to the order of the set of drivers that was discussed. Initially, the followed order was based on a ranking on effect size of the drivers. It however proved that it was beneficial for the natural flow of the interview to group together similar drivers and discuss them simultaneously. The main reason for this change thus was of a practical nature.

After inspection of the first filled in score sheet, it proved the respondent did not understand all drivers; scores for some drivers were not provided or question marks were placed instead of scores. After a quick comparison of the scores and the interview records it proved that a number of scores were rated in a ‘should be’ manner rather than the desired ‘as is’. To cover the first point, a description of each of the drivers was added that was in line with the description as discussed in the literature study. To cover the second issue, the manual was adapted to make the instructions explicitly state ‘as is’ ratings should be provided.

Besides the inclusion of a description, small changes were made to the list of drivers to be covered and their naming. It proved that the drivers cross functional teams and team work quality gave rise to confusion considering the already extensive number of team oriented drivers. As neither pilot interview had resulted in any recognizable reference to the usage of cross functional teams within ASML this driver was dropped. Similar reasoning was used to drop quality of team work, with the additional note that each respondent was part of a different team, limiting the overall generalizability and thus usefulness of the potential findings for this driver. It also proved that team dedication and commitment was wrongfully interpreted as team motivation, to avoid this from
occurring again the name of this driver was changed into \textit{time allocation}. It also proved that the drivers \textit{customer involvement}, \textit{marketing proficiency} and \textit{supplier involvement}, were more appropriate for the phase preceding the product introduction (see Figure 8) and these were consequently dropped from the score sheet.

For the sake of comparability, the respondents that turned in the first score sheets were contacted a second time with the question to verify their initial answers. This led to a revision of a number of scores, aligning them better with the outcomes of the interview. In turn this is evidence that the revised score sheet was more clear and comprehensible and ready to be used for the other respondents.

### 3.4 Data analysis techniques & steps

The methods and steps used to analyze the collected qualitative and quantitative data are equally important as the methods used to gather the data in the first place. This section describes how both types of data were analyzed.

#### 3.4.1 Analysis of the in-depth interviews

A standalone analysis of the interviews has not been carried out in detail; instead the findings were used as input for the discussion on the results of the score sheets, the model and the recommendations. This input was generated by bundling and reviewing all passages from all interviews related to each specific driver.

#### 3.4.2 Analysis of the score sheets

The analysis of the score sheet data was a process that consisted out of various steps. This section provides an overview and explanation of these steps.
3.4.2.1 Data review

Because the score sheets were returned after the interview had taken place, the consistency of the scores and the answers given by the specific respondent during the interview was checked via a direct comparison of the answers of the interview and the score sheet. In case of discrepancies the respondent was contacted to clarify the deviating score or to provide the missing data.

This procedure was followed by a consistency check between respondents. A certain amount of difference between ratings can be expected simply due to the fact that no two people will judge or perceive a situation exactly the same. Moreover, the respondents work in different parts of the company, so differences in their scores were to be expected. Therefore it was not considered problematic when similar trends were mentioned but with slightly different values (e.g. 8, 7, 7, 6, 6 and 9, 8, 8, 7, 7, 6 were not considered meaningfully different). When scores provided by a respondent had deviating directionality or when a single score deviated more than 3 points from the second highest or lowest score, this was considered problematic. Omission of this data was no option as the sample size already was small; if scores after contacting the respondents still deviated this was accepted.

To limit the influence of extreme ratings, for each driver the sum of ratings per respondent was calculated and the highest and lowest sums of scores had their scores for each machine replaced with the mean of the remaining values. If the highest or lowest sum was shared by more than one respondent, no replacement was carried out as this would have resulted in taking the mean over too few cases.
3.4.2.2 Visualizing the trend line

Before starting with the modeling, the scored data was used to create a visual representation of the development of each driver over time with the help of a trend line. This intermediary step was used to get a better feel and understanding of each individual driver before they were all considered simultaneously in later steps.

To establish a general trend line, the average of the provided scores for each of the machines numbers was calculated for each driver. It can be argued that by using the average, opposite score trends may cancel each other out, potentially resulting in a lack of effect found; yet as discussed above the scores have already been checked and corrected for consistency. It remains true that more extreme trends can get dampened by less extreme ones, yet trying to avoid ending up with a set of indistinguishable trend lines for different drivers was one of the major reasons to include a scale of 1–10 in the score sheet. The averages for each machine number were then plotted in a graph and fitted with a trend line: a 3rd order polynomial equation was chosen to fit a trend line as it served the purpose of a good fit to the data points without being unnecessary complex or allowing overfitting to occur.

3.4.2.3 Multiple regression analysis

Regression analysis was chosen as the technique to determine the quantitative driver model. Regression analysis was chosen as it helps one understand how the value of the dependent variable changes when one of the independent variables is varied, while the other independent variables are held fixed; this fits well with the lever analogy introduced earlier. Generally, regression analysis is used to estimate the conditional expectation of the dependent variable given a certain set of values for the independent variables.
The first step in the analysis was determining the dependent and independent variables. Since the focus of this thesis is on cycle time improvement (the learning curve is grounded in decline over time) it is rational to pick the difference between cycle times of the machines in the series as the dependent variable and the difference in scores of the drivers as independent variables. By taking the difference between scores, the number of cases per score sheet dropped to 5 since the first case has no predecessor, making the total number of cases: 40 (N=40).

The cycle times of the machines were aggregated to match the level of detail of the drivers. The method chosen to do so was taking the average of the cycle times of each interval (e.g. #1–14, #15–29 etc.). Aggregating the most detail rich data was preferred over blowing up the least detail rich data by interpolation; that method would not have added any new information to the data. The independent variables were based on the individual drivers as a factor analysis proved inconclusive. A forward entry method was used since the data set was small and the number of drivers relatively large; this way only the most important drivers made into the model.

After analysis of the full dataset, additional analyses have been carried out on partial data sets, based on the background of the machines. The split between the NPI and the Volume data was at machine number 40, and was based on the actual NXT series. The amount of data did not allow for further differentiation between the backgrounds of the respondents.
4. Results

This chapter provides an overview of the findings that resulted from using the methodology described in the preceding chapter. Both input from the in-depth interviews and the statistical results is provided. In the second section of this chapter an internal ASML publication, *NXT: Lessons Learned*, is used as additional input. This booklet summarizes a number of lessons learned from an earlier NXT cycle time improvement program.

4.1 Integral model

The regression analysis aimed to find the most important drivers of the cycle time as elements of an integral model of the cycle time. The resultant model is shown in Equation 2. This model passed commonly used statistical tests for multi-collinearity and normality\(^1\).

\[
\Delta CT_i = \beta_i + \beta_i x_i + \varepsilon_i
\]

\[
\Delta CT_i = -3.718 - 2.783 \times speed\ emphasis_i + \varepsilon_i
\]

*Equation 2: The integral model of cycle time improvement (i = machine number, units in weeks)*

Only one driver is included in the model: *speed emphasis*\(^2\). Even though there is a single driver included, the model can already explain 22% of the observed variance in the amount of cycle time improvement (Adjusted \(R^2 = 0.22\)). The standardized beta coefficient signals that increasing the emphasis on speed with one standard deviation will benefit the amount of cycle time improvement realized by approximately half (.49) a standard deviation. Further statistical details can be found in Appendix F.

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\(^1\) Durbin Watson, significance of the F statistic, VIF, normal probability plot of the residuals.

\(^2\) The fact that there is only one driver in the model is the result of the final methodology. During the project various other methodologies have been tried, but it proved that the current methodology is the most sound.
In the interviews the emphasis or focus on shorter cycle times has been mentioned in connection to the period at the end of the NPI phase. At this point the responsibilities are transferred to the Volume organization and production is ramped up. After a while the focus on cycle time improvement decreases. This does not mean however that there is no attention for cycle time improvement at all, but rather that other performance measures become prevalent.

These shifts in focus can also be seen in the pictures outlining the development of the various drivers (see Appendix G). When one compares the graphs that display the degree of focus on the drivers and the graph that illustrates the development of the cycle time (Figure 6) it seems that much cycle time improvement is realized by doing the things right from the start, but that gradually there is a shift in priorities that makes that attention is directed away from the drivers responsible for the improvement. This has as a result that the rate of cycle time improvement goes down. It proves from the interviews that there are two kinds of shifts in priorities important in explaining the development of the focus on drivers during the series:

- **Shifts in cycle time reduction priority**

  The initial focus during the series is on getting the manufacturing performance up to specification. When it has been proven that the specification is met, the demand for the machines surges and production is ramped up. Since the goal then becomes to output as many machines as possible, the focus shifts to producing machines faster by reducing the cycle time. When a large number of machines have reached the customer and are operational in the field, the priority shifts to keeping these machines running at high productivity, i.e. the availability.
This is however not the point where priorities stabilize, to the contrary: after these three stages a new product immediately follows. Table 2 shows how stage 3 of the old product is directly followed by stage 1 of the new product, much like a continuous wheel fuelled by ASML’s aggressive technology roadmaps.

<table>
<thead>
<tr>
<th>Shifts in platform priority</th>
</tr>
</thead>
</table>
| At the start of a new platform, that platform gets all the support that is needed to get it running; however during the interviews it became very clear that shortly after a machine has proven to perform up to specification, there is a shift of attention towards new platforms or machine types, often well before the initial product is mature.

The fact that speed emphasis has proven to be important enough to make it into the integral model can thus be explained. The lack of other drivers in the integral model can also be explained as the chosen methodological approach resulted in an integral model that does not include all drivers of cycle time that are relevant for ASML, but only those with an influence large enough to be identified considering the current sample size. Since the intent of this research is explorative, it makes sense to also have a look at the drivers that were close to being included in the integral model. This will be done in the next section.
4.2 Partial correlations: drivers of NPI & Volume

Partial correlations are a measure of similarity in the development of variance between two variables without a correction for other variables, making it a bivariate correlation. This means that if multiple partial correlations are considered simultaneously it is possible that there is a degree of shared variance. The partial correlations in this section can be seen as the upper limit of the unique variance explained in the variable of interest by each of the independent variables. Because of the possibility of shared explained variance this section predominantly looks at the level of significance of the drivers and puts less emphasis on the effect size in determining a driver’s importance.

Partial correlations are the building blocks of linear regression models. The sample size determines how many of these blocks can be correctly identified and included. Significant partial correlations are informative even when the corresponding drivers are not part of the integral model as they can be regarded as the first candidates in line to enter the model when more data would be available. The smaller the value of the significance the more unlikely it is that its relation with the dependent variable is coincidental. As a cutoff point 0.05 is used in industry and most academic research.

The earlier carried out literature review resulted in the hypothesized differentiation between NPI and Volume drivers that was introduced in chapter 2. As explained in chapter 3, subsets of data for the NPI and Volume phases have been analyzed separately. The differences in partial correlations found for the two phases support the suggestion that using different drivers for the NPI phase and the Volume phase is appropriate. Results for both phases are discussed in the next sections.
4.2.1 Drivers NPI

In this section the drivers of the NPI phase will be presented. For each driver in Table 3 a comparison with the hypothesis and the *NXT: Lessons Learned* booklet is provided.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Significance</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed emphasis</td>
<td>0.039</td>
<td>-0.452</td>
</tr>
<tr>
<td>Team stability</td>
<td>0.053</td>
<td>-0.420</td>
</tr>
<tr>
<td>Organizational support</td>
<td>0.053</td>
<td>-0.419</td>
</tr>
</tbody>
</table>

Table 3: Overview of partial correlations in the NPI phase

- **Speed emphasis**

  In the integral model covering both the NPI and the Volume phases, *speed emphasis* already proved to be the most prominent driver and the same is true for the NPI phase. In fact, it is the only driver that has a significance of below 0.05. For further details on this driver in terms of the interview outcomes the reader is referred to section 4.1, where it is discussed at length.

  That *emphasis on speed* is allocated to the NPI phase is not in line with the hypothesis. The reasoning used to place it in the Volume phase was that speeding up the process is more applicable in a setting that is more stable and certain. The hypothesis is thus only partly supported since having it important in two phases was not an option. That the integral model finds it important for both the NPI and Volume phase suggests that it does not suffice to focus on speed temporarily.
The most prominent reference to speed emphasis made in the Lessons Learned is that cycle time should be managed in an integral and proactive manner in which transparency on cycle time issues, target setting and management toward targets are central. This requires strong and influential leaders, support of higher management and sufficient resources. In terms of other drivers, structural cycle time improvement is thus related to goal effectiveness and organizational support.

Team stability

Team stability is an important driver of the NPI phase even though in terms of significance it is a border case. During the interviews, the use of stable teams was recognized by many respondents as helpful. There are three important aspects as to how team stability works out and where it should be taken in regard:

1) Type of task – The work in the NPI phase involves more tacit knowledge, making transfers difficult and inefficient.

2) Amount of transfers – Frequent transfers are considered problematic because they require administration and often are a source of miscommunication. The introduction of complex work schedules with multiple shifts and 24*7 operations directly influences team stability.

3) ‘Players that know how to play the game’ – The third reference to team stability is found in transferring lessons learned and know how: creating organizations from scratch and including many external people or people otherwise unfamiliar with the way of working of ASML will result in major inefficiencies.
In terms of the hypothesis, the find that \textit{team stability} is important just for the NPI phase is misleading. The explanations and examples given by the interview participants with both NPI and Volume backgrounds, clearly underline the importance of team stability. In the Volume phase transfers are a big disruptor that can be tackled with team stability. In the NPI phase the potential of this driver lies more in stability of groups of people over introductions and to a lesser degree within introductions. Again the hypothesis is only partly supported as attributing a driver to two phases was not an option.

\textbf{NXT: Lessons Learned}

A reference to \textit{team stability} is found in the implicit suggestion to emphasize the presence of the same representatives at the progress meetings over time. This suits well with the suggestion made in this research; that by inviting the same people they get acquainted with each other and the ‘game’, making the division and allocation of tasks and responsibilities more efficient.

\begin{itemize}
  \item \textbf{Organizational support}
  
  In terms of significance \textit{organizational support} is also on the borderline, however it is broadly recognized by the interviewees as an influential factor in the amount of focus during daily operations:

  \begin{itemize}
    \item Early on, higher level managers are more visible in the factory and during progress meetings, where their presence helps to make sure that discussions are sharper and people are more eager to take their responsibilities.
    
    \item After a while higher management is predominantly involved in a reactive manner, in particular when things get out of control. Continuous involvement is however considered positive and beneficial.
  \end{itemize}
\end{itemize}
Historically, higher management was involved more closely in the operations, too closely according to some respondents, and this worked adversely. With the growth of the organization the level of detail in which higher level managers were involved in operations declined and the degree of autonomy has since then risen, which is experienced as a positive development. This makes it important to look for a balance in the degree of management involvement.

+ Link with hypothesis +

The hypothesis allocated to organizational support to the NPI phase and is thus supported. To safeguard continuity in this phase, characterized by uncertainty, organizational support by top managers is important to make decisions on which directions to follow, ensure resource availability with regard to the priority the project has relative to other projects, and to make sure that the broader picture is oversighted. Key words here are thus focus and sharpness, support and resources, and very important: visibility and leading by example to ensure buy in.

+ Link with NXT: Lessons Learned +

The term governance is used extensively in the Lessons Learned and contains a link with organizational support and team leadership. Together they explicate the desire to cooperate better by bringing people together and determine responsibilities after setting clear priorities to promote support and commitment. Organizational support is thus important as higher level management is involved to help determine direction and keep track of the bigger picture by discussing progress in daily meetings. This bigger picture is closely related to the goals and priorities the organization sets itself and thus is related to goal effectiveness.
4.2.2 Drivers Volume

In this section the drivers of the Volume phase will be presented. For each driver in Table 4, a comparison with the hypothesis and the *NXT: Lessons Learned* booklet is provided.

<table>
<thead>
<tr>
<th>Volume (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driver</strong></td>
</tr>
<tr>
<td>Goal stability</td>
</tr>
<tr>
<td>Standardization</td>
</tr>
<tr>
<td>Innovative firm climate</td>
</tr>
</tbody>
</table>

*Table 4: Overview of partial correlations in the Volume phase*

- **Goal stability (& clarity)**

Goal stability is a highly significant driver, but according to the results primarily for the Volume phase. Together with goal clarity it is part of the broader concept of goal effectiveness, and that is why these two are considered here together. The input from the interviews was strongly aligned:

  - High level goals – On a higher level, goals are very clear: the NXT, the current flagship, must be sustained wherever possible but the focus is on making the NXE possible, since this platform has to become ASML’s new flagship.
  - Low level goals – On a lower level, goals are much less clear. Respondents mention a dividing line at the director level; from that point downwards goals are either not or poorly communicated.
Further from the fire – In the NPI phase the communication lines are shorter and contact with other direct stakeholders is more frequent. In the Volume phase this is less the case, which makes clear and stable goals very important as the people here are ‘further from the fire’.

+ Link with hypothesis +

The hypothesis is supported in its allocation of this driver to the Volume phase. The underlying reasoning used was that in the Volume phase learning occurs through repeating small sets of tasks often enough to master them. To allow this learning by repetition, it is important that changes to goals and operations are limited, so goal stability and standardization are in that sense related.

+ Link with NXT: Lessons Learned +

In the Lessons Learned there is much emphasis on the use of dashboards and KPIs. Though these are certainly helpful to determine direction and keep people sharp, too many or the wrong ones slow down operations due to a loss of focus. A lot of time is now spent on determining what to measure, how to measure and who will measure, without there always being a direct link with added value for the organization; the earlier mentioned bigger picture. Continuing this course of action will make people and processes more rigid and less flexible, and is again closely related to standardization and formalization.

Ownership is also related to goal effectiveness. If people identify with their goals and acknowledge them, ownership is ensured. A concrete example of creating ownership is found in the creation of an ownership structure for production milestones.
- **Standardization (& formal process use)**

  Standardization proves a highly significant driver of the Volume phase. This driver is inherently connected to *formal process use*. Together these two drivers were often referred to in the interviews as part of the institutionalization of ASML. All respondents recognized this development in their daily work in one way or the other and there was a high degree of convergence in opinions:

  - **Cowboys** – The pilot organization is in general less process orientated. Many respondents describe the people working there as cowboys; corner cutting and inside bends are not exceptional. This cowboy mentality is a typical representation of ASML’s innovative culture.
  
  - **Implementation** – Creating processes and procedures proves easy, but implementing and following them is more difficult. Not only because processes often change, but also because of the attitude towards rules and regulations. This means that *formal process use* lags behind *standardization*. This is now wrongfully interpreted as a need for more formalization.
  
  - **Discussion** – Formal details are often a source of discussion and disagreement which leads to delays and frustration.
  
  - **Process levels** – High level processes are covered in detail, but lower level process descriptions often are inaccurate and incomplete. People are however required to use them in their daily work.

+ **Link with hypothesis** +

The hypothesis allocated *standardization* correctly to the Volume phase, meaning that this part of the hypothesis is supported. In line with the discussion on *goal stability* and ASML’s emphasis on *lean manufacturing*, the tail–heavy emphasis of standardization and formalization is no surprise.
A clear reference to standardization is found in avoiding multiple interpretations and discussions on roles and definitions. The lessons learned explicate a strive for more structure in how operations and processes are carried out, but this is done rather implicitly. The discussion on KPIs also contains traces of standardization but is already more specifically covered in the goal effectiveness section. Interestingly there seems to be no attention for the question just how much standardization is actually compatible with the innovative culture.

- **Innovative firm climate**

Having an innovative firm climate comes out as counterproductive during the Volume phase. It would however be incorrect to conclude from this result that innovation during the Volume phase should not take place because it disrupts stability. On the contrary, it will be beneficial, but predominantly if one has a longer term orientation: innovations in the Volume phase should be carried over and used for new products. That from the interviews becomes clear that ASML is a very innovative company should be no surprise, but there are interesting aspects as to how this manifests itself in the organization:

- Types of innovation – D&E takes care of the design and hardware, making innovation in their area of expertise mostly technical in nature. The operational process is the responsibility of M&L; they do not interfere with the technical aspect of the machine but do innovate in terms of processes.
- Autonomy – In general the culture of ASML allows employees a degree of autonomy. One of the respondents provided an analogy to travelling, the destination is set, but the route is largely open for initiatives on how to get there.
Work pressure – People like to innovate, but work pressure from the direct job responsibilities are mentioned as an important reason of why innovative initiatives are put on hold; any time that becomes available in the schedule is immediately used for these kinds of activities.

Operators – In close accordance with the discussion on whether operators should become button pushers, respondents from the Volume organization often mentioned their frustration with an organization that has little to no regard for initiatives that come from the operators on the floor.

+ Link with hypothesis +

The hypothesis allocated innovative firm climate to the NPI phase. This is not the same as not emphasizing it in the Volume phase as is the current outcome. It is hypothesized to be relevant for the NPI phase because of its disrupting character, which makes it easy to understand that it should be used in a dosed fashion in the Volume phase which—as the other drivers discussed in the section made clear— is more based on conversion and stability. However, as not all types of innovation are strictly disruptive, this part of the hypothesis can be considered inconclusive.

+ Link with NXT: Lessons Learned +

Innovative firm climate has not been covered in the Lessons Learned. This is remarkable as it is an important characteristic of ASML embedded deeply in the company culture.
5. Discussion, conclusions & recommendations

This chapter wraps up the thesis project and draws further conclusions before forwarding a number of recommendations. In the first section the hypothesis will be discussed. The chapter then continues with reviewing the answers of the research questions and subsequently culminates in a set of recommendations.

5.1 Discussion

In chapter 2, the allocation of the drivers of the cycle time to phases of the learning curve that resulted from the literature review, was introduced as the hypothesis of this thesis. It contained the theoretical answer to the question of what the drivers of the cycle time of ASML are. This hypothesis was subsequently tested by comparing it with the division of drivers over the NPI and Volume phases based on their partial correlations and input of the interviews. Table 5 contains an overview of the outcomes of this comparison that was carried out in chapter 4.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Hypothesis</th>
<th>Outcome of thesis</th>
<th>Hypothesis Supported/Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed emphasis</td>
<td>Volume</td>
<td>NPI &amp; Volume</td>
<td>Partly supported</td>
</tr>
<tr>
<td>Team stability</td>
<td>Volume</td>
<td>NPI &amp; Volume</td>
<td>Partly supported</td>
</tr>
<tr>
<td>Organizational support</td>
<td>NPI</td>
<td>NPI</td>
<td>Supported</td>
</tr>
<tr>
<td>Goal stability</td>
<td>Volume</td>
<td>Volume</td>
<td>Supported</td>
</tr>
<tr>
<td>Standardization</td>
<td>Volume</td>
<td>Volume</td>
<td>Supported</td>
</tr>
<tr>
<td>Innovative firm climate</td>
<td>NPI</td>
<td>NOT Volume</td>
<td>Inconclusive</td>
</tr>
</tbody>
</table>

Table 5: A comparison of the findings at ASML and the hypothesis
When reviewing Table 5, the conclusion can be drawn that the allocation of the drivers, based on the characterization of the two phases of the learning curve, was largely correct. Most drivers were allocated to the right phase, but in a number of cases the broadness of the concepts made it difficult to consider a driver inherently useless in one phase and very beneficial for the other. This makes it hard to reject parts of the hypothesis. Overall, there is more evidence supporting the hypothesis than rejecting it.

Even though the conceptual differentiation between phases appears valid, it must be noted that the strict division made between the phases is an abstraction. In reality the carryover period contains an overlap of the NPI and Volume phases, much like an oblique joint. Regardless of whether this transfer phase should be treated as a separate –perhaps hybrid– phase with its own set of characteristics and drivers, in the very least it is worthwhile to look further into how the interface between the phases should be managed given the differences in cultures and characteristics.

What is also very noticeable in Table 5 is that there are no findings for most drivers of Diagram 1. It has already been explained that this is largely due to the small sample size. However, it is unlikely that all potential drivers will prove important for ASML, no matter how large the sample size will be. This means that a number of drivers that have proven useful in other research settings are not helpful for ASML. This hints to heterogeneity of the drivers. Cankurtaran et al. (2012) and Chen et al. (2010) also encountered this phenomenon and introduced a measure of homogeneity: cross situational consistency. Ironically enough the findings for this measure are not consistent between the two studies. This leaves readers with a list of more than twenty drivers and no ‘compass’ or suggestion on which drivers to consider first. It was exactly this that was central in this thesis: finding a method to determine which drivers are important given the particular setting. Though the methods employed in this research succeeded in doing so, not all business practitioners will have the time that was available for this thesis project. To help with the selection of the drivers that are most likely to be helpful in a given situation, a step in the right direction would be to refine the current theoretical frameworks with differentiations on one or more of the following project characteristics:
- **NPD phase** – NPD projects consist of many phases, as was illustrated in Figure 8; even the NPI and Volume phases are only a part of the entire PGP. In this research different drivers have been found relevant for different phases. Cankurtaran et al. (2012) and Chen et al. (2010) however do not differentiate between phases and instead consider as a project from start to finish as a whole. Eisenhardt and Tabrizi (1995) forward two strongly different strategies, but these were originally meant for separate projects and make no mention of the possibility to apply them to project phases. An exception is found in Dröge et al. (2000). Similarly to this research, Dröge et al. (2000) investigate two consecutive phases within one project. In line with the findings of this thesis, Dröge et al. (2000) find differences in the drivers to emphasis in each phase. This can be regarded as evidence for the case made in this thesis: that the timing of the drivers in terms of phases of the NPD project is a very important aspect to consider in applying them.

- **Type of NPD project** – Another issue related to the appropriateness of drivers can be found in the popular differentiation between *incremental* and *radical* innovation programs. In this thesis the emphasis was on the NXT1, which can be classified as a technological breakthrough and thus a radical innovation. Its successor, the NXT 2, is an incremental innovation, while the NXE again can be considered radical or disruptive. Is it appropriate to focus on the same drivers for the NXT2 as the NXT1? This question cannot be answered with the current theoretical frameworks, and should be investigated further.

- **Industry** – Besides the ‘within projects’ and ‘between projects’ nuances discussed above, another differentiation that deserves attention is that between companies and industries. Conflicting finds for drivers in different research settings, gave rise to meta–analyses like that of Cankurtaran et al. (2012) and Chen et al. (2010). These kinds of studies aim to turn the specific into the general. Practical applications of theory –like this thesis– work the other way around, from the general into the specific, and would benefit if it can be made insightful whether certain drivers can be linked with industries or company profiles.
The fact that specific parts of the hypothesis were only partly supported makes a conceptual difficulty apparent: the multi-facetness of drivers makes it difficult to attribute them exclusively to a phase. In the hypothesis, team stability and speed emphasis have both been attributed to one phase because of their fit with the characteristics of the models of Eisenhardt & Tabrizi (1995). Attributing them to both phases was not an option as the differentiation forwarded by Eisenhardt and Tabrizi (1995) was very sharp. However, during this project it proved incorrect to make the equally sharp judgment that a driver is helpful in one phase and not in the other. The work of Dröge et al. (2000) supports this suggestion and finds several drivers important for multiple phases.

The multi-facetness of the drivers is related to the broadness of the drivers’ terminology and the level of detail in differentiating between drivers. In this research many respondents connected and intertwined related drivers and had difficulty discussing drivers in isolation. This raises the question whether a very fine-grained differentiation between drivers is necessary if it results in a larger set of strongly related and hard to distinguish concepts. Instead it would be more practical to have a set of drivers or constructs that are more conceptually different. The fact that neither this research nor Dröge et al. (2000) succeeded in uncovering these constructs through a factor analysis, does not dismiss the need of further scholarly attention for this topic.

5.2 Conclusions & recommendations

Now the results have been presented and the hypothesis is discussed, it is time to bring these outcomes together to answer the research questions raised at the beginning of the project.

**What are the drivers of the cabin cycle time?**

It was made clear that it is of the utmost importance to focus on shorter cycle times during the entire product introduction. This makes speed emphasis the most important driver of the cabin cycle time. For the NPI and Volume phases additional but different drivers have been found: team stability and organizational support for the NPI phase and goal stability, standardization and innovative firm climate for the Volume phase.
The attempt to make an integral model from the above mentioned drivers by making use of regression analysis succeeded to the point of including only *speed emphasis* due to sample size constraints. In itself already a modest amount of variance in cycle time improvement can be explained with this single driver in the model. It proves that increasing the emphasis on speed with one standard deviation will benefit the amount of cycle time improvement realized by approximately half a standard deviation.

Throughout this thesis there has been focus on the effect of timing. Continuing that line of reasoning, it can be argued that to accelerate the learning curve it is necessary to do the right things at the right times, or in other words: make use of windows of opportunity. The right times are in this case the right moments in the learning curve. The right things are the practical implementations of the earlier identified drivers of cycle time improvement. Conclusions for both these aspects follow below.

- **When to act:**

  From the discussion on the priorities of cycle time improvement it follows that the learning curve can be divided into four windows of opportunity, each displaying different cycle time improvement characteristics (Figure 10).

  The goal of acceleration of the learning curve is to establish a short and stable cycle time as early as possible. With the current division of windows of opportunity, it seems there is much to gain by continuing the strong improvement realized at the start of the NPI phase in the second part of that phase as well.

  By the time the Volume phase starts, most improvement should have been realized already, but there is still potential for further improvement. The degree to which the transfer moment of release for Volume (R4V) is effective and successful, determines to
a large extent how much of this potential gain can be achieved in the period immediately following the release for Volume. If in windows of opportunity 2 and 3 appropriate actions have been taken, the remaining cycle time reduction potential for the fourth window of opportunity has been strongly reduced. Windows of opportunity 2 and 3 thus have priority.

**What to do:**

With the priorities in windows of opportunity determined, this section forwards the appropriate actions to be taken in the respective windows of opportunity. These recommendations have been distilled from the interviews and literature sources and have been validated by direct stakeholders.
Recommendations for Window of Opportunity 2:

- **Emphasis on speed**
  - Focus on speed by making shorter cycle times a concrete goal for the entire organization, from start to finish and from high to low;
  - Reconsider the simultaneous timing of the temporary focus on cycle time reduction and the ramp-up for volume.

- **Team stability**
  - Keep D&E people involved until the R4V;
  - Minimize the number of transfers to increase perceived ownership and limit inefficiencies;
  - Use the same people for different product introductions; it is important to keep the people together that know how to play the game.

- **Organizational support**
  - Managers should be present during the progress meetings, but limit their role to supervision and not being directive; act as a referee while the directly responsible people play the game;
  - Managers should ensure support, not only in words, but also in actions and resources: lead by example.
Recommendations for Window of Opportunity 3:

- **Goal stability (& clarity)**
  - Focus on keeping goals, e.g. shorter cycle times or other KPIs, stable and clear. Put more emphasis on the bigger picture (organizational goals) and make individual contributions more visible to help eliminate the adverse micromanagement of islands;
  - Use concepts as mission and vision to pave the road to better understanding and cooperation;
  - Goal effectiveness depends on goal clarity: simply having well picked and stable goals is not sufficient; they should be communicated well throughout the company.
- **Standardization (& formal process use)**
  - Limit the number of design changes and upgrades;
  - Limit the number of processes and do not try to cover everything in a process: focus on the most important basics required to get people going (the *what* and not the *how*);
  - Use processes as guidelines and be flexible;
  - In general: aim for standardization and formal process use, but match the level of detail with the company culture.
- **Innovative firm climate**
  - Continue to promote going the extra mile and thinking out of the box, and make capacity available for initiatives, but be critical about the added value and number of projects;
  - Be more open for input from the operators and other primary process employees;
  - Think long term: if an improvement suggestion is not applicable for the current machine type, it can potentially be used for a successor.
5.3 Limitations

As in any research the specific choices that were made during the project influence the validity, reliability and the limitations that have to be taken into account when trying to apply the findings and recommendations in practice:

- In terms of application the prediction power of the model is not large enough to prove the intended 5% improvement in learning rate.
- The integral model does not include all drivers of cycle time that are relevant for ASML, but only those with an effect large enough to be identified considering the current sample size.
- Drivers were assumed antecedents for semantic and conceptual reasons.
- The number of respondents that has been used to come to the current results was very small, making the influence of each respondent on the outcomes very large.
- The respondents were appointed by the principal and not randomly selected.
- Respondents have been asked to score machines that were not from their respective phase, increasing the potential for inaccuracies.
- The findings cover the specific setting of ASML making it is possible that the finding have limited validity outside the context of ASML or even outside the NXT platform.
- In the conceptualization of the phases a strict division between the NPI and Volume phases has been used, in practice this division less strict, as is also visualized in Figure 8 by the oblique joint.
5.4 Further Research

This thesis uncovered at least two new topics for ASML to be investigated in follow-up (thesis) projects. A direct question that comes forth out of this research is how the interface between the NPI and Volume organizations should be organized with respect to the current outcomes. Another option would be to look into the other windows of opportunity.

To extend, improve or refine the approach used in this research, future researchers should consider the following methodological suggestions:

- Use the same approach but increase the number of respondents – The current approach has more potential but sample size restrictions limit its return. This way the research in only extended.
- Collect driver specific data for each machine – Objective data is more reliable and accurate than the currently used estimations, using this kind of data would make the outcomes more trustworthy.
- Try alternative methods for modeling besides regression analysis – Techniques like system dynamics potentially fit well with large sets of interrelated drivers, but this approach deviates strongly from the approach employed in this thesis, resulting in first having to do a step back in order to advance.

In terms of suggestions for further scholarly research, this thesis has stressed the need for further differentiation of driver frameworks like those of Chen et al. (2010) and Cankurtaran et al. (2012) in terms of phases of the NPD project, incremental vs. radical innovation projects, and whether drivers and industries can be linked. This thesis also explicated the need to find a better balance between the absolute number of drivers considered in the frameworks and the interrelatedness of those drivers.
References


Appendices

Appendix A: Cause & Effect Tree
Appendix B: Cycle time breakdown in milestones & process steps

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Name</th>
<th>Process phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FASY</td>
<td>FASY</td>
</tr>
<tr>
<td>2</td>
<td>FASY</td>
<td>FASY</td>
</tr>
<tr>
<td>3</td>
<td>WS SPM</td>
<td>TEST</td>
</tr>
<tr>
<td>4</td>
<td>WS Dry</td>
<td>TEST</td>
</tr>
<tr>
<td>5</td>
<td>WS Wet</td>
<td>TEST</td>
</tr>
<tr>
<td>6</td>
<td>RS &amp; IL Module</td>
<td>TEST</td>
</tr>
<tr>
<td>7</td>
<td>Optical Coarse</td>
<td>TEST</td>
</tr>
<tr>
<td>8</td>
<td>Optical Fine</td>
<td>TEST</td>
</tr>
<tr>
<td></td>
<td>Slot 1 Upgrade</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Metrology initial</td>
<td>TEST</td>
</tr>
<tr>
<td>10</td>
<td>Metrology Grid</td>
<td>TEST</td>
</tr>
<tr>
<td>11</td>
<td>Metrology Setup</td>
<td>TEST</td>
</tr>
<tr>
<td></td>
<td>Slot 2 COCP</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Stability + CSR + FFAT</td>
<td>TEST</td>
</tr>
<tr>
<td>13</td>
<td>Prepship - GSD</td>
<td>Prepack/pack</td>
</tr>
</tbody>
</table>

Clarification:

Each process phase consists out of one or more milestones (i.e. sub process steps). As can be seen in the cycle time breakdown, TEST is by far the lengthiest process phase of the cabin cycle time (75% for the NXT cycle time) and consists out of the most milestones.
Appendix C: The Interview Guide

Part 1: Introduction

1.1 Introduction of me, the research, the content of the interview and what is expected from the respondent. Additionally, it will be made clear what will be done with the input the respondent provides and again mention the collective feedback session.

1.2 The interview then begins with a number of basic questions aimed at making the respondent feel comfortable and encouraging him to talk freely, e.g.:

- How long have you been working for ASML?
- What is your current job?
- Can you describe your involvement in the NXT project?
- How long were you involved in the NXT project?

Part 2: Drivers from the framework

2.1 The framework is then introduced and one by one the drivers are explained and for each at least the following questions will be asked:

- Is this driver important or covered for ASML?
- How is it covered?
- Can you give examples from practice?
- Is there any data source that you know of that covers this driver?

2.2 After each driver the respondent is asked to fill in a score sheet by providing a rating scaled from 0-10 (0 is least important and 10 most) to signal the importance of each driver for machines #1,15,30,45,60,75.

Part 3: Drivers @ ASML

After all drivers are covered the following topics will be dealt with:

3.1.1 Are there any mechanisms or practices that ASML uses that have not been covered yet? For each example, explain what ASML does and why.

3.1.2 Determine a top 10 of the drivers to reflect their importance for ASML (1 is most important and 10 least).
### Appendix D: Score sheet

<table>
<thead>
<tr>
<th>Driver</th>
<th>How to interpret</th>
<th>Degree to which this is the case for ASML @ machine #</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>team stability</td>
<td>Degree to which the people on the team remain the same during the project</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>time allocation</td>
<td>Degree to which a person works on different machines or platforms simultaneously</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>internal integration</td>
<td>Degree to which there is mutual adaption between various departments</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>strength and influence</td>
<td>Degree to which team leaders have the expertise and influence to claim resources,</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>team empowerment</td>
<td>hire and allocate people and steer the project</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>goal instability</td>
<td>Degree to which goals and priorities change frequently</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>goal clarity</td>
<td>Degree to which goals and priorities are clearly communicated</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>standardization</td>
<td>Degree to which the machines and processes are standardized</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>formal process use</td>
<td>Degree to which formalized procedures are actually followed</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>organizational support</td>
<td>Degree to which high level managers are visible and actively engaged in the project</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>availability of resources and facilities</td>
<td>Degree to which FTEs, money, tools etc. are sufficiently provided to carry out tasks</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>innovative firm climate</td>
<td>Degree to which the firm promotes and allows employees to engage in creative, out of the box activities, even if not directly related to the job</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>problem solving proficiency</td>
<td>Degree to which the firm is capable of finding &amp; solving problems in a timely manner</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>team learning</td>
<td>Degree to which learning is facilitated, organized or otherwise emphasized</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>technical proficiency</td>
<td>Degree to which employees have the technical know how to carry out their work</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>process concurrency</td>
<td>Degree to which work is done in parallel</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>testing</td>
<td>Degree to which the product and its parts are tested</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>speed emphasis</td>
<td>Degree to which a short cycle time is a high priority</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
<tr>
<td>project priority</td>
<td>Degree to which the project has priority over other projects</td>
<td>1 15 30 45 60 75</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E: Score sheet manual

Toelichting op score sheet:

Om te garanderen dat de input die geleverd wordt door het invullen van de score sheet voldoende bruikbaar is, volgt hier een kleine toelichting op de manier waarop de sheet ingevuld moet worden.

De gedachte achter het schema is dat het aannemelijk is dat de mate van invulling of focus op een aantal drivers verandert over de tijd. Om inzicht te krijgen in hoe de ontwikkeling van de drivers eruit ziet heb ik een aantal ijmpunten bepaald in de vorm van zes machines uit de NXT serie. De NXT introductie staat hier dus centraal; wanneer je besluit om een vergelijkbare introductie in gedachte te nemen bij het invullen, maak hier dan een notitie van.

Idealiter dienen alle drivers een score te krijgen voor elke machine. Om de vergelijkbaarheid van resultaten te kunnen garanderen, is het noodzakelijk om een schaal van 1-10 te gebruiken. 10 is hierbij de hoogste mate van waarheid/belang/invulling en 1 de minste. Probeer vooral zoveel mogelijk in te vullen, alleen als je iets echt niet kan schatten moet je het open laten. Er is ruimte beschikbaar voor eventuele opmerkingen, maar je bent niet verplicht om hier gebruik van te maken.

Twee voorbeelden:

- **Team stability:**

  “gedurende de serie zie je duidelijk dat er steeds meer geschoven wordt met mensen om in te springen op nieuwe prioriteiten”

  => de stabiliteit van teams neemt dus over de tijd af

<table>
<thead>
<tr>
<th>Machine #</th>
<th>1</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

- **Formal process use:**

  “hoe groter de rol van de NPI organisatie, hoe minder procesmatig er gewerkt wordt”

  => over de tijd neemt de invloed van de NPI organisatie af en de mate van gebruik van processen neemt dus toe

<table>
<thead>
<tr>
<th>Machine #</th>
<th>1</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
### Appendix F: SPSS Output of the integral model

#### Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>dCTav</td>
<td>-3.99673</td>
<td>5.222722432</td>
<td>40</td>
</tr>
<tr>
<td>team stability</td>
<td>-.800000</td>
<td>.8812707737</td>
<td>40</td>
</tr>
<tr>
<td>team dedication and commitment</td>
<td>-.300000</td>
<td>.5726431942</td>
<td>40</td>
</tr>
<tr>
<td>internal integration</td>
<td>-.433333</td>
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### Model Summary

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a. Predictors: (Constant), speed emphasis
b. Dependent Variable: dCTav

### ANOVA

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a. Dependent Variable: dCTav
b. Predictors: (Constant), speed emphasis

### Coefficients

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a. Dependent Variable: dCTav
Appendix G: Trend line graphs

**speed emphasis**

\[ y = 1E-05x^3 - 0.0021x^2 + 0.0949x + 7.269 \]
\[ R^2 = 0.9776 \]

**team stability**

\[ y = 1E-05x^3 - 0.0015x^2 - 0.0226x + 8.2645 \]
\[ R^2 = 0.9894 \]

**organizational support**

\[ y = 1E-05x^3 - 0.0006x^2 - 0.0688x + 9.4615 \]
\[ R^2 = 0.9947 \]
goal stability

\[ y = -3E-05x^3 + 0.0035x^2 - 0.0421x + 4.4663 \]
\[ R^2 = 0.9984 \]

standardization

\[ y = 3E-06x^3 - 0.001x^2 + 0.1376x + 2.8385 \]
\[ R^2 = 0.9964 \]

innovative firm climate

\[ y = 1E-05x^3 - 0.0012x^2 - 0.0068x + 8.8381 \]
\[ R^2 = 0.9993 \]