A Framework for Implementing Simulation-Driven Design

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Abstract

Simulation-Driven Design (SDD) is an approach where simulations are performed throughout the entire design process with the intention to explore options and guide the user, as opposed to just verify or falsify a design in the later stages of the process. From enabling and promoting early simulation usage by design engineers (DEs), a company can expect to have their lead times reduced, costs cut and quality of products increased. Despite having adopted the technology, companies have yet to adapt their workforce and processes to reap the benefits of proper simulation usage.

The purpose of this thesis project was to develop a framework for implementing SDD in product developing companies, and to investigate its preconditions. Market intelligence on traits of Best-in-Class companies was summarized and aggregated with theory on technology implementation, resistance to change, and change management. The framework was then developed based on this aggregation and consists of four phases: Map, Analyze, Execute, and Review. In total, the phases are made up of 19 stages that focus on processes that enable SDD.

Through interviewing DEs, specialists and managers, it was found that most companies have a lot of room for improvement. The most concerning issue identified was that simulation is not considered an enterprise question, i.e. simulation and enabling processes are rarely discussed. Also, simulation results are handled poorly, simulation is not used in a standardized way, and the communication between DEs and managers is lacking. We believe that if simulation would be an enterprise question, the processes that enable SDD would be developed naturally and the previously mentioned preconditions would not be apparent. Preconditions enabling an implementation were however also found, for example, attitudes toward simulation is positive, DEs would not react negatively to mandatory training, and there is a perceived need for more simulation.

As every company is somewhat different, the framework must not be used as a manuscript, but rather as a guide. It is not a necessity to meet all the stages perfectly, but rather the ones that are most important to the situation at hand. Given the preconditions, the importance and potential benefit of using the framework is evident. We believe the presence of an implementation project based on this framework will suffice to make simulation a big enough topic to thrive and anchor in an organization’s foundation.

Keywords: Simulation-Driven Design, Simulation, IT Implementation, Change Management, CAx, Product Development Process, Working Method
Sammanfattning

Simuleringsdriven Design (SDD) är en process där simulering utförs genom hela konstruktionssprocessen med avsikt att utforska alternativ och vägleda användaren, i motsats till att endast verifiera eller falsifiera en konstruktionslösning i de senare stadierna av processen. Genom att möjliggöra och främja att konstruktorer använder simulering kan ett företag förvänta sig att ledtider minskar, konstnader sänks och produktivitet ökar. Trots att företag har tagit till sig tekniken har många ännu inte anpassat sin personal och sina processer för att skörda fördelarna med effektiv simuleringsochändning.

Syftet med detta examensarbete var att utveckla ett ramverk för implementering av SDD i produktutvecklande företag, och att utforska förutsättningar för implementationen. Marknadsintelligens relaterad till egenskaper hos företag med framstående produktutvecklingsprocesser har sammanfattats och sammanslagits med teori om implementation av ny teknologi, motstånt mot förändring samt förändringsledning. Implementationsramverket baserades på denna sammanslagning och består av fyra faser: Kartlägg, Analysera, Verkställ och Följ upp. Faserna består i sin tur av totalt 19 steg som hanterar processer som möjliggör SDD.

Det framgick i intervjuer med konstruktorer, specialister och chefer att det finns stort utrymme för förbättring. Det mest allvarliga hinder som identifierades var att simulering inte behandlas som en fråga för hela företaget, det vill säga, simulering och möjliggörande processer diskuteras sällan. Vidare hanteras resultat från simulering undermåligt, simulering används inte heller på ett standardiserat sätt och kommunikationen mellan konstruktorer och chefer är dålig. Vi tror att om simulering skulle vara en fråga för hela företaget skulle de möjliggörande processerna till SDD utvecklas naturligt och tidigare nämda förutsättningar skulle inte existera. Förutsättningar som möjliggör en implementation identifierades dock också. Till exempel var inställningen till simulering positiv, konstruktorer ser inte negativt på obligatorisk utbildning och det finns ett upplevt behov av mer simulering.


Nyckelord: Simuleringsdriven Design, Simulering, IT-Implementation, Förändringsledning, CAx, Produktutvecklingsprocess, Arbetsmetod
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Thank you!
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BiC</td>
<td>Best-in-Class</td>
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<tr>
<td>CAx</td>
<td>Computer-Aided technologies</td>
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<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
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<tr>
<td>CAE</td>
<td>Computer-Aided Engineering</td>
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<tr>
<td>CAM</td>
<td>Computer-Aided Manufacturing</td>
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<td>CFD</td>
<td>Computational Fluid Dynamics</td>
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<td>DE</td>
<td>Design Engineer</td>
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<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<td>FEA</td>
<td>Finite Element Analysis</td>
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<tr>
<td>PLM</td>
<td>Product Lifecycle Management</td>
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<td>SDD</td>
<td>Simulation-Driven Design</td>
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Chapter 1

Introduction

1.1 Background

New product development has been identified as one of the most important aspects of a company’s survival (Ulrich & Eppinger, 2012; Clark & Fujimoto, 1991; McGrath, 2004) and the external pressures to develop the product development process are getting higher (Aberdeen Group, 2017). This hardened environment demands a reduction of lead time, higher product quality and a continuously improved process in order for a company to remain competitive (Wheelwright & Clark, 1992).

To aid in the development process, companies make use of a wide variety of different methods and supporting technologies. Some of these technologies go under the name of CAx (Computer-Aided technologies), where CAD (Computer-Aided Design), CAE (Computer-Aided Engineering) and CAM (Computer-Aided Manufacturing) are examples. However, companies remain to fully adapt their working methods to these proven technologies, despite the software having been around for a long time. One such technological tool is simulation, and it is frequently seen in today’s product developing companies’ software portfolios. If simulation is used appropriately, a company can expect to see their lead times lowered (Sellgren, 1994), costs reduced (Pavasson et al., 2014), product quality increased (Shephard, Beall, O’bara, & Webster, 2004) and number of prototypes decreased (Sellgren, 1994). While many companies make use of simulation, far from all do it optimally. (Aberdeen Group, 2017)

There are many ways of using simulation but, in most companies, it is solely used to validate designs in the final steps of the product development process (Aberdeen Group, 2017). This approach often lead to crucial design flaws being discovered late, costing a company time doing unnecessary rework. On the contrary, Simulation-Driven Design (SDD) is an approach that emphasizes simulation usage early in the process, to guide design engineers (DEs) to avoid design
paths inherited by flaws, and thus reach better solutions. As simulation is a key technology of the
future (Aberdeen Group, 2016b), companies now stand before the choice of either adapting their
human workforce to make effective use of the technology, or trailing behind their competitors.
The problem of becoming simulation-driven can therefore be said to be greatly influenced by
the ability of humans to change their working-habits.

Implementing change into already established processes is seldom an easy task (Wheelwright
& Clark, 1992). There are many dimensions to consider when undergoing change (Leonard-
Barton & Deschamps, 1988), for example, the influence of managers on subordinates, types
of resistance to change and ways of communicating change. Also, humans require different
incentives to change. For example, it is not always as straightforward as having managers using
their authority to influence employees. Resistance to change is to be expected and it introduces
more intricacy to the change project (Kotter & Schlesinger, 2008). This calls for a structured
approach to meet the complexity of changing working-habits and improve the chances of success
in the implementation of SDD.

1.2 Purpose

The purpose of this study was to develop a framework for implementing SDD in product devel-
oping companies. Also, we have in the report investigated and presented preconditions for an
implementation of SDD in Swedish industry, as well as traits of companies that use simulation
effectively.

1.3 Research Questions

1. How can Simulation-Driven Design be implemented in a company?
2. What are the preconditions for implementing Simulation-Driven Design in companies to-
day?
3. What are the characteristics of companies that use simulation effectively?

1.4 Delimitations

- The study covers the organizational and operational aspects of implementing SDD, not
  the simulation-technical. Best practices for simulation usage and specific working methods
  in SDD are not presented.
Introduction

- The focus of this study is on simulations performed in a 3D CAD environment. Manufacturing simulation, such as simulation in digital factories was for example not considered.
- The study does not cover the financial aspects of an SDD implementation. Analysis and quantification of costs and revenues are not presented.

The companies that were studied:

- are located in Sweden
- have an in-house product development process
- could make use of linear simulation in the product development process.

As the processes that enable SDD are multifaceted and sometime extend across departments, it could be of interest to study more than just the R&D departments, for example IT departments or HR. This is however left outside the scope as it was deemed too time-consuming to identify the relevant individuals of these departments at each company. Instead, we chose to interview people with the following roles of the R&D department:

- Design engineers
- Simulation specialists
- Product development managers
- R&D managers
- Project managers
- Team managers
Chapter 2

Methodology

2.1 Research Design

The research was based on the following sequence of actions:

1. Literature review
2. Development of implementation framework, based on the literature review
3. Empirical study
4. Evaluation of feasibility and discussion on implementation framework

The work was initiated with a literature review with the intention of providing a foundation of knowledge for the development of the framework and the analysis to come. Then, we developed a framework based on the literature review that was used to develop the interview questions. The empirical study was then conducted in order to discover preconditions for implementing SDD and evaluate the framework. After collecting the empirical data, the feasibility of the framework and the individual phases and stages were discussed with regards to what was found in the interviews. The intention of designing the research this way was to have a resulting framework with a strong theoretical basis that was generalizable while still being specific to the companies that were studied.

2.1.1 Literature Review

The aim of the literature review was to develop our knowledge in the fields of change management and SDD respectively, and to provide a foundation for the resulting implementation framework. The areas of research were mainly: product development, simulation, Simulation-Driven Design, implementation processes and change management. Furthermore, market intelligence studies on simulation and SDD were used to illustrate an ideal state of simulation usage.
As a resource database for the literature, we mainly used Google Scholar, Web of Science and Primo. Keywords and search methods were adapted as the research progressed to find articles relevant to current knowledge gaps. In many cases, to further explore a subject, we identified sources by going through the reference lists of articles that had previously been used. On large subjects such as product development processes and implementation processes, we used sources by reputable authors with a relatively large number of citations. In the cases where an article was deemed relevant but its quality could not be ensured, articles that the study in question referenced to were reviewed. With research on for example SDD, where not much research has been conducted, we made an effort to use research with high esteem, while comparing articles against each other to ensure their validity.

2.1.2 Development of Implementation Framework Based on Literature

The layout of the implementation framework was largely based on theory of planning change implementation, handling resistance to change and IT implementation. Other relevant literature was used to further adapt and deepen the individual stages of the framework. A majority of the resulting stages were derived from the market intelligence studies concerning how prominent companies enable effective simulation usage.

2.1.3 Data Collection

Since our interest was to study the organizational preconditions for implementing SDD in a contemporary setting, a suitable exploratory strategy was to conduct multiple case studies (Yin, 2003). The aim was to get an as extensive as possible overview of the companies’ product development processes while still limiting the number of studies to an approachable level. The selected method of conducting several case studies did limit the scope, but did in turn allow for a deeper analysis than a pure survey would (Yin, 2003). Conclusions were drawn based on the respective companies and from the differences between their environments and situations. This provided a broad empirical foundation to strengthen the resulting framework.

Data from an unpublished internal report written for SolidEngineer, the commissioner of this thesis project, has been used in addition to the empirical data collected specifically for this project. The project took place in the autumn of 2018 and was used as a prestudy for this master’s thesis project. One of the authors of this thesis participated in the prestudy project. In the project, DEs, specialists and managers were interviewed with the purpose of mapping how the companies were using simulation. This makes for a data set that is not entirely comparable to the one that was collected specifically for this thesis. A lot of the data is however transferable and act as an elongation of the empirical data in this report. Some of the interviewees from the previous project were however asked to answer follow-up questions or were interviewed again.
Methodology

In total, 28 individuals were interviewed at 12 companies. By conducting interviews with people of varying roles, we managed to get a holistic picture of most organizations. The idea was to get a deeper understanding of the processes by interviewing DEs, simulation specialists and managers specifically. There were three sets of questions prepared for each of the three roles (see appendix A–C). The questions were prepared in a way that allowed us to get feedback to the framework and through this, investigate its feasibility. Having overlapping questions between the sets allowed us to get different perspectives on the same subject and, validate the the truthfulness of the portrayed organizational situation.

The interviews were conducted with a mixed method approach where the interview contained both a structured part and a semi-structured part. This enabled for a descriptive and comparable data set, but also deeper exploration to get a more qualitative result.

The companies that were contacted were either direct contacts of one of us, or a company that was in some way related to SolidEngineer. There were primarily two ways of acquiring contacts at companies related to SolidEngineer. Firstly, a customer database was used to find interviewees, and some of the ones using simulation were contacted. Secondly, companies or individuals recommended by employees at SolidEngineer whom they had an established connection to were also contacted. Depending on the role of the initial contact, either an interview was booked, or a colleague of them was referred to. Also, after an interview, the interviewee was asked if there was anyone else at the company that could be interviewed. When possible, the interviews were held face to face at the office of the interviewee’s company, otherwise via telephone.

2.1.4 Data Analysis

To organize and analyze the answers from the interviews in order to be able to compare them, close-ended questions were interpreted in a quantitative way and open-ended in a qualitative. The quantitative way being a sheet where answers to key questions were portrayed. The most important aspects were categorized in order to make for a comparable data set. The qualitative notes contained a summary of the interview as a whole, capturing the key aspects and giving a more in-depth picture of the interviewees’ thoughts and perspectives. The data was then analyzed with regards to the respective phases and stages of the framework. Finally, each stage was further clarified and developed based on what was found in the interviews.

Upon answering questions in the interviews, a certain mindset might have been taken on by the interviewees. Hypothetically, they might have thought that there was a certain way that the questions should be answered, either to please the interviewers, or perhaps the company they worked at. For example, if an individual was an inexperienced simulation user, they might have felt questioned and portrayed an untruthful picture. This is a reason why the data from the interviews had to be analyzed very critically.
2.2 Reliability, Validity and Generalizability

To limit the amount of questions open to interpretation, closed-ended questions were asked when possible. However, because of the often different interpretations of a certain phenomena between the interviewers and the interviewee, an answer sometimes needed to be more deeply analyzed than just accepted as was, given the context of this thesis. In some cases, to further investigate the interviewees motivation for an answer, follow-up questions were asked. Also, an effort was made to avoid formulating interview questions that were too leading. This was done in order to let the interviewees answer from experience and tell the truth rather than conforming to what they interpreted as the “correct” answer. Also, given that we were representing SolidEngineer, the interviewees might misinterpret the intentions of the interview, changing their mindset.

Another factor that influences the reliability of the research is that the people whom were interviewed, were often recommended by the individual that received the initial call. It seems reasonable that the receiver would recommend individuals with positive attitudes toward simulation, this cannot however be confirmed. To get a true and reliable picture of a company, individuals who are less enthusiastic about simulation would also have to be interviewed.

Most of the companies interviewed in this study were customers of SolidEngineer that, amongst other things, are retailers of CAX software, and provide courses in simulation and other CAX areas. Consequently, the answers regarding availability of software, education and training might not be representative of the whole industry.
Chapter 3

Literature Review

3.1 The Product Development Process

New product development is crucial to the success, competitive advantage and longevity of producing companies (Cooper & Kleinschmidt, 1986; Clark & Fujimoto, 1991; McGrath, 2004; Ulrich & Eppinger, 2012). It enables firms to diversify, adapt and reinvent their products to either follow a shifting market or create new ones (Narver, Slater, & MacLachlan, 2004). The product development process is the sequence of steps an organization goes through to design, realize and commercialize a product. The generic process generally consists of a structured sequence of operations, i.e. planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up (Ulrich & Eppinger, 2012; Wheelwright & Clark, 1992).

![Figure 3.1: A traditional product development process.](image)

The linearity of the product development process has historically been reinforced by organizational structures, negatively impacting lead times and leading to rigidities in the process (Charney, 1991). The goals of the different operations in the process often differ, for example, DEs might want to design based on usability while those responsible for manufacturing want a product that enables a simple manufacturing process (Sellgren, 1994). When the product is handed over to the next step, the objectives and reasoning behind many choices are often left behind. If the product does not meet some of the requirements of the next stage, it can be sent
back for modification, further increasing the lead time (Wheelwright & Clark, 1992). Therefore, designing it right the first time is an important factor in effective product development.

The design decisions are often verified in terms of structural integrity, manufacturability and ergonomics by physical prototyping. While building physical prototypes gives advantages in terms of verifying designs and discovering flaws, their benefits are often out-weighed by their drawbacks (Ulrich & Eppinger, 2012). Producing complex prototypes further increase time to market (Sellgren, 1994) and lower flexibility of the design (Becker, Salvatore, & Zirpoli, 2005). Errors discovered in later stages of the process are therefore substantially more costly than those made early, if obsolete prototypes must be re-made or discarded. More recently, in order to avoid these shortcomings, a more cross-functional, integrated product development process has begun taking a larger place in industry. The integrated product development process enables better communication and cooperation, and leads to a more effective product development process (Clark & Fujimoto, 1991; Brown & Eisenhardt, 1995).

Despite the importance of designing new products, companies have historically lacked clearly defined processes for the product development. In 1986, Cooper and Kleinschmidt studied 123 companies carrying out 256 projects and found that higher level of coordination between people and departments, in a more formally laid-out process in the product development phase, leads to improvements. Possessing good product development capabilities is however not enough. The development capability must be continuously updated and upgraded to remain competitive in the market over a long period of time, why adopting new technology can be crucial (Wheelwright & Clark, 1992).

Standardized processes is seen by Morgan and Liker (2006) as an important key to product development success. It is mentioned to be beneficial to standardize tasks, work instructions and the sequence of tasks in the process, including downstream processes like testing and manufacturing. By making use of process standardization, concurrent engineering and synchronization of cross functional processes are enabled. The standardization can then be utilized as a basis for continuous improvement. Furthermore, Morgan and Liker (2006) stress the fact that while macrolevel milestones and high-level standardization should be used at company-level, working-level standardization should be used at each individual function.

DEs operate as a bridge between abstract ideas and tangible products, meaning they have a large impact in the coordination of aspects in the product development process (Bucciarelli, 1994). A necessity in a coordinated cross-functional product development process, is for DEs to clarify goals and spread knowledge amongst members of the process (Hong, Vonderembse, Doll, & Nahm, 2005). The responsibility of performing simulation has in the design process historically fallen on simulation specialists. However, a trend that was seen as early as 2006 (Aberdeen Group, 2006) was that more and more simulation is taking place earlier in the design phase by DEs as a complement to the work of the experts.
In their book entitled “Product Development Performance”, Clark and Fujimoto (1991) list three dimensions of product development performance: *total product quality* which includes design quality and a company’s ability to produce the design, *lead time* which is the time from concept to market, and *productivity* which is measured in engineering hours, materials for prototype construction, and other equipment and services used. Clark and Fujimoto further argue that optimizing these functions lead to long-term competitiveness.

### 3.2 Simulation and Simulation Software

Virtual simulation has long existed and its applicability is today spread over many disciplines. Banks (1998) defines simulation as “...the imitation of the operation of a real-world process or system over time” (p. 3). He explains its usability as an indispensable problem-solving methodology that aims to develop an understanding and to provide a picture of a real-world problem. Additionally, simulation is said to aid in asking “what-if” questions about a system as well as aiding in the design process of a system.

In product development, prototyping has long been the go-to method for testing a product’s capabilities. However, since the inception of virtual simulation tools, physical prototyping is becoming less of a necessity (Aberdeen Group, 2014). In today’s industrial environment, many different kinds of virtual tests can be performed to avoid physical tests, with the right competence at hand. For example, Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD).

**Finite Element Analysis:**

One of the most common methods of simulating a model’s durability under strain is through FEA. FEA is a numerical method where a mesh consisting of a finite amount of geometric
shapes is created on a model onto which forces are applied and evaluated (Kurowski, 2011). An illustrative interface showing different levels of stress throughout the model is then generated and can be used by engineers or analysts for evaluation. The result of this type of simulation method can be seen in figure 3.2.

**Computational Fluid Dynamics:**
CFD is used to analyze fluids and thermal transport (Anderson & Wendt, 1995). This can be utilized in areas such as flow simulation in valves and piping, aerodynamics, and heat transportation. The result of this type of simulation method can be seen in figure 3.3:

![Figure 3.3: Example of a flow simulation in a valve (Dassault Systèmes, 2014).](image)

### 3.2.1 People and Software

An issue posed by companies is that the role of the DE and specialist does not overlap, in the sense that they are not using the same software. For example, some of the simulation software used by specialists cannot be used by DEs simply because of the complexity involved with using it (Aberdeen Group, 2006). This poses a problem in that the integrated software and the stand-alone software does not communicate very well, resulting in a less efficient design process.

Due to an increasing demand for a more effective product development process, companies are turning to using consolidated configurations of software (Aberdeen Group, 2015a). This means that software where simulation is integrated into the modelling software is utilized to
a greater extent and the usage of software from multiple vendors is minimized. The purpose of consolidating the software is to simplify the use of simulation in relation to computer aided product development. For example, instead of the DE having to export and import models, an integrated software can handle this on its own. Also, eventual compatibility issues between systems with a consolidated platform become less apparent.

According to another study by the Aberdeen Group (2015b), in the case where a consolidated simulation platform is used, an estimated 16 hours per week per DE are spent performing tasks that are of low engineering value, (i.e. the handling of large files, data transfer, mesh creation etc.). To compare with, an estimated 21 hours are spent with the use of an unconsolidated solution.

3.3 Simulation-Driven Design

3.3.1 How has Simulation-Driven Design Been Defined Through the Years?

Despite seeming quite obvious, defining an exact framework for what the concept Simulation-Driven Design actually implies, is not straightforward. As will be presented, many definitions have been made but only a general consensus can be identified amongst researchers. Karlberg, Löfstrand, Sandberg, and Lundin (2013) provide an aggregated review of researchers’ definitions, some of which will be presented below.

As early as in 1993, Glidden spoke about a simulation-driven approach that rapidly made the then normative prototyping approach to circuit board design obsolete. In figures 3.4 and 3.5 respectively, a process with and without a simulation approach is presented. As can be seen, the simulation-driven approach does not need a redrawing of the schematic capture, in opposition to the prototyping approach.

![Figure 3.4: The old approach to designing boards with prototypes, adopted from Glidden (1993).](image)

In 1994, Sellgren was also among the first to present the concept SDD in writing. In his article “Simulation-Driven Design: Necessity and Feasibility”, he defines SDD as “a design process
where the major functions and related processes are verified and optimized with the support of computer based product model simulations.” (p. 12). Just as Glidden (1993), Sellgren further concludes that the usage of SDD will reduce the need for prototyping. Also, as shall be seen, an interpretation that puts too much emphasis on verification as opposed to exploration, could be misleading for a practitioner.

![Common Database and Framework](image)

**Figure 3.5:** The simulation-driven approach to designing boards, adopted from Glidden (1993).

A few years later in his doctoral thesis entitled “Simulation-Driven Design: Motives, Means and Opportunities”, Sellgren (1999) elongates his previous definition by stating SDD to be “a design process where decisions related to the behavior and the performance of the design in all major phases of the process are significantly supported by computer-based product modelling and simulation.” (p. 4). This definition adds to the previous in the sense that it specifies that simulation should be used in all major design phases, not necessarily just in the end as a tool for verification.

The role of the DE has historically been to just create models, whilst simulations have been performed by specialists (Aberdeen Group, 2014). Some do however say that in order to improve the design process and to become simulation-driven, one must make the DE perform simulations as well. In 2001, Larsson adds his contribution to the discourse. He puts further emphasis on the notion that in order to have a truly simulation-driven work method, you must focus on exploring as opposed to just verifying. He states: “The prototype system facilitates the idea of distributing analysis possibilities from simulation experts to engineers, hereby increasing the usage of simulation in product development. The purpose is to arrive at a simulation driven design rather than a simulation verified design.” (p. 1).

In Larsson’s thesis, it is further mentioned that an area of investigation is where in the design process simulations should be performed. This further showcases the ambiguity of the concept SDD in the past, as there, at the time, seemed to be no stated consensus of when simulations should be performed. Another key takeaway is the importance of the usability of simulation
tools. By making the simulation software easier to work with, Larsson says that DEs are further enabled to adopt the tools.

Adding to Larsson’s notion of including the human aspect of working with simulation, Bylund (2004) argue that an integration of the role of the DE must take place. In the thesis it is stated: “Getting the development process more simulation-driven means that more of the simulation has to be done by the actual DE. This is possible by making the simulation tools more user-friendly and adapted to the problems at hand, as shown in this paper. Also the view of the DE/drafter as a person that only generates geometry has to be changed. The work has to be recognized as the process of going from requirements to a computationally verified solution. The demands on the designer/drafter will change, the ability to design complex shapes will remain and the ability to run integrated analysis programs or even to alter them to better fit the situation will increase.” (p. 154).

Wall (2007) bases his definition of SDD on Sellgren’s (1999) and elongates it. He adds that: “...it is here further emphasised that an approach that can, rather than only verifying solutions that are already decided upon, support dialogues with customers, stimulate creation of new concepts and provide guidance towards more optimised designs, especially in early development stages, should be strived for.” (p. 2).

In 2007, Löfstrand published his doctoral thesis on how simulation was coupled to business decisions and financial aspects. In the article, SDD is — very much like the previously mentioned definition — defined as a process where “...simulations are used before development of the product as a predictive tool rather than after development as a verifying tool. The SDD approach further allows identifying a set of solutions that meets the criteria, thus, in engineering terms supplying evaluated, accepted concepts for the designer.” (p. 164).

Lockwood (2009) puts further emphasis on the aim of SDD being to speed up the design process. He states: “The goal of simulation-driven design is to converge on optimal solutions as rapidly as possible. By exploring diverse concepts early in the process, engineers can quickly understand the design approach that will best meet performance objectives and use that concept to specify detailed design.” (p. 3).

Bocchieri et al. (2013) add to Lockwood’s idea of putting emphasis on increasing the speed of reaching solutions in their book entitled “Design Against Blast”. Bocchieri et al. present a definition of the related area of Simulation-Based Design as “The concept of a Simulation-Based Design (SBD) system is to apply numerical simulation methods that allow for the rapid iterative evaluation of various concepts in the design process.” (p. 164). It is further stated that this system should be able to manipulate features — in this case vehicle geometry, material properties, material thickness and treat types or locations — and provide rapid feedback to the user. A flowchart of this process can be seen in figure 3.6 below.
Karlberg et al. (2013) further identifies four areas of focus from aforementioned researchers’ definitions of SDD. These are presented in the list below.

1. A general definition where the emphasis is put on reducing the number of prototypes used in the process (Glidden, 1993; Sellgren, 1995).
2. Emphasis on SDD as an enabler of faster and better engineering work (Larsson, 2001; Bylund, 2004; Bocchieri et al., 2013)
3. How simulations should be performed (Wall, 2007; Löfstrand, 2007)
4. An aggregated perspective where narrowing down on an as good a result as possible in minimal amount of time is the goal (Lockwood, 2009)

### 3.3.2 Definition of Simulation-Driven Design in this Thesis

Based on aforementioned theory in previous sections, a definition that will henceforth be used has been reached. The definition will be based on answering the questions: How? Why? and By Whom?

**How?**
Performing simulations in the initiating stages of a project is of great importance. However, the benefit of performing simulations at later stages is still significant, why it must be said that they should be performed throughout the entire process.

**Why?**
As a goal of using SDD is to speed up the design process by avoiding errors early in the design stage, crucial to defining SDD will therefore be to include that simulations are to be performed with the intention of exploring and guiding the DE, as opposed to just verify or falsify a design at the end of the design process.
By whom?
As it has historically been the specialists task to perform simulations late in the process, a shift toward including the DEs in the simulation process has to be made. Since it is predominantly the DE’s responsibility to do the early stage modelling, they are the natural choice of performing simulations at this point.

The Definition
The concept Simulation-Driven Design will henceforth be used according to the following definition:

*Simulation-Driven Design is a process where simulations are performed throughout the entire design process with the intention to explore options and guide the user, as opposed to just verify or falsify a design in the later stages of the process. The simulations performed in the early stages shall primarily be done by the design engineer, specialists should only be included in the later stages or whenever the complexity of the computations goes above the competency of the design engineer.*

3.3.3 Benefits of Simulation-Driven Design

In general, the main benefits of SDD are: decreased lead time and time-to-market (Sellgren, 1994; Pavasson et al., 2014; Shephard et al., 2004), lower costs (Zhang, Wang, Chen, & Zacharewicz, 2010; Shephard et al., 2004; Thomke, 1998) and increased quality of products (Sellgren, 1994; Aberdeen Group, 2017; Shephard et al., 2004). SDD leads to the creation of more innovative products that are more likely to work after the first iteration and require much less modification in later stages of the design process. In their study, the Aberdeen Group (2017) discovered a 21% decrease in engineering change orders issued after the product moved into its production stage and a decrease in length of development time by 29% with the usage of SDD. Furthermore, the necessity of prototyping is not as large if an SDD method is adopted. Best-in-Class (BiC) companies saw a 27% decrease in number of physical prototypes after adopting SDD in one study (Aberdeen Group, 2017) and a 35% lower amount when compared to all others in another (Aberdeen Group, 2006). Performance improvements as a result of SDD in BiC companies can be seen in figures 3.7 and 3.8 respectively.

At the same time as products are becoming increasingly complex, the lack of tolerance for design flaws is substantial within the product development process (Aberdeen Group, 2014). According to the Aberdeen Group (2017), this leads to an increased importance of having an effective way of validating design, such as SDD. It is also said that dedicated simulation experts have increasingly become a bottleneck in the design process. So, a shift in work methods and responsibilities in the design process might be necessary. By introducing simulation into the
role of the DE, these bottlenecks can be circumvented. The simulation specialists can instead be used as a consulting or aiding resource in the process.

![Figure 3.7](image)

**Figure 3.7:** Performance improvements as a result of SDD (Aberdeen Group, 2017).

![Figure 3.8](image)

**Figure 3.8:** Effects on product development performance from using SDD (Aberdeen Group, 2017).

Sellgren (1999) further states that an SDD process not only can help to verify properties of design, but it can also provide support to the innovative dimension of engineering. Along the lines of Sellgren, Becker et al. (2005) state that virtual simulation tools do not only decrease development time and cut costs, but also alter the way engineers solve problems. It is argued that when using physical testing, mostly conservative innovation is achieved because previous generations of designs more often will act as a basis for the new. By using virtual simulation tools,
the engineers can observe phenomena in a much more controlled environment, and therefore develop new problem solving abilities that enables more radical innovation.

3.3.4 Challenges to Simulation-Driven Design

In a study conducted by the Aberdeen Group (2006), the main challenges to using SDD was identified. Lack of time was considered the largest challenge. This contradicts the time saving advantages of proper SDD usage. What companies have trouble realizing is that while SDD is more time consuming in the earlier stages of the design process, time is often saved in the later stages of the development due to fewer required iterations. Lack of expertise and complex product behaviour reflect the need of increased training and education for DEs. As a response to these challenges, education, training and best practice documentation has been the major solutions.

Wheelwright and Clark (1992) mention that engineers often prioritize hitting release dates because of perceived pressure from supervisors. This leads to them disregarding problems and defects in the model which leaves a lot of unnecessary work to the specialist in the later stages of the process. As can be seen in figure 3.9 below, a problem that companies experience is that they are understaffed, overburdening the DEs with work. This creates further issues as they do not feel as they have the time to learn how to simulate, which in turn would reduce the lead time and their workload.

Figure 3.9: Perceived level of staffing in product developing companies (Aberdeen Group, 2016a).

The Aberdeen Group (2007) has also found a relationship between company sizes and simulation adoption rates, which can be seen in 3.10. According to them, larger companies tend to adopt simulation a lot slower than the smaller.
### 3.4 Adopting Technology and Working Methods in Organizations

Developing an effective product developing process is not an easy thing to do (Wheelwright & Clark, 1992). The required capabilities are deeply founded parts of organizations and involve everything from strategies, to tools and people. The fact that these capabilities are deeply rooted could bring great advantages, but could also lead to difficulty if attempting to change or improve them. It could be argued that implementing SDD is not comparable to introducing new technology to an organization, since SDD is a working method and that most companies already do make use of simulation tools. It is however in this thesis argued that the introduction of SDD will require getting over technological hurdles, as DEs will be exposed to new software and potentially a new systems infrastructure.

As early as in 1947, Lewin developed a model for achieving social change in group environments. This model was then built upon by Kwon and Zmud (1987) and later aggregated with, the then unpublished, work of Zmud and Apple (1992) by Cooper and Zmud (1990). The model showcases IT-implementation stages with related activities and it can be used to map and analyze an implementation process.

1. *Initiation*

   - **Process:** Active and/or passive scanning of organizational problems/opportunities and IT solutions are undertaken. Pressure to change evolves from either organizational need (pull), technological innovation (push), or both.

   - **Product:** A match is found between an IT solution and its application in the organization.
2. **Adoption**
   - Process: Rational and political negotiations ensue to get organizational backing for implementation of the IT application.
   - Product: A decision is reached to invest resources necessary to accommodate the implementation effort.

3. **Adaptation**
   - Process: The IT application is developed, installed, and maintained. Organizational procedures are revised and developed. Organizational members are trained both in the new procedures and in the IT application.
   - Product: The IT application is available for use in the organization

4. **Acceptance**
   - Process: Organizational members are induced to commit to IT application usage.
   - Product: The IT application is employed in organizational work.

5. **Routinization**
   - Process: Usage of the IT application is encouraged as a normal activity.
   - Product: The organization’s governance systems are adjusted to account for the IT

6. **Infusion**
   - Process: Increased organizational effectiveness is obtained by using the application in a more comprehensive and integrated manner to support higher level aspects of organizational work.
   - Product: The IT application is used within the organization to its fullest potential (Sullivan Jr, 1985).

One additional way of implementing change into the product development process presented by Wheelwright and Clark (1992), is the use of a demonstration project. Ongoing or specifically initiated projects can be used to introduce new skills and tools to realize improvements and changes. The projects will let the organization try out a new method of development directed at a specific product or process in action. The goal of the project is to teach the organization how the methods can be used and demonstrate their possibilities.

### 3.4.1 Success Factors to Adopting New Technology

One important factor companies often overlook when adopting new technology in the product development process is to consider how the technology will affect the existing process and people
(Morgan & Liker, 2006). The technology itself does not always lead to advantages and implementing it into an already defective development system will not help mend its fundamental flaws. Efforts to fit the technology into already existing processes are more important.

The Influence of Management

Karlsson and Åhlström (1997) conducted a case study on a manufacturing company’s change of product development strategy and identified five key lessons to be learned. Firstly, companies should view product development as an important executive area with responsibility for the companies competitive position instead of a specialized staff function. Secondly, market issues should not only affect marketing, but also product development and production. Thirdly, management control systems should consider achievement of set goals in addition to time, productivity, quality and money to avoid a too large focus on time and monetary measurements. Next, a major lesson is to look at the present in the company by identifying its capabilities, what is wanted by the customers and what is technologically possible for the company. The final lesson involves seeing product development as an issue for the complete firm, not only the directly related product development department, i.e. making it an enterprise question (cf. Aberdeen Group, 2015a) and the importance of having cross-functional meetings.

Rivard, Pinsonneault, and Bernier (1999) mean that the potential results gained from using an IT tool is very much dependant on how it is used. They further mention that having an engaged management, a clear vision and a good understanding of IT and its potential impact, to be success factors when implementing IT tools. Furthermore, Nutt (1986) concluded that managers who are determined to implement a new technology are more likely to provide, for example, technology training, user support, hardware and software accessibility and effectiveness. Also in 1999, Laughlin discussed the implementation of Enterprise Resource Planning (ERP) and also identified having an engaged management to be an important factor for success. In 2001, Klein et al. evaluated two success factors for implementing new technology, namely “Management Support” and “Financial Resource Availability”. In the study, it is concluded that both of these factors have a positive correlation to an implementation project’s policies and practices (e.g. training, user support, rewards for technology use, and high-quality hardware), but also to the implementation climate.

Leonard-Barton and Deschamps (1988) further comment on management’s influence on the adoption of new technology in organizations. It is said that the authority that manager’s possess is sometimes counteractive when trying to influence employees to adopt an innovation. Whether an individual adopts an innovation or not is further concluded to depend on who this individual is and whether they are compliant to authority or not. Leonard-Barton and Deschamps say that “In complex organizational environments, characterized by highly decentralized decision processes, increased professionalization of subordinates, freer communication,
and looser structure (Lawrence and Lorsch 1967; Thompson 1965), persuasive messages issued by a competent person (Galbraith 1995) or members of the social system (Mcguire 1985) could be more effective and less costly (Fidler and Johnson 1984) than formal authority’s attempts to influence subordinates’ attitude and behavior” (p. 1254). They further say that implementing an innovation that is of high complexity, i.e. when a large portion of an organization must use it in order for it to be beneficial, is a process of internal diffusion. Worth noting is that a manager’s decision to implement a new technology is not always sufficient, many secondary adoption decisions are made by end-users after the initial authority decision is made. In figure 3.11, the dynamics of an individual deciding whether to adopt a technology or not, can be seen.

![Figure 3.11: Model of individual innovation adoption with interaction of individual and managerial determinants, adopted from Leonard-Barton and Deschamps (1988).](image)

According to Milgram (1965), an employee’s perception of their own competence and capabilities as greater than their manager’s, might cause them to diminish the legitimacy of how they perceive a message from them. In the case of technology implementation, requests from a manager to adopt an innovation might result in fewer instances of adoption in an organization, should above-written be the case. Along the lines of Milgram, Daft (1978) argues that skilled employees sometimes do not feel as the management’s knowledge of technological innovations is good enough to judge whether it should be adopted or not. This is however somewhat opposed by Zmud (1984) who argues that management’s influence on adoption of innovation is greater in technological settings than in administrative.

Leonard-Barton and Deschamps (1988) further state that the more skilled part of the population is not as dependent on managerial nudges to adopting new technology as are the less
skilled. It is said that in the case of skilled individuals, the diffusion process is very much like it is outside of organizations, i.e. word of mouth and perceived easy access to the technology are primary factors for diffusion. The authors put further emphasis on the need for easy access for these kinds of individuals. However, the less skilled individuals will await a managerial message and do not appreciate the easy access to the same extent. It is speculated that when implementing new technology, management might want to firstly provide a working infrastructure and advertise the usage of the new technology. When this is done and the early adopters have begun using the technology, management’s focus should turn to the late adopters and motivate them to use the new technology.

The SDD Champion

Despite not being entirely clear to which extent management’s influence on innovation adoption amongst employee’s reaches, it has been concluded that influential individuals play a key role in these situations. For example, Chakrabarti (1974) writes about the importance of having a so-called “champion”, in new product development. A champion is, according to Tanenbaum et al. (1966), defined as “...an individual who becomes intensely interested and involved with the overall objectives and goals and who plays a dominant role [...] through some of the stages, overcoming technical and organizational obstacles and pulling the effort through to its final achievement by the sheer force of his will and energy.” (p. 15).

Additionally, Chakrabarti presents six key characteristics of a Product Champion:

1. Technical competence
2. Knowledge about the company
3. Knowledge of the market
4. Drive and Aggressiveness
5. Political astuteness

As the list provided above is based on a definition of product champion and not SDD champion as is the object of this thesis project, only some of the items can be used in defining an SDD champion. The technical competence of a product champion is said to be important “to be able to realistically assess [the product’s] technical limitations and advantages.” (Chakrabarti, 1974, p. 61) In the case of SDD, knowledge of simulation and SDD is of importance in order to be able to assess how and when simulations are to be performed, given the specific circumstances of the company. Just like in the case with product innovation, implementing SDD will require a champion to possess great knowledge of the company where it is supposed to be implemented. Knowledge of the market is however a trait that is not fully applicable to an SDD champion as there is no real market related to the implementation of SDD. Drive and Aggressiveness is a trait not exclusive to a product champion, but should be a trait of any champion. This
is because pushing ideas, getting work done, making decisions, confronting adversaries and withstanding resistance are tasks that need to be done by all champions. Political astuteness will also be important as SDD champion since the political aspect will always be present in any type of change project. Chakrabarti also present data from 45 projects where the cases where champions could be identified yielded a positive result, while the cases where no champions could be identified yielded less positive results, see figure 3.12.

<table>
<thead>
<tr>
<th></th>
<th>No. of Relatively Successful cases</th>
<th>No. of Less Successful cases</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases where the presence of product champions was identified</td>
<td>16</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>No. of cases where the presence of product champions could not be identified</td>
<td>1</td>
<td>27</td>
<td>28</td>
</tr>
</tbody>
</table>

**Figure 3.12**: Identification of product champion in 45 cases (Chakrabarti, 1974).

Chakrabarti also mention that the champion mainly act in three different roles, namely, stimulator, initiator and legitimizer, which are defined by Rogers and Shoemaker (1971) and can be seen in figure 3.13.

Howell, Shea, and Higgins (2005) further identify three key areas that an innovation champion excel in:

1. Expressing enthusiasm and confidence about the success of the innovation.
2. Persisting under adversity.
3. Getting the right people involved.

Roure (1999) further summarizes definitions of product champion and concludes that there is a wide spread between them. This puts further emphasis on the fact that the role as champion is complex and not always easily specified. With this said, identifying a suitable SDD champion will therefore be a complex task that will need to be adjusted to the specific situation at hand.

Roure (1999) also argues that the hierarchical level of the champion will greatly influence their ability to interest top management support, which could be beneficial as the top management primarily possess the authority to make changes. It is further said that a champion on a higher hierarchical level will have closer to the top management and is therefore more likely to create interest.
Literature Review

Figure 3.13: Collective decision process (Rogers & Shoemaker, 1971).

Adopted from aforementioned studies, the interpretation of a champion’s qualities in this thesis, to fit a champion in an SDD implementation project, can be seen in the list below.

- Knowledge about simulation and SDD
- Knowledge about the company
- Drive and aggressiveness
- Political astuteness

3.4.2 Challenges to Adopting New Technology

In their article entitled “Information Technology Implementation Research: a Technological Diffusion Approach”, Cooper and Zmud (1990) argue that in order to reap the benefits of an IT solution, organizations need to have full control over the processes of implementation, signaling a need for a structured approach. Furthermore, it is said that it is necessary by the management to recognize critical issues that need to be handled during the implementation process.
On another note, Mirvis, Sales, and Hackett (1991) argue that conflict and reluctant compliance of users might be a drawback of strict top-down control and troubled relations between management and workers when introducing new technology. There usually exists a gap in the perception of the need for change between managers and employees. Conflict can arise over disagreement of reasons behind change, severity of current problems and internal competition for capital. Mirvis et al. further state that education is key for developing a knowledge for the affected workers about the technology and its advantages to improve their perception of the costs and benefits of the implementation. A study on the implementation of CAD-software in British engineering firms (Arnold & Senker, 1982) showed that there existed many learning difficulties. It is also mentioned that best practices in productivity took an average of two years from the initial CAD implementation to be achieved, signifying the difficulty in implementing certain software.

O’Connor, Parsons, Liden, and Herold (1990) list three takeaways from Mitchell, Rediker, and Beach’s (1986) framework for how the relationship between management strategies and tactics, and implementation objectives are impacted by human response to technological change:

1. Clear specification of implementation outputs or objectives.
2. Systematic analysis, planning and execution of implementation inputs.
3. Explicit understanding and management of human responses to technological change.

They further mention that the objectives of the new technology need to be clearly articulated and presented to the organization. Furthermore, the authors state that the individuals directly responsible for the implementation should be closely guided by senior managements’ specification of project priorities. Adding to this, Becker et al. (2005) mean that introducing new technology not only is a technical matter, but an organizational and management task as well.

Kotter and Schlesinger (2008) say that including the influenced employees in the design of the change is a good way of implementing change. However, they also present the constraint that this is only applicable if the influenced individuals possess the right amount of knowledge on the subject that is the change. In the case of SDD, perhaps only a few individuals of an organization possess the right amount of knowledge. Worth noting is however that there are several aspects of implementing SDD. The technical aspect (performing the actual simulation), is known by primarily specialists, but knowing when simulations are to be performed and by who, is also important. This knowledge is not necessarily possessed by any single employee in an organization why defining the degree of employee involvement in an SDD implementation is not straightforward.
3.4.3 Resistance to Change

When implementing new technologies, not all the affected individuals will have a positive attitude toward it. Some will adopt the technology, but some will be avoidant or even resist it. In 1950, Zander presented his article “Resistance to Change — its Analysis and Prevention”. In the article, it is stated that six factors that influence the resistance to change has been identified, these are listed below.

1. If the nature of the change is not made clear to the people who are going to be influenced by the change.
2. If the change is open to a wide variety of interpretations.
3. If those influenced feel strong forces deterring them from changing.
4. If the people influenced by the change have pressure put on them to make it instead of having a say in the nature or the direction of the change.
5. If the change is made on personal grounds.
6. If the change ignores the already established institutions in the group.

Furthermore, three ways of avoiding resistance to change is according to Zander (1950) by encouraging:

1. participation in discovering the need for change
2. free discussion of obstacles
3. group planning to affect these changes.

Lawrence (1969) is one of the earlier to criticize the notion of subordinates “resisting” technological change, and provides an alternative explanation and perspective. It is argued that it is not the technical aspect that creates the issues, but rather the social ones. In an example provided in the article, Lawrence presents two scenarios taking place in a production environment where a different way of working is communicated in two different ways to a worker, by two different people. In the first episode, the one to introduce the new way of working was familiar to the operator who did not mind the change. In the second episode however, a new person was introducing the new working method without much explanation of why this was done, yielding a poor result. The explanation to this is that in the first episode, only a technical change was introduced, whilst in the second example, a technical and a social change was introduced. This made the operator feel uncomfortable which lead to a different, more negative, reaction to the change. The summary of the example can be seen in figure 3.14. It is further stated that the operator did not resist the technical change as such but rather the accompanying change in their human relationships. When implementing SDD, a focus on how the changes are communicated to the involved employees can therefore be concluded to be of great importance.
In their article from 1986, Hyclak and Kolchin investigate technology implementation in a manufacturing company. It is concluded that worker involvement is important when implementing new technology because of two reasons. Firstly, through engaging the workers and having them participate early on in the process of the implementation, direct and indirect resistance to change is avoided. Secondly, by having the workers involved in the design process of the implementation, the phasing-in period will be much smoother and more rapid.

Kotter and Schlesinger (2008) further provide a framework for planning a change initiative, which can be seen in figure 3.15. It is stated that different types of change projects call for different strategies for implementation, with regards to speed of change, level of resistance, and employee involvement. The further a strategy is located to the left in the strategic continuum, the more crucial it is to have a clear deployment plan and less involvement of employees. These fast changes leave no room for resistance, and is often accompanied by a coercive way of handling it. To the far right of the continuum, the opposite can be seen. A slower process allows for a less planned deployment with more involvement of employees in the beginning of the change. It is said that this kind of change project often result in low resistance amongst employees.

Kotter and Schlesinger further state that inconsistent strategies, i.e. the ones that do not follow the specified relations in the continuum, tend to yield poor results. They showcase this by saying: “...efforts that are not clearly planned in advance and yet are implemented quickly tend to become bogged down because of unanticipated problems. Efforts that involve a large number of people, but are implemented quickly, usually become either stalled or less participative.” (p. 8).
Kotter and Schlesinger then move on to discuss the situational factors and their implications to a change project’s position on the continuum.

- The amount and kind of resistance that is anticipated.
  A greater resistance calls for more diplomatic way of managing a change project as the implications of combating the resistance will be too great.

- The position of the initiator vis-à-vis the resisters, especially with regard to power.
  An initiator with more internal power has more influence and can thus be situated more to the left, whereas an initiator low on the hierarchical ladder or with low internal power must keep to the right.

- The person who has the relevant data for designing the change and the energy for implementing it.
  If the initiator feel the need to obtain information and commitment from others to aid the change, they must move to the right of the scale.

- The stakes involved.
  If an organization is in a state of impending peril and a change project can influence this, one must move to the left of the scale.
It is further stated that a common mistake often caused by managers is that they try to move too quickly and avoid involving people, causing them to not consider key information that is possessed by others. It is also said that most change projects are not clearly a left or right sided affair, and that the initiators have some freedom to choose approach. It is recommended that staying as much as possible to the right is probably the better option as it has fewer economic and social drawbacks. Also, forcefully imposing change on people can have both short-term and long-term side effects. The different approaches to handling the resistance to change can be seen in figure 3.16.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Commonly used in situations</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education + communication</td>
<td>Where there is a lack of information or inaccurate information</td>
<td>Once persuaded, people will often help with the implementation of the</td>
<td>Can be very time consuming if lots of people are involved</td>
</tr>
<tr>
<td></td>
<td>and analysis.</td>
<td>change.</td>
<td></td>
</tr>
<tr>
<td>Participation + involvement</td>
<td>Where the initiators do not have all the information they need to</td>
<td>People who participate will be committed to implementing change, and any</td>
<td>Can be very time consuming if participators design an inappropriate</td>
</tr>
<tr>
<td></td>
<td>design the change, and where others have considerable power to</td>
<td>relevant information they have will be integrated into the change plan.</td>
<td>change.</td>
</tr>
<tr>
<td></td>
<td>resist.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilitation + support</td>
<td>Where people are resisting because of adjustment problems.</td>
<td>No other approach works as well with adjustment problems</td>
<td>Can be time consuming, expensive, and still fail.</td>
</tr>
<tr>
<td>Negotiation + agreement</td>
<td>Where someone or some group will clearly lose out in a change,</td>
<td>Sometimes it is a relatively easy way to avoid major resistance.</td>
<td>Can be too expensive in many cases if it alerts others to negotiate for</td>
</tr>
<tr>
<td></td>
<td>and where that group has considerable power to resist.</td>
<td></td>
<td>compliance.</td>
</tr>
<tr>
<td>Manipulation + co-optation</td>
<td>Where other tactics will not work or are too expensive.</td>
<td>It can be a relatively quick and inexpensive solution to resistance</td>
<td>Can lead to future problems if people feel manipulated.</td>
</tr>
<tr>
<td>Explicit + implicit coercion</td>
<td></td>
<td>problems.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.16**: Strategies for handling resistance to change (Kotter & Schlesinger, 2008).

Kotter and Schlesinger then provide a step-by-step guide for managers to improve the success rate of their change projects, which is presented below.
1. **Analyze the organization.**
   Map out the current situation, the problems and their potential causes. Specify the importance of solving the problem and the speed with which these have to be addressed to avoid further problems. Also, try to generalize what kinds of changes are needed.

2. **Analyze factors that produce and enable the change.**
   Put emphasis on identifying: 1. who might resist the change, why and to which degree, 2. who possesses the required information to design the change and 3. who is good to cooperate with and the required position relative to others (e.g. power, trust, modes of interaction etc.)

3. **Select a change strategy.**
   Based on step 2., conclude which speed of change is appropriate, how much preplanning is needed, the degree of involvement of others, select specific tactics assigned to various individuals and groups, make sure that it is internally consistent.

4. **Monitor the implementation process.**
   Despite rigorous planning, unexpected events will occur, that is why careful monitoring is required in order to identify eventual problems as soon as possible.

### 3.5 National Differences in Organizations

In 2005, Lubatkin et al. published their article entitled “Origins of Corporate Governance in the USA, Sweden and France”, where corporate governance is compared and discussed. It is concluded that Swedish corporate governance primarily is based on norms of collective responsibility and voluntary compliance, France’s is based on norms of self-interest, and the US’ is based on norms of self-interest, opportunism and enforced compliance.

As stated by Leonard-Barton and Deschamps (1988), some people are not that susceptible to managements’ instructions. Based on the work of Lubatkin et al. (2005), it can be argued for that in order to implement new technology in Swedish organizations, it may be needed to engage more than just the management to a larger extent than in, for example, the United States.

In Hofstede’s (1980) influential work, cultural dimensions of different nations are discussed. One of these dimensions is called “power distance”, which is a measure of existence and acceptance of differences in hierarchy and power. In 1993, Shane discovered that nations with a high score on the power distance dimension are more likely to prefer putting emphasis on managers to diminish resistance to innovative change. As Sweden has a low score on the power distance scale, this is perhaps not necessary to the same extent.
3.6 What Does the Best-in-Class Do?

The Aberdeen Group has conducted a substantial amount of market research on the subject of simulation and SDD (2006, 2014, 2015a, 2015b, 2016a, 2016b, 2017) and have identified traits of the Best-in-Class (BiC) companies. To establish a foundation of what lagging industry might need to do in order to become simulation-driven, the following paragraphs will present research of what the BiC companies do, based on aforementioned studies.

BiC companies according to the Aberdeen Group (2015a) are firms that are the top 20% in meeting product goals in terms of time, cost and quality and has decreased their length of product development the most over a two-year period. Companies classified as BiC see greater advantages of simulation in the early stages of the design process than other companies (Aberdeen Group, 2017), as seen in figure 3.17. Additionally, the companies located around the mid 50% are denoted as “Industry average”, and the bottom 30% as “Laggards”.

In a report from 2015a, the Aberdeen Group write that to support DEs, who are a limited resource in most companies, some companies are emphasizing further collaboration between DEs and specialists in order to capture knowledge. Implementing simulation governance tools is also a method used by some in order to learn from previously performed simulations and to document a best practice. Furthermore, additional benefits can be seen should there be a standardization of simulation interface in the simulation tool. The thought of this being to ease the use of simulation to the less experienced. In figure 3.18, the top actions to improve product assessment can be seen.
Literature Review

To further increase the effectiveness of simulation in the early stages of the design process, education and training is provided for DEs. What separates BiC firms from all others is a focus on specific examples rather than generic ones and training materials to combat the lack of expertise. (Aberdeen Group, 2006)

The Aberdeen Group saw that in 2006, all BiC firms used simulation in the design phase of product development, while the utilization for Laggards was at 78%. Additionally, 36% of BiC firms used simulation software embedded within CAD application and the same proportion used simulation software that handled files transferred from CAD software, while no BiC companies exclusively used independent software. 27% used a combination of all options. All others on the other hand, used less embedded simulation software and transferred fewer files from CAD to other software and some companies used only independent simulation.

While BiC companies issue fewer change orders from products after the design phase (Aberdeen Group, 2017), 96% measure the number of change orders issued, compared to 62% for all others, as an indicator of the quality of the conducted simulation (Aberdeen Group, 2006).

As can be seen in figures 3.19 and 3.17 respectively, usage of simulation in the early stages of the modelling process is a trait of BiC companies. Simulation of system-level, detailed component design and sub-system behaviour and interactions in these early simulations have proven effective for BiC companies. It enables trade-off analyses and determination of optimal system architectures and optimization of design.
In one of the studies, the Aberdeen Group (2015a) investigated the view of simulation amongst managers of BiC companies. It was found that, in comparison to how they value, for example, Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP) and CAD, they view simulation as an independent enterprise decision, as opposed to just a part of an overall system.

According to the report from 2017, specialists are outnumbered by DEs in today’s organizations. Since specialists are the ones to primarily perform simulations, this has caused problems as they have not been able to perform these simulations in the early stages of the design process. As a result of this, 50% of BiC companies are turning to pushing simulation to the DEs as a corporate initiative. As can be seen in figure 3.20, senior management of BiC companies is supporting and monitoring deployment of simulation to non-experts.

The Aberdeen Group (2017) further states that the expertise of CAE specialists in BiC companies is captured through the collaboration between DE and specialist. This is said to ease the deployment of simulation in the early stages of the design process. It is also said that BiC companies capture simulation best practices and, through this, make modern simulation techniques more accessible to non-experts.
Below is a list that summarizes the characteristics of BiC companies and their usage of simulation:

1. BiC companies emphasize collaboration between DEs and specialists. (Aberdeen Group, 2017)

2. BiC companies use simulation during the early stages of the design process. (Aberdeen Group, 2006; Aberdeen Group, 2017)

3. BiC companies use simulation software to analyze component and system-level, as well as sub system interactions before physical testing. (Aberdeen Group, 2015a)

4. BiC companies use a consolidated simulation platform to a greater extent than all others. (Aberdeen Group, 2015a; Aberdeen Group, 2015b)

5. Engineers in BiC companies are provided with simulation tools integrated in the CAD software. (Aberdeen Group, 2006)

6. BiC companies provide training and education for DEs. (Aberdeen Group, 2006)

7. 96% of BiC companies measure the number of change orders issued after the product has moved from the design phase. (Aberdeen Group, 2006)

8. BiC companies push simulation to DEs. (Aberdeen Group, 2017)

9. BiC companies’ management support and monitor deployment of simulation to non-experts. (Aberdeen Group, 2017)
10. BiC companies capture simulation best practices through customized simulation workflows and make it available to non-experts. (Aberdeen Group, 2017)

11. BiC companies’ managers view simulation as an independent enterprise decision, as opposed to just a part of an overall system. (Aberdeen Group, 2015a)
Chapter 4

The Situation at the Companies

4.1 Description of Companies and Interviewees

In this section, a brief description of the interviewed companies is presented. As can be seen in the table below (4.1), interviews were held at companies of varying sizes. Primarily DEs were interviewed, but also managers and specialists. It should be noted that some of the interviewed individuals had multiple roles, simultaneously acting as for example DE and manager. The size of the departments where the interviewees worked at was quite similar between the companies, independent of the size of the company as a whole. The products of the companies vary a lot, ranging from small medical devices to large industrial apparatuses. The need for and benefit from using simulation was however apparent in all twelve companies.

4.1.1 The Structure of the companies

There seems that there are many ways of configuring an organization of DEs and simulation specialists. Depending on the perceived needs, some companies opt to integrate the specialists into the group of DEs, while some have decided to separate the two. At one company, it was said that they previously had a specialist department located in a different geographic area but that this has changed, and they are now located in the same building. The reason behind this was to try to simulate earlier in the product development process and avoid making mistakes. One DE also states that the more complex simulations are outsourced to a consultancy firm, as they feel as these simulations are not performed frequently enough to develop the competency to handle this in-house.
4.2 The Product Development Process

In general, the product development processes at the companies begin with a product specification. The process is then in many cases split into stages or gates, where the end of each stage marks the beginning of the next one. This kind of process is often referred to as a stage-gate process (see figure 4.2). In order to move on, it needs to be ensured and shown that the product adheres to its specification and meets the set criteria decided in the initiation. Between the companies, these stages and requirements are either more or less defined. One manager in a company with a relatively strict process did however mention that smaller projects sometime omit some of the less important stages in order to cut down on development time. In one company, a DE claimed that the product development process was unclear and was decided on a
The Situation at the Companies

project to project basis by the DEs responsible for the specific product. Analyses to guarantee quality of the product were however done.

![Figure 4.2: An example of a stage-gate process.](image)

Some interviewees worked with incremental development of already existing products. In one case, the development was initiated by the marketing department identifying a demand for improvement or modification of a product. Then, a specification document was developed, which was further used to determine what resources and competence would be needed to carry out the project, and available DEs were assigned. Another company only worked with development of one single product and was in the process of developing a fourth iteration of this product. This company used a stage-gate model that was continuously developed and adapted as the product generations went by.

A large majority of the interviewed companies had a documented development process. Some large companies had overarching documentation covering the whole organization, while one smaller had clear documentation for the department working with incremental development of products while the department for new product development had none at all. It was made clear by some interviewees that while there was a documented and standardized process in place, the DEs were not well informed of it and only followed its main points. Furthermore, managers seemed more inclined to answer that there was a documented process, while DEs were more restrictive.

Only one company, making single components to fit in larger systems, had no documentation of the product development process at all. The process begins with either a drawing of a requested part or a request based on the complete design of the product. A DE stated that every engineer has their own style of development, but they are working toward a better documented and standardized process. In one company, a manager claimed that they had a documented process while the DEs said that they did not. Instead they often went with their “gut feeling” and used whatever method they deemed effective.

A large variety was seen regarding the systems infrastructures in the development processes of the companies. Most interviewees claimed to not have a working infrastructure. Especially
troublesome was handling simulation files, where almost exclusively reports were saved in project folders, simulation-models were seldom saved and made available to others. Usual problems that occurred include trouble finding the information you are looking for, not everyone utilizing the system, and poor documentation of simulation results. PDM systems were in some cases used to document information about products, but simulation results were exempt from this standard. Some of the interviewees also added that the process of sharing results does not work very well and could be improved significantly.

4.3 The Roles of DEs, Specialists and Managers

4.3.1 Design Engineers

DEs spend a varying amount of time with CAD software. Some estimate to spend only 20% while others claimed to spend 50% or more of their time with CAD software. Several DEs also had other responsibilities apart from design work, while still holding the title of DE, such as administrator or project manager, or was seen as more of an expert in a certain area.

All interviewees answered that they believed to have too much to do based on their current workload, and among them, several mentioned that the workload varies over time. All but one of these said that this does affect how much they use simulation and how much they attend courses. Some said that it affects them, but not so much, whilst others said that being short on time is a big problem.

Eleven out of fourteen DEs use simulation themselves in some way. In general, it lies on the individual to decide if they want to make use of simulation software or not. Half of the interviewed DEs did however believe that they do not have sufficient knowledge of simulation to perform it well enough.

All the interviewed specialists answered that they perform some simulations that they believe DEs are able to perform with their current knowledge and skills. In the same vein, all specialists saw value in having the DEs using simulation to a greater extent than they currently do and that not much training would be needed for it to be beneficial.

4.3.2 Simulation Specialists

Every company but one worked with some sort of simulation specialist. Companies where the development department was large or where the need for simulation was especially high often had a department specifically devoted to simulation, while others had one or a few specialists, or outsourced the activity to external parties. Uniformly between all specialists was that they
mainly use dedicated, stand-alone simulation software. Furthermore, two out of the three asked believed that they have too much to do.

The most common work process of simulation specialists starts with a request of some kind, sent from a DE, and ends with a report being sent back. No simulation files are being transferred, only visual and descriptive reports covering the most important result. Furthermore, only half of the interviewed specialists claimed to have a documented and standardized work process.

4.3.3 Managers

While all interviewed managers held a leadership role, some variance was present in terms of titles. Four managers had a more project management-oriented role while six had a more senior, higher-level role. One manager also held the title of specialist. Most were however the DEs primary manager but held additional responsibilities, and some also carried out design work themselves.

Out of the nine DEs who were asked, five said that their closest manager had good knowledge of how they were working, while three answered that their managers had some or little insight and one claimed they had none at all. Furthermore, two DEs said that their manager had direct influence on how they carried out their task, while the rest said that they had little or none at all. All DEs answered that their manager had enough technical knowledge to understand the tasks they carry out while three answered that they were lacking when it came to simulation.

4.4 The Attitudes at the Companies

4.4.1 Attitudes Toward Simulation

When asked about the attitude toward simulation at the company, an absolute majority of the interviewees answered that it is positive. Two of them did however mention that the attitude is neutral, or that there is no attitude at all since simulation has never been a topic of discussion at their company. One of them also said that a while back, the management was a bit more skeptical but that was not the case today. Another DE described a situation where some DEs are positive, whilst others are negative. This was believed to have to do with age, that the young are more positive than the more senior. A similar case can be seen at another company where a manager said that the majority of the DEs have a positive attitude toward simulation, the only skeptics are the ones who find it tedious to learn new software. At yet another company, three DEs are positive toward simulation usage and a manager claimed that the R&D-management is positive as well. However, one DE said that the management has never discussed the subject
of simulation with them. Upon being asked whether there is any difference in attitude toward simulation between DEs and management, no manager seems to be aware of any major ones. Also, all but one of the asked managers said that there are some individuals at their companies that are significantly more positive toward simulation than others. Who this is, is however not univocal and examples of these individuals are: the project manager, the specialists or certain DEs. Even though many interviewees said that the attitude toward simulation at the company is positive, it was said that it is not a topic that is widely discussed, i.e. it is not an enterprise question. For example, it was said that the management simply has not discussed the subject with the DEs at all, along with other instances of poor communication.

Of the asked DEs, all of them said that they have a positive attitude toward the usage of simulation. Also, a clear majority answered that they would benefit from using it even more than they are today. One DE did however say that they would not benefit from simulating more, simply because there is no need for it. Upon asked whether they would benefit from performing more complex simulations, the DEs answered a concordant “No”. It was only in two interviews that DEs said that it could potentially be positive. One of them mentioned that this would however require training and close communication with the specialists to conclude a reasonable knowledge level for the DEs to strive for. Most DEs also said that the benefit received from learning more simulation would not be large enough to make up for the time spent in training.

The DEs were also asked what would be needed in order to make them simulate more, and the answers varied. Three of them answered that time is an issue; when you have already learned one way of working, you do not want to spend time learning another. Also, performing simulations is not prioritized when deadlines are getting close. Furthermore, they expressed that they would need more time to be able to try simulation out and better get to know the software and the techniques. Three of the DEs answered that a greater need for simulation in a project would ease the implementation of simulation. This is because they feel that simulation is used too seldom; they learn it once, and then forget about it. One DE further said that if the management was to push and showcase the benefits of simulation to a greater extent, they would want to learn and use it more. One DE also answered that they would need to know that the simulations yield reliable results, they simply do not believe in it as it is. One last DE, who is a keen simulation user, expressed a need for simulation to be more fun to perform, that is the only way to make this DE simulate more.

When managers were asked what the reasons as to why the departments do not use simulation to a greater extent, one third answered a lacking need for simulation. The same amount of managers answered that it is a question of habit, while other reasons were: lack of resources, not enough gained benefit while comparing it to invested time, and a need for someone to push for it. What would be needed to increase the simulation usage in the product development
process apart from directly counteracting the reasons was: higher competence, more people knowledgeable in simulation software, and clarification of the advantages of using simulation.

Upon asking whether there should be anyone responsible for the processes surrounding simulation, the answers varied from both managers and DEs. Some answered that simulation is a natural part of the design process and that having someone responsible would not lead to anything positive. Others felt quite the opposite, that it has to be documented and structured. One DE said that solely having someone appointed as responsible would suffice, no matter who this is. The quality department, the head of design, a project manager or a DE are examples that were mentioned. There was also a majority that answered that someone in a managerial role should have this responsibility. One manager did however say that, in the end, it should be a mutual responsibility.

4.4.2 Attitudes Toward Changing

An integral part of changing is learning new things, however, the responses to these kinds of questions are handled in the section entitled “Training” below.

Most of the DEs respond that it would be positive if the management was to promote and push simulation usage. Several DEs also commented that it is a matter of trustworthiness; if a manager is to push simulation, they should be knowledgeable. One DE did however answer that it would just be tedious if the management was to push simulation usage, since everyone does not enjoy performing simulations.

Upon asking where the initiative to change should come from, the answers differed depending on the role of the interviewee. The DEs tended to put the responsibility on the management, with a slight majority saying that such an initiative has to be established at a higher level. One DE said that if it does not come from a manager, people will start questioning and thereby hinder the implementation. More than 50% of the DEs also added that it is important that individuals with technical knowledge, for example DEs, should be involved in the process. Some DEs also did say that it should be documented in a process or in the project specification to get peoples’ attention. One of the DEs also said that the more experienced DEs should take the initiative, as they possess the technical knowledge. Two DEs also mentioned that the quality department could be involved and one of them also mentions the marketing department.

On the contrary, the managers portrayed a picture where the DEs play a more central part. A majority of the asked managers thought it to be best if the initiative came from beneath, founded in the interest of the DEs themselves. One manager said that their department has a lot to do, this is why the question of having the DEs simulating more has not yet been handled. Also, this manager did not think it is reasonable to have an initiative come from higher up in
the organization than himself, the best solution would be to have the DEs take the initiative with support from the manager. Only one of the managers said that a manager should be responsible, in this case they think it should be a project manager. Half of the specialists also said that it takes a manager to get the impact required. It is also commented that simulation would have to be manifested at management level, but that it would also be very helpful if it was established in the process documentation. The other half answered that it should be up to the project manager or specified in the projects’ documentation. Two interviewees also added that, to get the acceptance of a majority, one needs to have a lot of involvement from the very beginning.

A majority of the DEs answered that they do not feel as if their managers are actively pushing them to perform simulations. At the same time, some of them did however feel as if the management, in general, wanted them to simulate more. However, eight out of ten managers mentioned that they push DEs to use simulation, either by encouraging or telling them. Only one DE answered that their manager pushes them to cooperate with and learn from the simulation specialists. It is said by one DE that they think that the specialists want the DEs to perform more simulations. Upon probing the specialists, four out of four said that they see the benefit of having the DEs simulating more.

### 4.5 How the Companies Work with Simulation

The products developed by the interviewed companies are to a large majority advanced enough to benefit largely from simulation. The rest are deemed to be less complex, but would still benefit from using it, although to a lesser degree. Out of the interviewed companies, all of them use simulation in some way. Furthermore, all companies but one answered that they use FEM in their product development process. Of the more uncommon simulation methods, three departments made use of drop tests, four used vibration simulation, while seven made use of flow simulation and six heat simulation.

Of the companies that had a documented product development process, five claimed to include simulation, while six did not. Furthermore, two companies claimed to be using simulation in a standardized way, and the rest believed it would be possible to do so even though they were not at the time. Seven out of all the companies claimed to make use of simulation early in the product development process, while six exclusively use it later on in the process. Of those who simulate early, most make further simulations throughout the whole process. Many companies use simulation as early as in the concept phase, based on the knowledge they have of the product at the time. In one company, it is mentioned that they use simulation to a large extent early in the process to choose one version out of a few to carry on with. Of the companies that were
asked, three out of eight also, to some extent, use simulation to choose between several design options at some point in the process.

As previously stated, out of all the companies where interviews were held, all but two made use of a simulation specialist at some point in the product development process. One company outsourced the service to an external party, and one hired consultants to do the job on-site. Despite the major use of specialists, DEs use simulation to some extent in all companies and of the DEs who were interviewed, ten did and three did not use simulation software themselves. The collaboration between DEs and specialists vary between the interviewed companies. In the companies where the simulation specialists reside close to the DEs, the cooperation is generally communicative and less defined, while those that outsource or have entire departments dedicated to analysis have systems of formal requests and reports. No simulation files are transferred between the DEs and specialists, only reports that either are saved in the project directory or PDM system, or presented orally to the DEs. Furthermore, half of the asked managers claimed that they push for cooperation between DEs and specialists but only one out of five DEs said that they experience this. When asked if simulation software was available to DEs who wanted to use it, a majority answered yes and the rest were uncertain.

As mentioned, the cooperation between DEs and specialists was mainly informal. In several companies, the communication is open and the DEs have the opportunity to ask specialists for an expert opinion when assistance is needed. In other companies, the specialists’ contribution is exclusively structured and request/report-based. Furthermore, all asked DEs and specialists answered that specialists only rarely are sent models where a lot of rework is discovered. Additionally, the specialists were asked whether they saw the benefit in having the DEs perform more simulations, and all of them replied that they did. It was also mentioned that they sometime receive poorly designed models from the DEs that could have been avoided by the usage of simulation. One specialist said that the DEs at their company do sometimes bring them models that need tedious rework that could easily have been avoided if simulation had been used.

All interviewed simulation specialists use stand-alone software and mainly use simulation with the goal of verifying designs made by DEs. In addition, half of the specialists claimed that they also simulate early on in the process for exploration of possible designs.

### 4.6 Training

Learning and further improving ones knowledge as a DE seem to be a rather straightforward process, according to the answers received. In many cases it is simply a question of asking your manager if you can partake in a seminar or take a course. Many interviewees answered that they attend courses at SolidEngineer, as they are their CAD-supplier. These forms of training are
also the most common at the companies. A few interviewees also said that at their respective companies, internal training, learning on the job and from the senior engineers are primary ways of developing and capturing knowledge.

A clear majority of the companies seem to have no standardized way of educating their employees, and the initiative to educate oneself predominantly comes from each individual. Managerial intervention did however appear in the form of performance appraisals with the employees, these often take place once each year. At one company, a manager did however say that they have a training process where DEs have to take courses throughout the year to pick up new methods of using simulation. It is further stated that they should not only learn about simulation, they should also master them. To which degree this is actually achieved is however unclear. At another company, each employee has a personal development plan which to some extent acts as a standardization of working with training. One DE did however say that there are mandatory courses that each employee must take upon employment at the company. A different DE stated that there exists certain mandatory courses, however none related to the usage of simulation.

Opinions on the way of handling training at the companies are few. It is however stated by one DE that creating a policy concerning training would be beneficial. It is even said that “even a policy that is against Simulation-Driven Design would be a policy”, nudging a need for structure and managerial initiative. At another company, a DE complained that it would be of interest to the organization to have managers showcase the benefits of performing simulations. It is further stated that the engineers at the company want to deliver a good result, but they feel that they do not have the time to learn new simulation tools and methods. It is strongly believed that if the managers would emphasize simulation usage, more people would want to develop their skills and knowledge in this area.

Adding to this, some of the interviewees felt as it would be a good thing if certain courses became mandatory. They said that most DEs would feel chosen, in the center of things, that the management take interest in what they do and that they would feel endorsed. One DE did however say that it would not be a good thing if the DEs had to take mandatory courses as some individuals simply are not interested in doing and learning new things. The fact that some individuals would react negatively was further emphasized by a manager at the same company.

When asked if they think that them pushing the DEs to learn to perform simulations would be responded to positively, only one of the managers answered that they did not. This manager further said that it is not an easy job to motivate all the DEs to want to learn. They were also asked if they would expect a different response if, instead of them, a DE were to push the other DEs to learn to simulate. All of them answered that the response would be positive in this case as well. Two out of the five respondents said that the response would probably be even more positive.
The Situation at the Companies

In the cases where applicable, most managers said that they do not actively encourage a learning collaboration between specialist and DE. One manager said that it simply is not necessary, because it happens naturally. Another manager at a company with a specialist department separate from the group of DEs, said that they do not emphasize a learning collaboration, but that they probably should. A specialist at the same company did however emphasize that the DEs should try to learn from the specialists. At yet another company with a specialist present in the group of DEs, a manager claimed that they do in fact emphasize a learning collaboration, but not very actively.

All of the asked DEs and managers consider training to be easily accessible; if you want to learn something, you seldom get turned down. It is commented that certain external courses are not scheduled very frequently, this was however not considered to be a major problem.

All of the asked DEs also felt as if they have too much to do. They also added that this affects how frequently they attend courses and spend time learning new things. It is also said that it affects how often they perform simulations, it is commented that it sometimes takes too much time to set up simulation models. Upon asked if the benefit from performing simulations is worth the time spent learning how to, all but one of the DEs answered no.

One DE mentioned that retaining a standardized working protocol is problematic as the young individuals tend to increase their knowledge in simulation by watching unofficial tutorials online. This is said to be positive as they can learn quickly when they need to, but at the same time negative as it cannot easily be standardized and best practices cannot be captured.

4.7 Continuous Improvement

A slight majority of the managers said that they do document best practices in some way, the extent to which this is done and how often they are updated is however not clear. It is however obvious that there is room for improvement in this matter. One manager said that their company recently started documenting it, two others said that they have certain guidelines, but only where they feel it is called for. Furthermore, only one, perhaps two, of the companies where the managers work, measure some kind of product development performance. One manager said that they do sometimes measure the length of projects and the quality of the delivered product, but this is not standardized. Another manager said that they think certain Key Performance Indicators are measured, but they are not entirely certain.

When asked if their company work to continuously improve their product development process, all the managers respond that they do. The most common answer was that they have a “Lessons learned”-stage after a project is finished. It is also mentioned that certain documentation is
continuously updated, as well as best practices. One manager said that they are working to become better at this very aspect and to have it standardized.

When the DEs were asked if best practices are documented, all but one answered that they do not. One of the specialists did however say that they do, after a project is finished. Simulation best practices are unanimously said to not be captured.
Chapter 5

The Implementation Framework

The outline for the framework is based on the factors provided by Kotter and Schlesinger (2008) for reducing resistance to change and the model for IT implementation by Cooper and Zmud (1990), i.e. the lists provided on pages 31 and 19 respectively. The reason to why these are chosen as the outline for the framework is that they highlight two important perspectives of IT implementation: handling of resistance toward change and the sequence of actions. Handling resistance to change is important as working methods of the companies often are deeply rooted (Wheelwright & Clark, 1992) and changing these might cause upset that needs to be taken care of. With this said, an appropriate plan of action with a well-thought-out sequence is of importance. For example, placing the SDD education early in the process, before simulation training, is necessary as it would otherwise cause resistance (Zander, 1950; Kotter & Schlesinger, 2008; Mirvis et al., 1991). Furthermore, most stages of the framework are constituted by the BiC company traits from the section “What does the Best-in-Class do?”, on page 35. Further relevant theory from the literature review has been used to strengthen the individual stages of the framework and their respective discussions.
Figure 5.1: A framework for implementing Simulation-Driven Design.
5.1 Presentation and Discussion of Stages

Map

Map the Organization

Mapping the organization is important to do in order to get all the required information that is needed for the implementation of SDD. The objective of this phase will be to document the current product development process as a whole, the design process, the roles and tasks of DEs and specialists, the systems infrastructure and how it is used, education, and simulation usage. The following guide should therefore be used to map the organization:

Figure 5.2: A guide to mapping the organization.
The Implementation Framework

Analyze

It will be necessary to have full control over the implementation process and to identify critical issues (Cooper & Zmud, 1990). Also, necessary technology will need to be adapted to the specific organization, why organizational knowledge is crucial (Morgan & Liker, 2006) and there will be a need for systematic analysis when implementing change (O’Connor et al., 1990). The objective of this phase will therefore be to analyze what was documented in the Map-phase, in order to identify problems and enabling factors that will affect the change. Each of the main areas in the guide on the previous page should be thoroughly analyzed and evaluated in order to be able to identify the most important aspects that should be targeted.

Analyze the Organization and Identify Problems

Since all organizations are different in some way, their prerequisites with regards to implementing SDD will differ as well, and should therefore be analyzed thoroughly. Some companies might have a working systems infrastructure, but do not have proper standardized working methods, why this would have to be addressed and emphasized when planning the implementation. Furthermore, if the company does not measure product development performance, now is the time to start doing so in order to have data to compare with in the end of the implementation.

Examples of questions that should be answered are:

- Is the systems infrastructure used inappropriately?
- Do DEs generally resist change?
- Are DEs and specialists overburdened with work?
- Is there a lacking collaboration between DEs and specialists?
- Is the communication between managers and subordinates inadequate?
- Are DEs and specialists following product development process documentation poorly?

Analyze Factors that Produce and Enable the Change

In order to design a process that handles the problems that were identified in the previous stage, one must identify what capabilities are at hand, and what speaks for the success of the implementation.

Examples of questions that should be answered are:

- Is there a natural SDD champion in the organization?
- What is the current knowledge level of DEs regarding simulation?
- Could the product development process documentation be adjusted to include simulation?
The Implementation Framework

- Could some simulations that are performed by specialists be done by DEs?
- Is appropriate simulation software available to DEs?
- Is the attitude toward simulation positive amongst DEs?

Select a Change Strategy

To set the tone of the execution, placing the project on the continuum (see figure 3.15 on page 29) will be beneficial. Since it is likely that most organizations will have largely similar problems and capabilities, an estimation of where on the continuum an SDD implementation project might end up, can be done. However, individual differences of organizations will of course create some fluctuation in the positioning. For example, the initiator’s hierarchical position relative to the DEs will affect the outcome. Since it will be necessary to have most DEs performing simulations early in the process and collaborate more closely to the specialist, a lot of people will be involved in the project. It is likely so that getting everyone involved will also be time consuming and different levels of resistance will be met. This calls for a diplomatic way of handling the implementation process where resistance is minimized, and a placement to the right on the continuum. As can be seen in figure 3.10 on page 19, larger companies tend to take longer time to adopt simulation, and this might influence the strategic positioning. Given a longer time to adopt, it can be further argued that a position to the right should be chosen. Adding to this, as DEs can be said to have a high technological competence and are skilled individuals, their power position in relation to their managers is rather high (Leonard-Barton & Deschamps, 1988). This signals that management’s influence is comparably low and a position to the right on the continuum is further called for (Kotter & Schlesinger, 2008). If the situation present at a company differs from the aforementioned, a position located further to the left is required. If the project takes a position to the left, the stages where education is carried out and input from affected individuals is considered will require less focus and involve mostly those that show interest in simulation to speed up the implementation process. Also, figure 3.16 on page 30 can be used to determine which methods to use for dealing with the specific types of resistance to change that are be to expected.

Discussion on Map & Analyze

As can be seen in the empirical results of this report, there are both noticeable similarities and differences between the companies, despite their respective sizes and products. This puts further emphasis on the importance of performing a thorough mapping of the company where SDD is to be implemented, as proposed by Kotter and Schlesinger (2008). For example, since the roles of managers, simulation specialists and DEs often extend beyond what their titles might suggest, a thorough mapping and documentation of roles is important for upcoming stages in the framework.
It could be argued that large companies do not operate the same as small companies do and that the structures are very different, and obviously this will affect how working methods and technology is adopted. However, it was seen in the study that the working groups and departments often consist of the same amount of individuals regardless of the size of the company. The interpersonal relations and dynamics (e.g. Kotter and Schlesinger’s (2008) work on resistance to change, and Mirvis et al. (1991) and Leonard-Barton and Deschamps’ (1988) discussion on the relation between managers and employees) are very much the same and it could be said that in the end, it all comes down to people trying to undergo change. The general guidelines provided in this framework can therefore be said to be relevant to companies of different types and sizes, but must still be adapted to the situation at hand.

It has been argued that a position to the right on the strategic continuum is called for; however, information gathered in the interviews contradict this to some extent. The DEs and managers said that the DEs would probably react positively if mandatory courses were introduced or if managers were to push for more simulation usage. Even though it is mentioned that there are certain individuals who would not react this way, a project with a more strict and preplanned approach might be beneficial in some cases. An eventual approach could therefore be to have the positive individuals learn simulation and make them use it in a project. If they would react as the interviewees believe, there would be no problem. The less enthusiastic individuals would then hopefully be inspired by the results and eventually want to learn themselves. This combined with an effort from the managers to push these individuals to learn would potentially be a lucrative approach, much in accordance with Leonard-Barton and Deschamps (1988).

On the contrary, there are aspects mentioned in the interviews that add to the arguments of having a position to the right. Many of the managers to the groups of DEs are project managers whose relative hierarchical level is lower than, for example, a Head of Design. This tells us that perhaps a more diplomatic, political, approach is needed. It is however often mentioned that the power distance in Sweden is low (confirming Hofstede (1980)), which diminishes the differences between managerial roles but adds to the fact that a more diplomatic approach is needed.

**Execute**

A trait of the BiC-companies is that they see simulation as an enterprise question, i.e. it is a topic of discussion on many levels and between departments in the companies (Aberdeen Group, 2015a). A goal of the implementation in general, and the *Execute*-phase in particular, is that it should help make simulation more of an enterprise question than it has been previously. It is believed that if simulation would be an enterprise question, the processes that enable SDD would be developed naturally, or at least with more ease. Additionally, there are four parallel stages in this phase which should be executed in an order that suits the situation at the specific
Monitor the Implementation Process

Why?
Despite rigorous planning and analysis, unexpected events often occur when implementing change (Kotter & Schlesinger, 2008). Therefore, continuous monitoring of the process is required to be able to identify and handle eventual problems as soon as possible. What is identified will then act as a basis for the Review-phase. Furthermore, BiC companies monitor the deployment of simulation to non-experts (Aberdeen Group, 2017).

How?
Monitoring of the implementation should be conducted in parallel to the rest of the implementation throughout the entire process. There is no absolute answer to who is most suitable for the task, but someone with a holistic view of the development process is required. The monitoring needs to take into account the opinions and reactions of DEs and specialists in order to discover resistances and problems as they occur.

Discussion
Not much was said in the interviews that alter neither the feasibility nor the importance of monitoring the implementation process. Since it is in the role of managers to monitor, it can however be added that it is probably they who should perform the actual monitoring. In the interviews it is also mentioned that the managers have more than sufficient knowledge of what the DEs do and how they are working, further calling for their involvement in this matter. The topic of appointing someone as responsible for the general work with simulation is further discussed on page 69.

Spark the Interest of Management and Approach Potential Champion

Why?
It has been argued by many that having an engaged management is important when implementing change. For example, it is the management that possesses the power and influence to make change happen (Leonard-Barton & Deschamps, 1988). Also, determined managers are more likely to provide training and user support (Nutt, 1986), which will be key in the implementation of SDD.

A champion acts as an initiator, stimulator and legitimizer, and often has an active role that is present throughout the project (Chakrabarti, 1974). It is obvious that involving someone that takes these roles, and possesses the traits of a champion (i.e. knowledge about simulation and
SDD, knowledge about the company, drive and aggressiveness, and political astuteness) will be beneficial to the implementation project. Also, as the champion will likely have a position in the company that allows them to communicate and influence both DEs and managers, the benefit of identifying and involving them is clear.

**How?**
To spark the interest of management, showcasing the benefits of SDD usage will be necessary. Some of the benefits are:

- Lead time is shortened (Sellgren, 1994)
- Costs are cut (Pavasson et al., 2014)
- Radical innovation is more likely to happen (Becker et al., 2005)
- Quality is increased (Shephard et al., 2004)
- Specialists are unburdened (Aberdeen Group, 2006)
- Number of prototypes is decreased (Sellgren, 1994)

Benchmarking against the Best-in-Class companies has also been said by Wheelwright and Clark (1992) to be an effective way of getting people involved, why this should be done if possible.

To identify a potential SDD champion, the individuals who are the most positive toward simulation should be approached. When this is done, the individuals should be evaluated according to the traits of a champion mentioned in the beginning of this stage. If someone is identified, this individual should be highlighted as an important person in the project and should, if possible, be given more authority and room to make simulation a topic of discussion.

**Discussion**
It was mentioned by for example Daft (1978) that having someone that is technologically knowledgeable is beneficial when influencing others to adopt new technology. As it was seen in the interviews that many of the managers in their previous position were DEs, having them involved will most likely be beneficial. In this specific case, the DEs might feel as the manager is not using solely their authority as a mean of convincing them, but rather their technical expertise. So, the counteractive mechanisms of authority that Leonard-Barton and Deschamps (1988) present, will likely not be much of a problem in these scenarios. Also, as mentioned by Milgram (1965), an employees’ perception of their own competence and capabilities as greater than their manager’s, will not likely cause a problem, if the manager has previously been a DE. This also means that if an SDD project is initiated from someone lower down in the hierarchy, communicating the need for adopting more simulation and sparking the interest of management will be less problematic.

It can also be deemed feasible to locate a potential champion as it is said that at each company there are some individuals who want the rest of the company to simulate more than they are
already. Given the definition of champion by Tanenbaum et al. (1966) on page 23, it cannot easily be said that one will be found at each company; however, at some of the interviewed companies, there are a few very promising individuals. These individuals have been DEs or specialists, not managers. This poses a problem as Chakrabarti (1974) presents one important aspect of a champion to be political astuteness, which is not an obvious trait that DEs or specialists possess. It is not necessarily the case that a manager possesses political astuteness in the sense of influencing others, it cannot however be denied that having a managerial role is beneficial in a situation like this. Also, as mentioned by Leonard-Barton and Deschamps (1988), in companies characterized by freer communication and looser structure, messages issued by a competent person could be more effective than messages by those that possess formal authority. These characteristics much likens what was seen in many of the interviewed companies and emphasizes that it might even be positive if the champion were to be a DE or specialist, as opposed to manager.

In the interviews, it was also mentioned that some DEs do not simulate because it is felt as if there is no need for it. However, most of them said that they would benefit from performing simulations more often than they are today. This is a bit of a contradiction and it seems that there is an issue with incentives to using simulation, there is no one telling the DEs that it is positive to perform more simulations or nobody that actively pushes them or expects them to do so. This is probably a task that suits the role of a manager, as it is often a manager that sets the goals and expectations in other areas of the DEs’ work. Some of the DEs also mentioned that they would want to learn simulation and use it more if the management would push them and highlight the benefits. This is further strengthened by the fact that a majority of the interviewees said that the DEs would respond positively to being pushed by a manager. The benefit and necessity of sparking the interest of management thus becomes evident.

Educate All Effected Individuals in SDD

Why?
Education is a key factor to the success of the implementation project. Resistance can arise if the nature of the change is not clearly laid out before those that will be affected by it, i.e. primarily DEs and specialists (Zander, 1950; Kotter & Schlesinger, 2008). Also, Education is important in order to improve the affected individuals’ perception of the costs and benefits of the implementation (Mirvis et al., 1991). Furthermore, since people might resist change that alter their role in the organization (Porras & Robertson, 1992), reducing uncertainties of what the technology brings can reduce resistance to change. Clarification also leads to less room for faulty interpretations of the aspects of the change and less disagreement of reasons behind it (Mirvis et al., 1991). So, the different benefits of SDD need to be effectively communicated to help reduce the level of resistance to the change that can be expected.
The Implementation Framework

How?
The social aspects of presenting the change and the fact that the information needs to be delivered strategically is important to consider (Lawrence, 1969). The expected outcomes and objectives of the change need to be articulated and presented to the organization (O’Connor et al., 1990) and the nature of the change made clear to those directly affected by it (Zander, 1950). How the work of DEs will change, why DEs need to simulate more, why a standardized method is necessary, and the benefits of SDD, are some of the aspects to be communicated in this stage.

Discussion
The interviews show an overwhelming positivity toward simulation, where all interviewed DEs held a favourable attitude toward it. Getting people to attend some educational event, whatever this might be, should therefore not be troublesome.

Since the size of the work groups — including managers and specialists — at companies have shown to sometimes reach beyond 20 individuals, it may be difficult to educate all of them thoroughly and at the same time. Despite this, at least an initial presentation of the basic idea of the SDD-project, with an attempt to get the entire department or work-group to participate, should be held. This is still in accordance with what for example Mirvis et al. (1991), Zander (1950), and Kotter and Schlesinger (2008) say about making clear the objectives of the implementation to improve the employees’ perception of it, even though it is not optimal. That is why an additional, more extensive, workshop could be held where the key individuals of the project partake to deepen the understanding and further anchor the knowledge. Should this workshop have been the only source of education, then the skeptics would avoid it and resist the change. By having the presentation and the workshop, everyone is included and exposed to the ideas of SDD, avoiding the mentioned issues to some degree.

While the DEs are positive toward simulation, this attitude only represents their current level of usage. One important reason for education was found to be the DEs’ attitude toward learning more simulation. They feel that they would benefit from using simulation more, but do not feel as if the time spent learning is worth the effort, so educating them in the benefits of SDD will prove beneficial. The reasons to why DEs are not simulating more — provided by both managers and DEs — are many. Some of them surely are justifiable, however, some certainly are not. A conclusion being that it is important to educate as many individuals as is manageable. Educating as many individuals as possible will also help in making the SDD-usage an enterprise question, as pushed for by the Aberdeen Group (2015a) and Karlsson and Åhlström (1997). Spreading the knowledge to everyone who will work directly with simulation will as mentioned have positive results, but reaching an even wider base than that can prove to be even more beneficial.
The Implementation Framework

It was found that managers showcasing benefits of increased simulation usage could be an incentive for DEs to use simulation to a larger extent. This will indirectly be taken advantage of by having the education initiated by the management, as the education will showcase the benefits of SDD. It was also mentioned by one DE that they strongly believed that if the management was to showcase the benefits of simulation, everyone would be interested and want to learn more. Even though it is just one case of witness, other interviewees have touched upon the same area and it is believed to be trustworthy, adding weight to the importance of this stage of the framework.

It is mentioned by most DEs and specialists that they feel as if they have too much to do, and thereby do not simulate or learn about simulation as much, as was also seen by the Aberdeen Group (2016a). Through this type of education and by showcasing the benefits with SDD and from performing simulations in general, priorities might change. This shows that combating this negligence of learning and using simulation is of utmost importance, further highlighting the necessity of this stage of the framework.

Get Input From Affected Individuals

Why?
Involving the concerned individuals will reduce the expected resistance to change in an implementation project, and allow for free discussion of obstacles (Zander, 1950). Doing this in the early stages of the process is key, as this will to some degree avoid direct and indirect resistance to change (Hyclak & Kolchin, 1986). It is also claimed to make the phasing-in period smoother and faster. One restriction is however that this could have drawbacks if the individuals do not possess the right amount of knowledge on the subject to make a worthy contribution (Kotter & Schlesinger, 2008). In the case of SDD, it is not completely clear whether the individuals possess the right amount of knowledge or not, why a cautious approach must be taken when analyzing the feedback. Also, self-interest from these individuals might skew the results to some degree.

How?
Including different departments in a change process will be important (Karlsson & Åhlström, 1997). In the case of SDD, getting feedback from both specialists and DEs can be said to be of relevance. Meetings where specialists, DEs and managers are present should therefore be conducted (Zander, 1950). This can further be argued to be of importance as the different perspectives from the individuals match the characteristics of SDD, which is both technical and administrative. The specialists will provide input on the technical aspects which, along with the perspectives of the management and the DEs will hopefully create a holistic picture of the project. Also, if you were to have a position to the left on the strategic continuum, it might be necessary to consider getting input from only the most important individuals.
Discussion
In the interviews, it was said that the specialists saw the benefit from having the DEs simulating more in the early stages of the product development process. Through this, it becomes clear that the specialists should be involved in setting the appropriate knowledge level and provide input concerning in which way the DEs could aid the process. In the same way, the DEs should be given the opportunity to state what they need in order to improve their simulation performance.

Upon speaking with the interviewees, it became apparent that most of them had similar thoughts and feelings about certain phenomena. It was however also apparent that there exists some individuals at their companies that had opposing views. The importance of including everyone and receiving feedback from both the skeptics and the more positive individuals thus becomes clear. Therefore, the theory that acts a foundation to this stage of the framework seem to be confirmed.

It was also mentioned that it is unclear whether the DEs posses the right amount of knowledge of SDD or not. The interviews have shown a wide gap where some are very aware of the consequences and benefits with SDD, while some show the opposite. This further highlights the need to critically analyze the input that is received.

Make Software Available to Those Who Can, and Want to, Use it

Why?
To further enable the internal diffusion process of adopting simulation, providing the required software to DEs and letting early adopters use the technology, will be beneficial, especially for the individuals who are more skilled in their work. (Leonard-Barton & Deschamps, 1988)

How?
This will be a task for the management, as they are most likely to be in the position of making the choice to purchase and distribute software to the employees. Management might want to firstly provide a working infrastructure and advertise the usage of the new technology (Leonard-Barton & Deschamps, 1988). When this is done, the management’s focus should turn to the late adopters and motivate them to start using the technology. To ensure that the software is easily implemented and is intuitive, the simulation tools should primarily be integrated in the CAD software (Aberdeen Group, 2006).

Discussion
In the interviews, it was mentioned that those who want to perform simulations mostly already have simulation tools available. This makes this stage of the framework rather obsolete as it seems as if there is no one that is missing at least the basic simulation software. What was seen in the interviews also much likens what was said by Leonard-Barton and Deschamps (1988),
the more skilled individuals seem to be using the technology that is available. However, just because someone says they have access to the appropriate software does not mean that there is no benefit to be gained from introducing software that they do not have today. In these instances, it is problematic as the threshold to performing simulation gets even higher. The importance of providing the correct software to those who want to use it still stands; however, the standard at the companies seem to be sufficient such that at least basic simulation can be performed, which goes a long way.

**Train DEs in Simulation and Make Courses Available**

**Why?**
As a successful SDD implementation will result in simulations being performed early in the design process, it will be crucial for DEs to learn how to simulate, should they not know already (Aberdeen Group, 2006). Training will also diminish the resistance to changing working methods amongst the DEs (Kotter & Schlesinger, 2008).

**How?**
Depending on the resources at hand in the companies, different approaches to training must be undertaken. Best-in-Class companies do however focus on providing specific examples rather than generic ones along with other training materials (Aberdeen Group, 2006). In the model by Cooper and Zmud (1990), it is also emphasized that training should take place before the employees are induced to commit to the technology fully. Furthermore, in order to phase in SDD, the DEs could be gradually trained, as the usage of simulation is spread throughout the department. Another way of training the DEs is by emphasizing collaboration with the specialists, this is further discussed in a stage below.

**Discussion**
The fact that training was said to be easy to access in all companies signifies that making courses available will not be a significant hurdle for most companies. However, training is mainly taken as courses externally and these will have to be taken as they become available. Alternatively, a larger utilization of internal training could prove to be beneficial. Having solely external courses to choose from might be problematic when considering the study by the Aberdeen Group (2006), where it is stated that the BiC-companies provide specific examples, which is difficult for an external supplier to do. Internal training might be a large endeavor in companies without a system in place, but the results could very well be worth the effort as it for example could enhance the communication within the department. Some interviewed companies did however already use internal training as their main form of education, showing that it might be the go-to option for some companies.

With their current level of simulation usage, half of the DEs did not feel as they had the knowledge of simulation to perform it well enough. This solidifies the need for training and
its key status for effective implementation. Also, it shows the need for more training that is specific to their current simulation work, in addition to what new tasks may come with an SDD-implementation. As software becomes available to DEs in the previous step, those that are able to use it can do so. DEs that however want to, but do not possess the required skills to make use of the technology, will have a hard time setting aside time to learn the software by themselves in their daily work, as DEs said they generally are overburdened with work.

Most companies did not use mandatory courses to educate their employees in product development related areas. Initiative for training mostly come from the DEs themselves or in discussion with their managers. A shift toward compulsory training might have a large impact on the DEs attitude toward the change since it starkly contrasts established norms. Some DEs did however state that they believe mandatory courses to be positive since it shows that the company cares about their development and invest in them, while making the simulation initiative more of an enterprise question. However, since it is commonly stated that some DEs most likely will not be interested in training, it is key to educate before training to show the benefits to stave off some resistance (Mirvis et al., 1991; Zander, 1950; Kotter & Schlesinger, 2008). A question that has to be raised is whether every DE should be trained or not. The more skeptical individuals might not want to learn simulation this early, why they should perhaps be spared from doing so initially to avoid resistance. It is believed to be a good idea to have the individuals who are positive toward simulation trained, in order to have them show the benefits of simulation to the skeptics later on in the pilot project. They would then be trained at a later point in time.

Encouragement of learning as opposed to mandatory training was generally looked more fondly upon. The managers themselves believe that the DEs would react positively to encouragement from above. At the same time, they believe that if the initiative would come from the DEs, they would react similarly or even more favourably. Encouragement and motivation can however only lead so far, as it will not make those reluctant to change substantially adjust their attitude. High knowledge in simulation is a requirement for SDD and has to be ensured in some way, so despite the drawbacks, mandatory courses will likely be a necessity in some cases. Furthermore, since the DEs claim to have too much to do, having a manager setting aside time for them will result in them, to a greater extent, accepting the time taken.

Specialists have shown to perform many simulations that they believe DEs to be capable of, with none or little training. In-house specialists make for an accessible source for the DEs. If possible, having specialists training the DEs can be one option to increasing their knowledge. Several DEs also stated that if they do not continuously work with or educate themselves in the software, they easily lose much of their knowledge. While a main point of SDD is to simulate more often, sometimes knowledge can get lost over time in the process. Having access to specialists who are able to train the DEs and keep them up to date in simulation knowledge can therefore be effective. Furthermore, it was revealed in the interviews that most companies do not possess a
standardized plan for education and training. Designing a plan for learning simulation based on the DEs current knowledge, attitudes and what resources are available could therefore prove beneficial.

**Start Actively Pushing the Usage of Simulation to DEs**

**Why?**
Having an engaged management is important when implementing a change project, so involving them in pushing simulation usage will be beneficial (Klein et al., 2001; Roure, 1999; Rivard et al., 1999). Consequently, it will aid the process of making SDD an enterprise question since the topic of simulation will more frequently be discussed. Also, BiC companies push simulation usage to DEs, further signifying the importance of this stage (Aberdeen Group, 2017).

**How?**
In the model presented by Cooper and Zmud (1990), this stage would correspond to *Acceptance*, where organizational members are induced to commit to the technology, before it is encouraged as a normal activity. Since there are individuals who do not want to use simulation, but could improve the performance of the product development if they did so, it will be necessary to phase in the implementation over time. One should therefore initially start to actively push the usage of simulation to the individuals who are more positive toward it. When the usage of simulation has started to spread within the department, management should start to communicate to the DEs that are yet to adopt the working methods of SDD that they shall begin to use it as well (Leonard-Barton & Deschamps, 1988). Communicating the need for simulation should be done regularly and should be delivered in a way that does not alter the social relationships between the ones who are pushing and the DEs (Lawrence, 1969).

**Discussion**
As there is a perceived need to simulate more, but still not everyone is using simulation software, pushing DEs to use simulation will in many cases be a good thing to do, especially to those not already skilled in simulation usage (Leonard-Barton & Deschamps, 1988). The expected effect of pushing the usage is further strengthened by the fact that the DEs themselves said that they would probably react positively if they were motivated to.

It is mentioned by some of the interviewees that implementing more simulation usage and new working methods is hard to do, perhaps mainly because of already ingrained ways of working and old habits. This signals a need for an external intervention, likely in the form of the motivation from a manager. Many of the interviewees agree upon the fact that in order to get people to listen, it must come from a manager, which speaks for the relevance of this stage of the framework.
In the interviews it is further mentioned that there are often some individuals who do not like to use simulation, either because they simply have never learned to use it or that they do not enjoy the process of performing them. It is however evident that having these individuals performing simulations would be beneficial to the organization. At most of the companies, it was said that it is up to the individual to perform simulations when they feel the need for it. If this is the case, an individual who do not want to perform simulations will probably never start doing so. This puts further emphasis on the fact that someone should be pushing for its usage. Not only to motivate the active users, but also the ones who are not already using it.

**Emphasize Collaboration Between DEs and Specialists**

**Why?**
To leverage the knowledge already held by simulation specialists and knowledgeable DEs, collaboration between them and the other DEs should be emphasized. To complement the previous training that the DEs have undergone, the collaboration will provide them with further support and knowledge, and enable better diffusion of simulation usage within the organization (Aberdeen Group, 2015a). Improving coordination between people and departments can also lead to a more effective development process (Cooper & Kleinschmidt, 1986). Through a close collaboration, the specialists can help to identify an appropriate simulation knowledge level for the DEs. This level should then be striven for by others in order to optimize an organizations simulation-usage.

**How?**
Based on the feedback received in the “Get input from affected individuals”-stage, a collaboration strategy should be formulated, with the intention of maintaining a feedback loop between DEs and specialists where knowledge and suggestions are communicated. This is very much dependant on where the simulation specialists are located and what kind of collaboration already exists. Communicating best practices performed by specialists will also be a key factor at this stage as this enables the DEs to develop their knowledge in simulation.

**Discussion**
In the interviews it was found that there are many different ways of configuring an organization with respect to specialists and DEs, and it is believed that this greatly affects the characteristics of the collaboration. The most extreme cases being either a configuration that is entirely separated with an external specialists group, or, an integrated configuration where the specialists are sitting alongside the DEs. It is believed that an internal configuration is to be striven for as the external configuration has inherited flaws. The external configuration creates a more formal relationship where a DE is expected to just provide an input, and the specialist is expected to return an output. Having a geographical distance between the parties also generates issues in
that it is troublesome to receive instant feedback and that no opportunities exists for learning collaboration. Also, an elongated lead time can be expected.

Being able to knock someone on the shoulder to ask for help and be able to see what your peers are doing is believed to be a better alternative. E-mails or reports are seldom written with such accuracy or pedagogical finesse that it trumps a personal, face to face interaction. Also, as the specialists often perform their simulations in different software than the DEs have access to, being able to show simulation models and results on the spot is a clear benefit.

A fact that must be considered is that the specialists have been seen to be outnumbered by DEs, (confirming the Aberdeen Group (2017)) and that they felt as if they have too much to do. This does call for having the DEs take some of the specialists burden by learning how to simulate. But obviously, it also hinders a fruitful learning collaboration as the specialists have fewer hours available to spend with the DEs. A challenge will therefore be to find the appropriate way of sharing knowledge between specialists and DEs, no matter the configuration. Also, as both the DEs and specialists feel as if they have too much to do, having a manager that pushes this collaboration will be key.

When it comes to the feasibility of this stage of the framework, there are both enablers and barriers. A barrier that was already mentioned is that both the specialists and DEs feel as if they have too much to do already. An enabler is however that the specialists explicitly say that they see the benefit from having the DEs simulating more. It is further mentioned that they receive poorly designed models that could be avoided if the DEs did simulate more. This does signal that they would probably see positively on the change if it was communicated properly (Lawrence, 1969), with a clear goal and how they would benefit from doing so (Mirvis et al., 1991; Zander, 1950; Kotter & Schlesinger, 2008).

The importance of this stage of the framework becomes evident as some of the managers said that they are emphasizing a collaboration, but most DEs and specialists said that this is not the case. Adding to the necessity and feasibility of this stage, some of the managers did mention that they should probably become better at this.

Lastly, as it is mentioned that most DEs do not use the same software as are the specialists, design collaboration is also somewhat hindered. The Aberdeen Group (2015a) states that a consolidated simulation platform might enable this; however, the extent to which this could be done at the companies in this study is unclear as it is stated to be a necessity that the specialists use stand-alone software.
Start Documenting Best Practices

Why?
The documented best practices can be used to modify and improve the standardized methods of SDD, and help spread simulation knowledge within the organization (Aberdeen Group, 2017). Best practice documentation is also a solution to DEs initial lack of expertise and uncertainties toward SDD (Aberdeen Group, 2006), meaning that documenting simulation best practices will aid in the diffusion of the technology (Leonard-Barton & Deschamps, 1988). Also, the DEs will perform the simulations more confidently, resulting in better simulation work.

How?
A structured way of handling documents containing best practices along with a policy of how it should be used and enforced, will be crucial to create. Current best practices performed by simulation experts should also be documented in order to make it available to DEs, to enable them to learn from it.

Discussion
As of today, most companies do not document best practices for their product development process and only very few do it for simulation. So for most, documentation of best practices for SDD is more difficult than just adding it to their current documentation. However, as all companies claimed to be working with continuous improvements, it should be in their interest to do so.

Continuous improvement of the product development process is important for the effectiveness of a company (Wheelwright & Clark, 1992). All interviewed companies claimed to work with continuous improvement in some way and many of the interviewed companies are in fact currently working on developing their documentation of best practices and an increased effort is generally put into this area. However, more managers than DEs answered that they are documenting best practices today, showing that simply documenting them is not enough to gain the benefits; the documentation has to be utilized fully and communicated to all involved parties. As one of the goals of documenting best practices is to have the DEs learn about simulation, it is a necessity that the documentation is widespread and commonly spoken about, not hidden away. As only a few companies are using best practices this way, the relevance of this stage of the framework is evident.

Standardize an SDD Working Method

Why?
Standardizing a way to work is key to make a product development process more effective, (Morgan & Liker, 2006) and so is also the case for SDD. Documentation and standardization will — if correctly used — lead to a homogenization of simulation usage. Standardization will also act
as a platform on which continuous improvements can be made. Furthermore, by standardizing a process, concurrent engineering and synchronization across functions can be further enabled (Morgan & Liker, 2006).

How?
The standardization will also have to be adapted to the process of the specific company. If there are documents stating how the company should be working with product development, i.e. there are certain stages in the process where different criteria has to be met, simulation should be included in these. Documenting a way of working that states when simulations are to be performed and by whom, how results should be documented and handled etc., will be key. In order to phase SDD in and not be overwhelmed by the change, early standardization should include basic simulation on relatively simple models, to over time be built on and improved once the processes become effective.

Discussion
Most interviewed companies claimed to have a documented product development process. However, there exists a large variety in what is included in it, and not many companies seem to document processes at a technical level and include characteristics of the DEs work tasks. The process is usually stage-based and the documentation includes what to achieve rather than how to achieve it. Detail-oriented, organizational-level standardization is an important factor to success in product development, meaning that an effort needs to be made to create more in-depth documentation and standardization (Morgan & Liker, 2006). What was generally seen at the companies was that when there was no clear incentive or requirement of simulation in the form of a process documentation, it was solely used by those that could and wanted to. The problem often seem to lie in clearly defining and articulating the need for simulation in the process documentation. Few companies seem to use simulation in a standardized way, but all who were asked believed that standardizing their methods of simulation would be possible. Also, some DEs stated that requesting simulation in the project description would be enough to make them perform it, further emphasizing the feasibility and importance of this stage.

Standardize a Way of Utilizing the Systems Infrastructure
Why?
To get the most out of the simulation usage and enable review and access to files and results, companies need a refined systems infrastructure. A standardized method of utilization can enable better collaboration, make old projects more accessible and learning from earlier problems easier. The importance of using the systems properly is evident as this is where for example best practices and simulation results are stored. Also, upwards of around 21 hours per week per DE is wasted on non-engineering activities, such as searching for files (Aberdeen Group, 2015b), further emphasizing the importance of this stage.
The Implementation Framework

How?
This could be done by either investing in a new system or defining methods for using the infrastructure already in place. The system should cover the need of the increased simulation use and criteria should be based on eventual flaws found in the Analyze-phase. PDM systems can track documentation of products and store relevant information for easy access and sharing, while simpler external drives can be used to store other project files. How files and documentation should be saved and stored, and who should have access to them should be clearly defined and all DEs, specialists and managers using the systems should be up to date in how to use it.

Discussion
Perhaps as a result of not using simulation frequently enough or in a standardized way, companies handle the results generated from them poorly. As has been mentioned, some material from the performed simulations is saved, however it is not distributed properly or made available to those who could benefit from accessing it, signifying the importance of this stage.

As is mentioned by the Aberdeen Group (2015b), 16–21 hours in total each week is spent performing tasks that is of low engineering value (i.e. the handling of large files, data transfer, mesh creation etc.). It is not clear how many hours are wasted looking for simulation results by the DEs and specialists in this thesis. As it seems simulation results are not utilized extensively, it is likely not that many. Some interviewees did however say that the results are saved poorly in a way that makes them hard to locate. Therefore, if simulation would be used more often, additional hours could be wasted. At that point it will be good to have a system in place and a standardized way of handling the results to prevent this wastage.

Why the companies are not using their systems properly seem to be a problem of simulation not being an enterprise question. That is, no one sees the importance of using and sharing the results. Also, simulation seems to be used in the interest of the single individual as opposed to the department, at least to some extent. Despite this, when a company reaches a sufficient level of simulation-utilization, handling the results properly seem to simply be a question of introducing a policy that specifies how the systems should be used. This stage of the framework therefore seems rather feasible to carry out.

Decide Pilot Project

Why?
Capability building in product development can effectively use projects as vehicles to introduce, test-drive and demonstrate new methods and tools (Wheelwright & Clark, 1992). The pilot project should test the developed methods for SDD in practice in a controlled manner and highlight the integrated change to bring forward eventual problems and uncertainties not yet resolved. In this way, the pilot project will help to phase in the SDD methods. In the specific project, the usage would correspond to Routinization in the model by Cooper and Zmud (1990),
where the method is encouraged as a normal activity. This further emphasizes the fact that it is still a project that is there to test the technology out, as opposed to full scale usage.

**How?**
While all the stages in the framework can be implemented over time in current projects, the specific pilot project should formalize and concretize the methods for SDD and thoroughly use them. The project should both build on and further develop best practices and standardized working methods, while taking advantage of the DEs increased knowledge in simulation. The lessons learned from the project will be used to formulate future projects when SDD is fully implemented.

**Discussion**
Since all DEs at this stage will be educated and some of them trained in SDD and simulation, everyone but the skeptics should be fit to officially start working according to the new principles. Since the interviews showed that there are varying degrees of interest in learning and using simulation, if possible, selecting a project with a higher degree of DEs who already are interested in and to some extent make use of simulation will therefore be beneficial. This is especially important as a substantial part of the pilot project is to simply showcase the benefits of simulation to the less enthusiastic. Also, as the interviews have showed that many of the DEs felt as if simulation is used too infrequently, identifying a project that could potentially involve performing more simulation than in others might therefore be beneficial.

The dedicated pilot project is not a necessity for the success of SDD, but can efficiently be used to explore SDD in a controlled manner. Furthermore, the interviewees answered that methods learned in training should be immediately used in projects to anchor the knowledge. The pilot project allows the DEs to formally test their newly learned skills.

**Review**

**Review that the Identified Problems are Handled**

**Why?**
It will take time to increase the scope of SDD to include all people and tasks, and thus reaching all the potential benefits of using simulation. Continuous review that the problems identified in the Analyze-phase have been solved will help in identifying where increased focus should be directed and if the selected change strategy needs to be modified.

**How?**
Using the monitoring as a basis, the same questions that were asked in the Map-phase need to be asked again in order to identify what differences have been made, to see if the prerequisites
have been changed, and to investigate if the problems have been solved. If the questions still yield similar answers, an emphasis on solving the problematic areas is required.

Discussion
As communication has been concluded to be poor at most of the companies, it is felt as if the Review-phase of the framework is of great importance. The reviewing can act as a communication channel that will further help to make simulation an enterprise question and imprint it on everyone’s mind. However, there must be someone actually performing the reviews, why the question of having someone with a general responsibility for simulation must be discussed. This is further emphasized by the fact that the process might be prolonged and take time to reach its full potential (Arnold & Senker, 1982), and might therefore need extra guidance. Without having someone responsible for performing the reviews, it will most likely not be done, or at least it would help to appoint someone. Some interviewees did however say that they feel as if appointing someone responsible would not be necessary. Also, some mentioned that it should be a mutual responsibility, confirming Lubatkin et al. (2005). With this said, it must therefore be said that listening to the group and analyzing the situation thoroughly is of importance before appointing someone.

Measure performance

Why?
In order to know whether an SDD initiative is yielding the wanted results or not, lead time and engineering hours have to be measured (Clark & Fujimoto, 1991). Also, most BiC companies measure the number of change orders issued after the product has moved from the design phase (Aberdeen Group, 2006). Furthermore, having a baseline performance to compare with will be beneficial when the usage of simulation gets increasingly streamlined and the results can be visualized.

How?
As just mentioned, tracking the number of change orders issued after the product has moved from the design phase, is a good way of measuring performance. In addition to this, measuring the supposed benefits of using SDD, i.e. change in costs, lead time, quality, engineering hours, and number of prototypes should also be done. Additionally, measuring the number of specialist interventions early in the design process as well as the type of intervention can be beneficial in order to evaluate how well DEs are performing simulations. If the company already has an established method for measuring performance, past results can be compared to what is now measured, if they are comparable. If no methods are in place they should be implemented together with the initiation of this framework, as mentioned in the Analyze-phase.
Discussion
During the interviews it was mentioned that some individuals, often the skeptics at the companies, do not fully believe in the results that some simulation deliver. One DE explicitly said that they would want to see that it yields reliable results before using simulation more than they were at the time. One manager also said that they believe that there is an over-reliance on simulation and that it would be beneficial if they could be even more certain that the models make for a sufficient representation of the real world. In this case, the product that was being developed simply could not fail, or it would have devastating consequences. In this specific case, measuring product development performance is justifiably a hard thing to do, as the projects are long and hardly comparable. However, in the companies where the stakes are lower and the cycles are more frequent, a system where performance is measured — in both how accurate simulations are and product quality, lead time and productivity (Clark & Fujimoto, 1991) — could help to either justify or falsify this skepticism toward simulation. Having just some individuals being unjustifiably skeptical toward simulation is not good, as it can hinder the internal diffusion and influence others negatively, which signifies the importance of this stage of the framework.

The companies said that they continuously work to improve their processes, which makes implementing some kind of performance measuring more feasible. However, as in the case mentioned above, a lot of companies do not have a perfectly cyclical development processes that allows for easily comparable data sets between the cycles. If a company has standardized product development processes it is still believed that measuring and working toward improving its performance is a beneficial thing to do, at least in the long run (Clark & Fujimoto, 1991). However, should ones cycles be uneven, then it will most likely be a large undertaking and should therefore be analyzed thoroughly in order to evaluate its actual relevance. In some cases, it might be better to — at least initially — target ones energy elsewhere.

Perform regular check-ups

Why?
A company’s development capability should be continuously expanded, upgraded and improved in order to be a source of sustainable advantage. Having an effective product development in the present is important, but not enough to ensure competitive advantage in the future. It is a must that an organization is both good now and continuously getting better, why performing regular check-ups is important to ensure that the product development is continuously being improved. (Wheelwright & Clark, 1992)

How?
Managers should regularly review the current product development process and ensure that best practices and standardizations are continuously updated while striving to improve the SDD working methods. They should also communicate with DEs and specialists to assess if
further education and training is needed and if the SDD processes are working as intended. If simulation has not been fully diffused in the organization, management should keep pushing the usage of it to reach the infusion-stage (i.e. reaching the full potential of the implementation) in the model by Cooper and Zmud (1990).

**Discussion**

It was mentioned in the interviews that there are annual performance appraisals being held at the companies. This is believed to be a good opportunity to perform check-ups, as they happen regularly and in a personal setting. During these sessions, it should be evaluated how well employees are getting along with training and education. As previously mentioned, these sessions can be used to develop the communication within the department and further make simulation an enterprise question. As it is easily implemented, it is believed to be well worth the effort. Also, managers should make sure that best practices and standardizations are actually followed by the DEs, as the interviews have shown that there is a communication gap in this area.

5.2 Additional Discussion

One phenomena that was made clear in the interviews was that managers and DEs often had different perception of whether certain actions were carried out or not. Managers often said that they do something, while DEs said they do not or have no knowledge about it. For example, it was previously discussed that more DEs than managers claimed that they do not have a standardized and documented product development process that is followed. Furthermore, DEs seem to have less overall knowledge of the product development process, despite being supposed to follow it. This miscommunication must be considered a big problem, not only in the case with SDD, but in the product development of a company in general. Sticking with SDD, an area that has been mentioned to be problematic is that simulation is not considered an enterprise question. Obviously, as the management and the DEs are not aligned in their views on simulation, communication has to be improved. However, it seems as the things that are actually communicated, for example project specifications and certain process documentation, are followed carefully by the DEs. This gives high hopes that when the importance of performing simulation is properly communicated, in combination with having it documented in a process, it shall be received well and used extensively.

There are certainly benefits to having someone appointed as responsible of simulation. The biggest perhaps being that simulation becomes more of an enterprise question and that simulation will more regularly be a topic of discussion and better founded in the companies’ documentation and enabling processes are cared for to a greater extent. But as the power distance
The Implementation Framework

has been said to be low and the hierarchy comparably flat (by both the interviewees and Hofstede (1980)), DEs in Sweden may be less obedient to managerial action than in other countries (Shane, 1993). This means that there could be situations where managerial intervention should be avoided, at least to some degree. It does however seem as it is impossible to remove the managers completely from the equation as some DEs have said that this motivation is required in order to achieve change (in accordance with Leonard-Barton and Deschamps (1988)). As mentioned, some DEs did however say that, as long as something is documented in a process or in the project specification, it will be carried out. This tells us that it is perhaps not necessary to involve managers as long as the work process is documented. Documenting the process might, in itself, require the influence of a manager to get done, but it is not a necessity. In the case where a lot of diplomacy is required, it might be an option to solely include the manager in getting the process description written, and then having them return to a more passive role. However, many interviewees pointed out that having a manager involved is seldom anything other than positive.

Some interviewees were even more absolute in their attitude toward managerial involvement, saying that it is a necessity (in accordance with Karlsson and Åhlström (1997), Rivard et al. (1999), Nutt (1986), Laughlin (1999); Klein et al. (2001), Cooper and Zmud (1990), Becker et al. (2005) and Leonard-Barton and Deschamps (1988)). Two DEs who has this standpoint also commented that there is a tendency that issues that are not brought forward by a manager is often neglected or passively resisted. However, there seems to be little disagreement that knowledgeable DEs, despite not possessing a managerial role, have a position that allows them to influence others to change (cf. Lawrence, 1969). The degree to which they can influence change is however unclear, but the feeling is that it is high enough — at least in some organizations — to actually make a difference. Despite this, and given the extent of the implementation project, a manager will most likely be required to lead the project and make sure it is followed through.

It was also found that especially in the smaller companies, the DEs could play a key role in the implementation. This could be explained by that, in the smaller companies, it was often the case that the Head of Design was involved in the design work, or had previously worked as a DE. The conclusion of this being that there are circumstances where it is called for to include the DEs more in the process of initiating and be the driving factor in an SDD-implementation project.

As has been mentioned, Leonard-Barton and Deschamps (1988) state that in certain organizational environments, authority is sometimes not appreciated by subordinates. In the context of this thesis, this means that there could potentially exist tension between the DEs and the managers. However, that has not been seen to be the case, at least not entirely. Going to your manager with an idea for improvement or with a question is said to be easier than in other
countries. This is interesting as the theory used in this thesis is predominantly based on research from the US or other parts of the world, and it emphasizes the involvement of managers and neglects the influence that subordinates can have on others (Rivard et al., 1999; Laughlin, 1999; Klein et al., 2001; Nutt, 1986; Cooper & Zmud, 1990; Becker et al., 2005). Perhaps it could be the case that the theory is somewhat misleading in the case of implementing SDD in Sweden. The situation in the Swedish companies would then allow the skeptical individuals to present their dissatisfaction and resist the change more actively, putting even more pressure on the manager. These skeptical individuals would have to be handled in a more diplomatic way with a long term goal of adoption. For example, having a pilot project where the keen simulation users are required to simulate could prove beneficial.
Chapter 6

Conclusion

6.1 Answering the Research Questions

There are three research questions that this thesis aims to answer. The answers to question 1. and 3. can be found in chapters 5 and 3 respectively, but are also, in short, presented in this section. The answer to question 2. is however not clearly stated in the report as such, why a summarized list of general preconditions is presented on the following page.

1. How can Simulation-Driven Design be implemented in a company?

SDD can be implemented in a company by firstly mapping the organization to get a holistic picture of how the company is working with simulation and product development in general. Secondly, an analysis should be carried out with the intention of identifying problems that need to be focused on, and which enabling factors exist in the organization already. Also, a plan for the implementation should be developed by positioning the implementation project on a strategic continuum. Thirdly, the decided plan should then be executed based on the analysis. The execution should cover: educating affected individuals, pushing simulation usage to DEs, standardizing working methods and initiating a pilot project. Lastly, continuous review should be performed in order to make sure that the project is yielding results. This should be done by investigating if the problems that were discovered in the Analyze-phase are solved. Also, check-ups should be performed continuously to ensure that the new working methods are followed as the implementation reaches its full potential.

2. What are the preconditions for implementing Simulation-Driven Design in companies today?

The identified preconditions are divided into two groups: Enablers and Barriers. Enablers are the favourable preconditions that make the implementation of SDD easier while barriers are areas that will make the implementation more difficult, that the framework aims to resolve.
**Conclusion**

**Enablers**

- The attitude toward simulation is positive at the companies.
- There is a perceived need for more simulation.
- Simulation software is available to DEs.
- The role of DEs involve performing simulations.
- DEs see the benefit in using simulation more often.
- DEs strictly follow what is written in documentation and project specifications.
- Companies have documented product development processes.
- Companies believe they could use simulation in a standardized way.
- Companies are continuously working to improve their product development process.
- Companies make use of simulation specialists.
- Education and training is easily accessible.
- DEs would not react negatively to mandatory simulation training.
- DEs would react positively to managerial push.
- Managers have good insight in the working methods of DEs.
- Managers are technologically astute.
- There exist potential champions more passionate about simulation than others.

**Barriers**

- Simulation is not an enterprise question.
- Simulation is not discussed between hierarchical levels.
- Companies are not using simulation in a standardized way.
- DEs and specialists are overburdened with work.
- Simulation is not included in the product development process documentation.
- Communication between DEs and managers is poor.
- Companies do not have an have effective way of using the systems infrastructure.
- Simulation results are handled poorly.
- Specialists cannot share simulation models with DEs.
- Collaboration between DEs and specialists is poor.
- Specialists are not located close to the DEs.
- DEs are not utilizing best practices.
- Product development performance is not measured.
- DEs do not follow a learning plan.
- DEs do not believe the benefit from learning more simulation outweighs the time it takes to learn.
3. What are the characteristics of companies that use simulation effectively?

The Aberdeen Group analyzed companies with effective product development processes and how they were using simulation. Some of the key traits that have influenced the framework the most are presented below. The full list of traits can be found on page 35.

- BiC companies emphasize collaboration between DEs and specialists.
- BiC companies use simulation during the early stages of the design process.
- BiC companies push simulation to DEs.
- BiC companies’ managers view simulation as an independent enterprise decision, as opposed to just a part of an overall system.
- BiC companies capture simulation best practices through customized simulation workflows and make it available to non-experts.

6.2 Conclusions on the Framework

An SDD implementation project based on the framework presented in this thesis might — due to its extensiveness — be felt as a challenging endeavour to undertake. However, many of the stages in the framework are not strict enablers of SDD, but simply aiding processes. It is not a necessity to meet all the stages perfectly, but rather the ones that are the most important to the situation at hand. In some companies, the systems infrastructure may be a big hurdle to get over, while other companies may experience problems with establishing a collaboration between specialists and DEs. With this said, it is evident that the framework presented must not be considered a manuscript for how simulation and nearby processes must be configured, but rather a guide to pointing a company’s utilization of simulation in the right direction. Furthermore, it was noticed that the companies that were interviewed had many similarities and differences in the way they were using simulation and how they were working in general. These similarities and differences, especially the latter, further highlight the fact that the framework must be customized to each organization.

Despite its extensiveness, the framework is deemed to be feasible for implementing SDD. The discussion on the respective stages of the framework highlight that some stages are more important than others; however, the feasibility of any specific stage was not found to be an issue. The biggest hurdle for an SDD implementation was identified as simulation not being an enterprise question (i.e. no one is talking about simulation and it is not being discussed between hierarchical levels). We believe that if simulation would be an enterprise question, the processes that enable SDD would be developed naturally and cared for to a greater extent. At the moment, many of the companies seem to not yet have understood that there is a benefit to using simulation in
a standardized fashion. It is merely used as a tool that is picked out of the toolbox every now and then, when someone feels it should be used. Furthermore, the knowledge of simulation does not yet seem to be so widespread that its applicability is commonly discussed. The importance of having at least one person propagating and marketing simulation to others, getting people involved, and treading the path in the company (i.e. a champion), thus becomes clear. Given the extent of the framework, a manager is concluded to be required to drive the project in its entirety forward. However, if there exists an influential, knowledgeable and trustworthy DE or specialist that is strongly propagating simulation, the project can more easily find footing.

Despite being far from simulation-driven, the companies have a positive attitude toward simulation, and it is starting to become a topic of discussion. This brings further hope that solely the presence of an implementation project based on this framework should suffice to make simulation a big enough topic to thrive and anchor in an organization’s foundation. And if simulation was to be an enterprise question, we believe that the stages of the framework that enable SDD would naturally be discussed, enabling a smoother implementation process.

6.3 Further Studies

- We feel as an actual implementation of SDD at a company, with our framework as guidance, would serve as a great complement to the work that has been done in this thesis project. Despite the framework being rather generalized, much like in design simulation, reality often pose problems that are too hard to anticipate. Also, some aspects of the framework could benefit from being trialed, for example, uncertainties regarding how individuals actually react to managerial push or mandatory courses. A result of this could be that the way pushing is communicated is changed, or perhaps the order of certain stages of the framework.

- Further studies should also evaluate the importance of certain phases and stages of the framework. As the framework could be felt as rather extensive to some companies, it would be worth investigating which stages are the most important and which could perhaps be diminished or even excluded. Obviously, some stages are more important than others and this has been somewhat discussed in chapter 5; however, we believe that testing the framework in reality could aid in further highlighting this.

- The stages and phases proposed in the framework could be further investigated, for example, more specific methods could be developed for how individuals should be educated within SDD, how they are best trained, and how the most beneficial DE-specialist collaboration should be set up in detail.
Conclusion

- The economical aspects of an SDD implementation have not been studied in this thesis, but could be an important thing to do. This is partly because it could be used as a mean to convince people and create interest, but also to evaluate different stages of the framework.

- As there is no specific receiver of the framework, it could be further studied how it could be customized to, for example, a consultancy firm or a specific individual at a company. If the framework is used by a consultancy firm, it could further be investigated who should be contacted at a potential customer.

- As most of the companies who were interviewed for this project use a traditional stage gate model for product development, it could be of interest to study how for example agile project management could affect simulation usage, and thereby SDD implementation.
References


References


Appendix A

Questions to Managers

The questions that were asked to the DEs are presented below in both Swedish and English. Since the interviews where held at Swedish companies, only the Swedish questions were asked. The English questions were directly translated for the international readers of this report, but were never used.

Questions in Swedish

- Vilken är din roll?
  - Vilka är dina arbetssysslor?
  - Vilken avdelning arbetar du på?
- Hur länge har du jobbat på företaget?
- Hur många arbetar på din avdelning?
  - Hur många inom R&D totalt?
- Vilka produkter utvecklas?
- Berätta kortfattat om produktutvecklingsprocessen, från idé tills dess att produkten är redo för serietillverkning.
  - Har ni en dokumenterad/standardiserad process?
    * Finns simulerings med i denna?
- Arbetar ni med simulerings?
  - Använder ni simulerings på ett standardiserat sätt?
    * Skulle det vara möjligt utifrån nuvarande förutsättningar?
  - Vilka typer av produkter och komponenter simulerar ni?
    * Vilken typ av simulerings utförs?
  - När simulerar ni?
– Vem är det som simulerar?
  * Hur arbetar konstruktörer och simulerings-specialister i förhållande till varandra?

● Hur utbildas konstruktörer?
  – På vems initiativ?
  – År utbildning lättillgänglig?
  – Om du skulle pusha, utan att det blir obligatoriskt, att konstruktörerna skulle lära sig simuler, hur tror du att de skulle reagera?
    * Om en konstruktör skulle pusha, hur tror du att de skulle reagera då?
  – Har ni infört obligatoriska kurser tidigare?
    * Hur reagerade konstruktörerna?
  – Hur tror du konstruktörerna skulle reagera om det blev obligatoriskt att lära sig simulering?

● Vad är din inställning till simulering?
  – Pushar du konstruktörerna att simulerar?
    * Hur?

● Vad tror du inställningen till simulering i företaget är?
  – Ledning?
  – Konstruktörer?

● Vad tror du är anledningar till att ni inte simulerar mer?
  – Vad skulle krävas för att ni skulle göra det?

● Tycker du att någon borde vara ansvarig för att simulering utförs?
  – Vem tycker du borde vara ansvarig för att simulering utförs?

● Finns det någon som tycker det är viktigare att utföra simuleringsön andra?

● Finns simuleringsprogramvaran tillgänglig för de som kan och vill använda den?
  – Tror du att det finns de som vill använda om de skulle ha tillgång?
  – Vet du vem som är ansvarig för inköp av simuleringsjukvaran?
    * Vilka kriterier tar ni hänsyn till?
    * Hur tänkte ni när ni implementerade mjukvaran?

● Pushar ni samarbete mellan specialister och konstruktörer?

● Dokumenterar ni best practice?
  – För simulerings?

● Mäter ni produktutvecklingseffektivitet?
  – Hur?
• Arbetar ni för att kontinuerligt utveckla produktutvecklingsprocessen?
  – Hur?
• Om man skulle vilja få DE att simulera mer, var borde initiativet då komma från?
• Hur har processen gått till som har lett er till situationen ni befinner er i idag gällande simulering?
  – Hur implementerade ni metoderna för simulering
  – Hur har processen utvecklats över tid
• Hur tror du man skule gå till väga för att en förändring av arbetsmetod bäst skulle accepteras?
  – Har du erfarenhet av misslyckat eller lyckat implementationsprojekt

Questions in English

• What is your role?
  – What are your work tasks?
  – What department do you work at?
• For how long have you worked at the company?
• How many individuals are working at your department?
  – How many work within R&D in total?
• What products are developed?
• Tell us about the product development process, from idea to product launch.
  – Do you have a documented/standardized process?
    * Is simulation included in this documentation?
• Does your company work with simulation?
  – Do you use simulation in a standardized way?
    * Would it be possible, based on current conditions?
  – What kind of products and components are simulated?
    * What kind of simulation is performed?
  – When are simulations performed?
  – Who is performing simulations?
    * How are design engineers and specialists working together?
• How are design engineers trained?
  – On whose initiative?
Is training easily accessible?

If you were to push design engineers to learn simulation, without it being mandatory, how do you think they would react?

* If a design engineer was to push, how do you think they would react then?

Have you previously introduced mandatory courses?

* How did the design engineers react?

How do you think the design engineers would react if it would become mandatory to learn simulation?

What is your attitude toward simulation?

Are you pushing design engineers to simulate?

* How?

What is the attitude toward simulation in the company?

Management?

Design engineers?

What are the reasons to you not simulating more?

What would it take in order to simulate more?

Do you think someone should be responsible for simulations being performed?

Who?

Is there anyone who thinks performing simulations is more important than most others?

Is the simulation software available to those who can and want to use it?

Do you think there are those who would want to use it if it was available?

Do you know who is responsible for purchasing of simulation software?

* Which criteria are considered?

* How did you implement the software?

Are you pushing a collaboration between specialists and design engineers?

Are you documenting best practices?

For simulation?

Are you measuring product development performance?

How?

Are you working to continuously develop the product development process?

How?

If one would want the design engineers to simulate more, where should the initiative come from?
• How has the process that has lead to where you are today played out, concerning simulation?
  – How were the methods for simulation implemented?
  – How has the process developed over time?

• How do you think one should proceed to get acceptance for a change of working methods?
  – Do you have any experience of a successful or unsuccessful implementation project?
Appendix B

Questions to Design Engineers

The questions that were asked to the DEs are presented below in both Swedish and English. Since the interviews were held at Swedish companies, only the Swedish questions were asked. The English questions were directly translated for the international readers of this report, but were never used.

Questions in Swedish

- Vilken är din roll?
  - Hur länge har du jobbat på företaget?
  - Vilken avdelning arbetar du på?
  - Vilka typer av komponenter eller produkter utvecklar du?
  - Vilka är dina arbetssysslor?
    * Hur stor andel av din tid spenderas i CAD?
- Hur ser strukturen ut på din avdelning?
  - Hur många arbetar på din avdelning?
  - Hur många inom R&D totalt?
- Vilka produkter utvecklas?
- Berätta kortfattat om produktutvecklingsprocessen, från idé tills dess att produkten är redo för serietillverkning.
  - Har ni en dokumenterad/standardiserad process?
    * Finns simulering med i denna?
- Arbetar ni med simulering?
  - Använder företaget simulering på ett standardiserat sätt?
    * Skulle det vara möjligt utifrån nuvarande förutsättningar?
- Vem är det som simulerar?
- Händer det att ni använder simulering för att välja mellan två varianter?
- När i processen simulerar ni?

**Arbetar du med simulering?**
- Om du simulerar, i dina nuvarande arbetsuppgifter, känner du att du har kunskapen om simulering för att simulera tillräckligt bra?

**Vilka typer av produkter och komponenter simulerar NI/DU?**
- Vilken typ av simulering utförs?

**Finns det någon beräknings-/simulerings-specialist?**
- Hur arbetar konstruktörer och beräknings/analys/simulerings-specialister i förhållande till varandra?
- Hur ofta får ni tillbaka modeller för stora justeringar efter ni har lämnat ifrån er dem?

**Finns det en fungerande systeminfrastruktur?**
- Vilka problem finns?
- Hur hanterar ni resultat från simulering?

**Vilka mjukvaror använder du?**
- Vilken simulering/mjukvara har du tillgång till?
  * Inbyggd i CAD?

**Dokumenterar ni best practice?**
- För simulering?

**Hur insatt är din chef i hur du arbetar?**
- Påverkar chefen hur du arbetar eller är det upp till dig?
- Anser du att din chef har tillräcklig kompetens för att förstå, rent tekniskt, vad du håller på med?
  * Vad gäller simulering?

**Hur utbildas konstruktörer?**
- På vems initiativ?
- År utbildning lättillgänglig?
- Finns det obligatoriska kurser?
- Finns kurser för simulering tillgängliga?
- Om det skulle bli obligatoriskt med kurs, hur skulle du/man reagera?
- Finns det motstånd att lära sig?
References

- Känner du att du har för mycket att göra?
  - Påverkar det hur mycket du utbildar dig?
  - Påverkar det hur mycket du simulerar?

- Vad är din inställning till simulering?
  - Ser du någon nytta i att du skulle simuleras oftare?
  - Mer komplexa simuleringar?
  - Känner du att nytten från att simuleras mer väger upp för tiden det tar att lära sig?
  - Vad skulle behövas för att du ska simuleras mer?

- Tycker du att någon borde vara ansvarig för att simulering utförs?
  - Vem i så fall?

- Finns det någon som vill att ni ska simuleras mer?
  - Känner du att dina chefer pushar dig att simuleras?
    * Att samarbeta med/lära från specialister?

- Vad är inställningen till simulering i företaget?

- Skulle det vara bra om cheferna pushade och visade sina fördelar med simulering?

- Om man skulle vilja simuleras mer, var tycker du initiativet borde initiativet då komma, från chefer eller från konstruktörer?

- Hur har processen gått till som har lett er till situationen ni befinner er i idag gällande simulering?
  - Hur implementerade ni metoderna för simulering?
  - Hur har processen utvecklats över tid?

- Hur tror du man skulle gå tillväga för att en förändring av arbetsmetod bäst skulle accepteras?
  - Har du erfarenhet av misslyckat eller lyckat implementationsprojekt?

Questions in English

- What is your role?
  - For how long have you worked at the company?
  - What department do you work at?
  - What products or components do you develop?
  - What are your work tasks?
    * How much of your time is spent in CAD
• What does the structure of your department look like?
  – How many individuals are working at your department?
  – How many work within R&D in total?

• What products are developed?

• Tell us about the product development process, from idea to product launch.
  – Do you have a documented/standardized process?
    * Is simulation included in this documentation?

• Does your company work with simulation?
  – Is the company using simulation in a standardized way?
    * Would it be possible, based on current conditions?
  – Who is performing simulations?
  – Do you ever use simulation to chose between several variants?
  – When are simulations performed?

• Do you work with simulation?
  – If you use simulation, in your current tasks, do you feel as if you have the knowledge to simulate well enough?

• What kind of products and components do you/your company simulate?
  – What kind of simulation is performed?

• Is there a simulation specialist?
  – How are design engineers and specialists working together?
  – How often do you get models returned for large adjustments, after leaving them to specialists?

• Is there a working systems infrastructure?
  – What problems exist?
  – How do you handle results from simulation?

• What software do you use?
  – What simulation software do you have access to?
    * Built into CAD?

• Do you document best practices?
  – For simulation?

• How involved is your manager in how you work?
  – Does your manager affect how you work or is it up to you?
- Do you feel as if your manager has enough technical knowledge to understand what you do?
  * Regarding simulation?

- How are design engineers trained?
  - On whose initiative?
  - Is training easily accessible?
  - Are there mandatory courses?
  - Are courses in simulation available?
  - If a course would be mandatory, how would people react?
  - Is there resistance to learn?

- Do you feel as if you have too much to do?
  - Does it affect how much training you do?
  - Does it affect how much you simulate?

- What is your attitude toward simulation?
  - Do you see any benefit in performing simulations more often?
  - More complex simulations?
  - Do you feel as if the benefit from learning to simulate more out-weights the time it takes to learn?
  - What would be needed for you to simulate more?

- Do you think someone should be responsible for simulations being performed?
  - Who?

- Is there anyone who wants you to simulate more?
  - Do you feel as if your managers push you to simulate?
    * To learn or cooperate with specialists?

- What is the attitude toward simulation in the company?

- Would it be good if managers pushed for and showed the benefits of simulation?

- If one would want to simulate more, where do you think the initiative should come from, managers or design engineers?

- How has the process that has lead to where you are today played out, concerning simulation?
  - How were the methods for simulation implemented?
  - How has the process developed over time?

- How do you think one should proceed to get acceptance for a change of working methods?
  - Do you have any experience of a successful or unsuccessful implementation project?
Appendix C

Questions to Specialists

The questions that were asked to the DEs are presented below in both Swedish and English. Since the interviews were held at Swedish companies, only the Swedish questions were asked. The English questions were directly translated for the international readers of this report, but were never used.

Questions in Swedish

- Vilken är din roll?
  - Vilka är dina arbetssysslor?
  - Vilka typer av produkter utvecklar du?
  - Var kommer du in i produktutvecklingsprocessen?
- Hur länge har du jobbat på företaget?
- Hur många arbetar på din avdelning?
  - Hur många inom R&D?
- Vilka produkter utvecklas?
- Berätta kortfattat om din arbetsprocess, från att du får en förfrågan till du redovisar resultatet.
  - Har ni en dokumenterad/standardiserad process?
  - Finns simulering med i denna?
    * Skulle det kunna vara det?
- Vilken simuleringsmjukvara använder du?
- Utför du simuleringar som konstruktörerna skulle kunna göra?
  - Utifrån nuvarande kunskap?
  - Med lite träning?
– Ser du någon nytta i att konstruktörerna skulle simulera?
  * Hur mycket skulle de behöva lära sig i så fall?

• Hur arbetar du med konstruktörerna?
  – Känner du att dina chefer pushar dig att samarbeta med/lära ut till DE?

• Hur ofta skickar ni tillbaka modeller på grund av fel som behöver justeras av konstruktörer?

• Hur är attityden mot simulering i företaget?

• Finns det en fungerande systeminfrastruktur?
  – Uppstår det någonsin problem med överföring av filer/modeller?
  – Hur hanterar/sparar ni resultat från simulering?

• Dokumenterar ni best practice?
  – För simulering?

• Känner du att du har för mycket att göra?

• Om man skulle vilja få DE att simulera mer, var borde initiativet då komma från chefer eller från konstruktörer?

Questions in English

• What is your role?
  – What are your work tasks?
  – What kind of products do you develop?
  – In what part of the product development process do you act?

• For how long have you been working at the company?

• How many individuals are working at your department?
  – How many within R&D in total?

• What products are developed?

• Tell us about the product development process, from idea to product launch.
  – Do you have a documented/standardized process?
    * Is simulation included in this documentation?

• What simulation software do you use?

• Are you performing simulations that could be performed by design engineers?
  – With their current knowledge?
  – With some training?
  – Is there any benefit in having the design engineers simulating?
How much would they then have to learn?

- How are you working in relation to the design engineers?
  - Do you feel as if your managers are pushing you to collaborate with and educate the design engineers?

- How often are models sent back to the design engineers for adjustments?

- What is the attitude toward simulation in the company?

- Is there a working systems infrastructure?
  - Are there ever problems with transferring files/models?
  - How are results from simulation handled/saved

- Are you documenting best practices?
  - For simulation?

- Do you feel as if you have too much to do?

- If one would want the design engineers to simulate more, where should the initiative then come from, the managers or the design engineers?