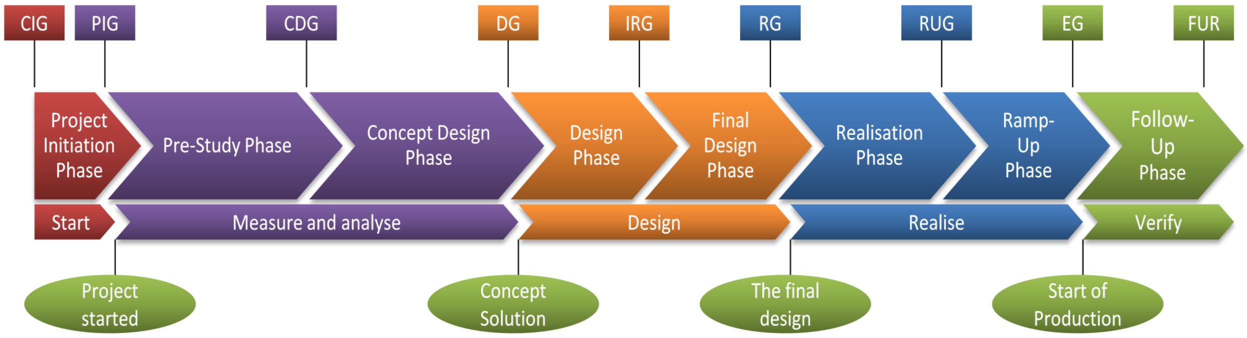


STUDY OF PRODUCTION SYSTEM DEVELOPMENT AT GKN AEROSPACE ENGINE SYSTEMS SWEDEN

The realisation of a production system

Master of Science Thesis in the Master Degree Programme Production Engineering

CARL DÄRNEMYR

MARCUS LINDELL

Department of Product and Production Development

Division of Production System

CHALMERS UNIVERISTY OF TECHNOLOGY

Trollhättan, Sweden, 2013

Study of Production System Development at GKN Aerospace Engine Systems Sweden

The realisation of a production system

CARL DÄRNEMYR

MARCUS LINDELL

Supervisor: Erik Lindskog

Examiner: Björn Johansson

Department of Product and Production Development

Division of Production System

CHALMERS UNIVERISTY OF TECHNOLOGY

Trollhättan, Sweden 2013

Study of production system development at GKN Aerospace Engine Systems Sweden

The realisation of a production system

CARL DÄRNEMYR

MARCUS LINDELL

Departments of Product and Production Development

Division of Production Systems

Chalmers University of Technology

SE-412 96 Göteborg

Sweden

Telephone + 46 (0)31-772 1000

Cover:

The picture on the cover is the proposed project model flow

Printed by ReproService, Chalmers

Göteborg, Sweden 2013

SAMMANFATTNING

När ett nytt produktionssystem utvecklas på GKN Aerospace idag, används en generisk projektmodell anpassad för systemutveckling. Dock har det uppfattas den senaste tiden att det skulle vara fördelaktigt att använda en projektmodell som är specialiserad för produktionssystemutveckling istället för den nuvarande projektmodellen.

Som ett underprojekt till forskningssamarbetet 'Visuell Produktion' som bedrivs av Chalmers tekniska högskola och GKN Aerospace Engine Sweden, har denna masteruppsatsen syftet till att föreslå en ny projektmodell specialiserad för produktionssystemsutveckling. Masteruppsatsen fokuserar även på att undersöka när och var det är lämpligt att använda simulering och visualiserings verktyg i utvecklingsprocessen. Den föreslagna projektmodellen är baserad på undersökningar i den akademiska värden, då i form av en litteratur studie, benchmarking besök för att undersöka olika arbetsmetoder och en utbildning i lean produktutveckling.

Resultatet är en sammanställning av åtta olika projektmodeller. De olika projektmodellerna kommer både från den akademiska världen och från benchmarking besöken. Resultatet har även tagit inspiration från lean produktutveckling, virtuell produktion och hur man designar ett produktionssystem för lean produktion. Den föreslagna modellen består av fem olika etapper uppdelade i åtta faser och nio grindar. En ny arbetsmetodik är också presenterad, denna är baserad på virtuell produktions teori men har även tagit inspiration från set-base engineering som finns i lean produktutvecklings teorin.

Nyckelord:

Projektmodell, Produktionssystem, Utveckling, Virtuell produktion, Simulering, Visualisering, Lean Produktion

ABSTRACT

When developing a new production system at GKN today a generic project model for system development is used. Although there have been perceived that it would be beneficial to use a specialised project model for production system development instead of the current project model.

As a sub-project to the research collaboration 'Visuell Produktion' between Chalmers University of Technology and GKN Aerospace Engine Sweden this master thesis purpose is to propose a new specialised project model for production system development. The master thesis also focuses on how and when it is suitable to use simulation and visualisation tools in the development process. The proposed project model is created by research in the academic world in the means of a literature study, benchmarking visits to investigate different ways of working and education in lean product development.

The result is a compilation of eight different project models found in both the academic world and through benchmarking and also contains inspiration from lean product development, virtual production tools and how to design the production system for lean production. The proposed model contains of five different stages divided into eight phases and nine gates. A new work methodology is also presented using virtual production and inspiration from set-base engineering found in the lean product development literature.

Keywords:

Project model, Production System, Development, Virtual Production, Simulation, Visualisation, Lean Production

ACKNOWLEDGMENT

There are a number of people we like to thank for their help, support and generosity during our thesis work. First of all, we like to thank our supervisors, both Erik Lindskog at Chalmers and Johan Vallhagen at GKN, for their support, advice and feedback during the thesis work. Both Erik Lindskog and Johan Vallhagen along with the examiner Björn Johansson have been invaluable when providing and pointing out contact persons for both interviewing and particularly in the benchmarking visits.

At GKN there are several persons we like to share our thankfulness to. The persons that have helped us during the thesis work is too many to mention all by name but a special thanks goes to Torbjörn Hillerström, Patrik Andersson, Oskar Höglund, Stefan Andreasson, Anders Lundblom and all the personnel at the office area CFK at GKN who have been supporting the thesis work in one special way or another. Two other persons that must be acknowledged for their generosity is Stefan Bükk and Lars Holmdahl who provided the education in Lean Product Development.

Lastly, a big thanks to towards GKN that provided the opportunity to conduct this thesis work and, again, to all the personnel at the office of CFK who have been very open, helpful and made us feel welcome during our brief twenty week stay at GKN.

Regards,

Carl & Marcus

This work is an important part of the project *Visual Production* which is funded by VINNOVA (Swedish Agency for Innovation Systems) and the NFFP5 program.

TABLE OF CONTENTS

1 INTRODUCTION

This thesis is carried out at GKN Aerospace Engine Systems in Trollhättan, Sweden, during the time period of November 2012 to March 2013. The thesis is a sub-project in the research collaboration between GKN Aerospace Engine Systems and Chalmers University of technology called 'Visuell Produktion'[1]. This introduction aims to give the reader a clear understanding of the background and the purpose of the thesis. The first part describes the background and gives the reason why the thesis is carried out along with a presentation of GKN Aerospace Engine Systems. The second part of the chapter brings up the purpose of the thesis with the goals and limitations as well as a description of the disposition of the report.

1.1 BACKGROUND

Manufacturing companies in Europe have a strong position in industrial engineering with the ability to provide attractive product solutions (Westkämper, 2006). Although offering attractive product solutions is not enough to stay competitive for a manufacturing company in today's economy (Rösiö, 2012). The customer's expects low prices and high quality but also that the products are delivered at the right time (Bellgran & Säfsten, 2010). To deliver all this to the customer a strong product realisation process is necessary. This process contains of two major parts, the product development and the production system development (Bellgran & Säfsten, 2010). Both academic and industry focus on the product development rather than on production system development (Bellgran & Säfsten, 2010). Together with the rapid development of 'lean production' since Jeffrey Liker coined the term in 1980 and its global impact on the manufacturing industry the authors argues that there is a potential competitive edge to gain if putting a greater weight on the production system development process.

A study on the design and evaluation of production systems was performed in the 1990's in Sweden, one of the findings was that "the procedure when developing production systems is not in focus" (Bellgran & Säfsten, 2010) and that the development process is rarely used to produce the optimal production system (Bellgran & Säfsten, 2010). One other finding from the same study was that there is no systematic and structured way of working in the development process (Bellgran & Säfsten, 2010). This finding is supported by Chryssolouris (2006) statement that trial and error is the most commonly used method when developing production systems. When using this method the success depends heavily on ability of the 'guesser', i.e. the designer (Chryssolouris, 2006).

[1] Translation SV to ENG: Visual production

In the aerospace business a company faces many challenges, the three most notable are the extreme quality requirements, strict environmental requirements and the long product life cycles (Vallhagen, Stahre, & Johansson, 2011). This unique situation for an aerospace company puts a lot of effort on the production system, it have to handle products in different stages of the life cycle which causes a very mixed production program along with fulfilling the extreme quality requirements. Newly introduced manufacturing process technology must be able to handle new engines as well as old engines which are not always the case, this leads to a large variety in production methods (Vallhagen, Stahre, & Johansson, 2011). These quite unique requirements on a production system call for a structured and systematic way to develop production systems.

1.2 GKN AEROSPACE ENGINE SYSTEMS

GKN Aerospace Engine Systems (from now on abbreviated GKN) is a manufacturer within the aerospace business and is specialised on engine components. GKN has a rich history from the start in 1930 (under the name of Nohab Flygmotorfabriker) which has been characterised with the company's close collaboration with the Swedish Air Force. In 1970's the company (then under the name of Volvo Flygmotor and later Volvo Aero in the 1990's) took the step out into space trough the collaboration with the European Space Agency with the Ariane space rockets and have been a part of the project ever since. In 2012 GKN acquire the operations from the Volvo Group and today engine components from the company can be found in 90 % of the world's new larger aircrafts (GKN, 2013).

1.3 PURPOSE

In a production system development project at GKN today, a generic model for system development is used. The project model fulfil its purpose of guiding the project forward but due to recent experiences the project model has been perceived as more demanding that it needs to be. This is thought to be because is not a specialised model for production system development and therefore consider areas that are irrelevant for this particular development process. The current model needs to be reviewed and improved to become a specialised project model for production system development.

The purpose of this thesis is to propose a new and improved project model to GKN that is specialised for production system development. This will be done by evaluation of the current project model, conduct a literature study and benchmark, to bring forward other ways of working and different project models used for this type of development. The focus for the thesis will be on how, when and to what purpose simulation and visualisation tools can be used in the development process and also how to design for lean production and how to plan the work to achieve a shorter development time.

1.3.1 Goals

- Provide a description of a methodology that can be used when developing a production system
  - Using a project model to guide the project forward
  - Describing how, when and to what purpose simulation tools[2] can be used
  - Describing how, when and to what purpose visualisation tools[3] can assist the development process
  - Pointing out a framework of design guidelines for lean production
- Creating a handbook describing the purpose and overall activities different phases and gates have and also point out main deliverables and when they are due to be delivered

1.4 Problem Description

The current project model is a generic project model developed for information and IT systems. This causes the project model to contain a lot of information and decision points that might not be relevant or applicable to production system development. Because of these factors it is believed that improvements could be made to the project model but it is not certain what could be done. Therefore there is a need to map how the current project model works at GKN and evaluate how suitable it is for production system development to identify improvement areas. To address this problem, the following research questions are investigated:

1. How does GKN develop a production system and how does the current project model work?
2. Is the current project model suitable for production system development and are there better alternatives?
3. Can the current project model used at GKN be improved to be more suitable for production system development?
4. How can visualisation and simulation tools be used in production system development?

1.5 Scope

The thesis is an individual project and will research the project model and work methodology used at GKN today in the development process of a new larger production system. The thesis will also research in literature and with benchmarking other ways of working when developing a new production system and propose a new specialised project model and a work methodology based on the findings.

---

[2] Simulation tools: Computer tool for rendering the real world in a mathematical model, an example is Discrete Event Simulation
[3] Visualisation tools: Computer model presenting the real world or a future state digitally

1.6 DISPOSITION OF THE THESIS

The first two chapters (2 & 3) describe the methodology used in the research and also present important theoretical parts for the thesis work. The next coming two chapters presents the focus point of the thesis, first the result of the mapping process is presented and later on the investigated project models are presented in a general sense. After these chapters the analysis (chapter 6 & 7) is described and a lot of information from the different project models is presented in tables. Chapter 8 presents the result of the whole thesis and describes the proposed project model with further descriptions in project organisation, work methodology and how simulation can be used in the development process. The last two chapters is discussion of important parts of the thesis work, conclusions and recommendations for GKN.

2 METHODOLOGY

The methodology chapter describes how the thesis research was performed. First a method map is presented to give the reader a brief overview of key phases in the research and which methods were used in the specific phase. Afterwards the specific method is described more comprehensively with its theoretical base and description of how the authors used the method. The order that the methods are presented is; Literature study, Interviews, Education in Lean Product Development, Benchmarking and finally Compilation process.

2.1 METHOD MAP

To fulfil the purpose of the thesis the research has been performed through four phases. In Figure 2-A an overview of the phases and what methods used in every phase are presented.

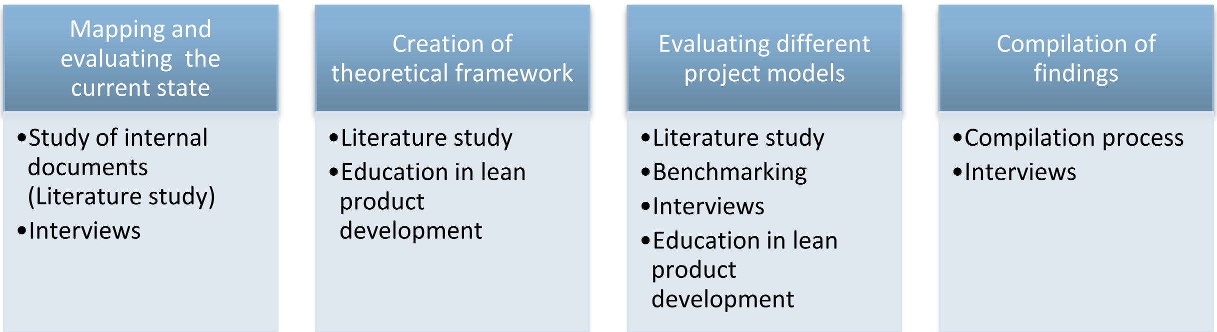


FIGURE 2-A METHOD MAP OF THE RESEARCH

During the *Mapping and evaluation the current state*-phase a study of internal documents was performed to familiarise and create a general description of the project model used. Afterwards, interviews with key-persons at GKN were performed to get a more in-depth knowledge and description of the project model.

Creation of theoretical framework and *Evaluating different project models* was conducted in parallel and simultaneously and therefore shares many of the methods used. The literature study was performed to gather information about different project models used elsewhere as well as bring forward specific methods suitable for production system development.

The *Compilation of findings*-phase was where all the relevant information acquired in the earlier phases was summarised and merged together in a compilation process to create a new and improved project model. To verify the usability of the created model interviews where once again held with key-persons within the organisation.

2.2 LITERATURE STUDY

The purpose of a literature study in general is to communicate what knowledge that exists in the field of the studied subject (Taylor, 2012). The documentation of the literature study must be inside the frame of the research, or in other words be guided by the research objective, and not be a summary of the available material (Taylor, 2012).

The performed literature study used a framework of three stages. The three different stages are; Input, Processing and Output, whereas the processing stage is the main component. The input stage focus on quality assurance of the literature studied. The output stage describes how the researcher should put the findings into writing. Still the processing stage is the main component for this particular study and needs a more detailed description. The processing stage is divided into six different tasks:

TABLE 2-A FRAMEWORK TO GUIDE NOVICE RESEARCHER TO PERFORM AND EFFECTIVE LITERATURE STUDY (LEVY & ELLIS, 2006)

Task	Description
Know the literature	This first task is about familiarise with the field but also read different articles and extract useful information from it
Comprehend the literature	This task aims at going deeper into the literature and not only know what information that exist but also comprehend the meaning and significance of the information
Apply	Applying the information brought forward means that the researcher must identify major concepts across the whole literature and putting information into the correct category
Analyse	The analysis show why the information is of importance for the research
Synthesise	The researcher must put all of the parts from the literature study into context and make the whole exceed the sum of all its parts
Evaluate	Evaluating the literature is to differentiate if a statement is a opinion, theory or an empirically recognised fact

Along with this framework the authors have contacted experienced researcher in the field for recommendations on what literature to study and what specific key words that can be used to bring forward relevant information. The search for literature has been performed both in the traditional sense of physically being in the library but also electronically in the databases of Chalmers Library and Google Scholar and the intranet at GKN.

2.3 INTERVIEWS

Interviews are often classified on the level of 'structure' that the interview method has (Rowley, 2012). Structured, semi-structure and unstructured interview, whereas the structured interview tends to give more quantitative data than qualitative data (DiCicco-Bloom & Crabtree, 2006). Also the structured interview is allowing limited answer alternatives and the pre-determined questions are asked in the same order and the free flowing conversation between interviewer and interviewee is very limited (Sandy & Dumay, 2011). The goal with the interviews are to bring forward qualitative data from the interviewees and take part of their experience and opinions, so it is natural that structured interviews will not be used in the research.

Unstructured interviews requires observation of the process and taking part (in more or less active way) in the process simultaneously as the interview recognise key persons to ask questions to and take notes of their answers (DiCicco-Bloom & Crabtree, 2006). One other part of the unstructured interview is the assumption that the interviewer does not know what questions to ask before the interview is conducted (Sandy & Dumay, 2011). Due to these facts, the semi-structured methodology is chosen because of the guided approach that is applied to hold the interview inside the frames of the research but also permits the ability to get more elaborated answers with non-scripted questions (Sandy & Dumay, 2011). One other positive aspect of the semi-structured interviews is the ability to perform in-depth interviews either with individual or with a group of people (DiCicco-Bloom & Crabtree, 2006).

The two forms of interview (individual and group) differ in some aspects that are important to take into account as an interviewer. The individual interview allows for a more deeply exploration in personal matters and ideas but on the other hand group interviews gives broader variety of experience and knowledge (DiCicco-Bloom & Crabtree, 2006). Also the group interview encourage reasoning about a subject between the interviewees but with the negative effect that more social interviewees takes the upper hand towards other in the group and group dynamics could affect the answers (Trost, 2005).

The methodology that will be used in this research is the semi-structured interviews with guiding questions or an A3-report[4] to act as discussion foundation. To bring forward the interviewees own experiences and opinions open-ended questions and a free-flowing conversation is going to be used (Hutchinson & Wilson, 2006). This combination of material for discussion and open-ended questions the authors believes have the possibility to give elaborated answers on the interviewees experiences

[4] A3-report: In a practical sense a A3-report is used because it offers a good overview of the subject but also can contain detailed data about the subject and is easily manoeuvrable in an interview or a meeting (Holmdahl, 2010)

and opinions as well as shed light on a relevant subject unknown for the interviewers, thus improving the research.

2.4 EDUCATION IN LEAN PRODUCT DEVELOPMENT

"Part of the theoretical foundation for development of production systems can be found within product development" (Bellgran & Säfsten, 2010), with this connection between product development and production system development the authors thought it would be beneficial to expand their knowledge base within the field of product development. The reason behind choosing an education in lean product development was that it offers techniques such as set-based engineering, A3-reports, visual management and the Reynolds model that the authors thought would be beneficial to use in a production system development project.

The education was based on Lars Holmdahl's *'Lean Product Development På Svenska'* [5] and the lectures where held by Lars Holmdahl and Stefan Bükk.

2.5 BENCHMARKING

Benchmarking is not just a method to compare one company to another; it can be seen as an effective tool to uncover new ways to improve the organisation (Andersen & Pettersen, 1997). This is achieved by adding a structural way of working in the areas of: finding new improvement ideas outside the own organisation, finding new and innovative methods to the improvement work and a way to establish methods that correspond to best practice.

According to Andersen & Pettersen (1997) there are four main reasons to use benchmarking as an improvement tool:

- It helps the organisation to understand and critical assess its own way of working.
- To promote an active learning process that motivates change- and improvement work.
- Finding new ideas for improvements.
- Find key-performance indicators of the most critical processes.

In the benchmarking process it is possible to compare the whole company or just some specific parts such as processes, functions or products. The type of benchmarking can be defined by what to compare and to whom (Andersen & Pettersen, 1997), see Table 2-B.

[5] Translation SV to ENG: Lean Product Development in Swedish

TABLE 2-B WHAT AND WHOM TO BENCHMARK (ANDERSEN & PETTERSEN, 1997)

What to benchmark	Whom to benchmark
Performance: Evaluate the company to other companies	**Internal:** Compare departments and manufacturing facilities in the same organisation
Process: Learn from the best, compare methods and processes	**Rival:** Compare yourself to your competitor
Strategic: Evaluate strategic decisions that other companies are taking to help the own organisations strategic planning	**Functional:** Benchmark companies with similar processes but are not competitors
	Generic: Compare to best practice regardless of business area

The chosen method for benchmarking in this study is to benchmark processes (the 'what') which corresponds to the thesis goal of investigate how the production system development process can be improved. When conducting a process benchmarking using a combination of functional and generic benchmarking (the 'whom') is the most effective (Andersen & Pettersen, 1997). The outcome of this approach is to benchmark companies with similar processes but not competitors to GKN or benchmark against best-practice companies. The reasoning behind this is that it is easier to gain relevant information when the companies are not direct competitors. The benchmarking study was conducted in accordance with the principles of the benchmarking wheel (Andersen & Pettersen, 1997):

- Plan: Chose the process to observe and indentify the important parameters
- Find: Find appropriate partners to benchmark
- Observe: Visit the company, observe and try to understand the process
- Analyze: indentify differences in performance, praxis and prerequisites
- Implement: Choose best practice and conduct changes accordingly

When selecting appropriate companies for the benchmarking study, key attributes that the company should have were selected. To fulfil every attribute for each bencmarking visit is considered hard and therefore the benchmarking visits are focused on one of the five attributes. The five different attributes and the company that was benchmarked corresponding that attribute is presented in Table 2-C.

TABLE 2-C BENCHMARKED ATTRIBUTES AND THE CORRESPONDING COMPAIES

Attribute	Company	Company description
A company of the similar size as GKN and handling a large amount of manufacturing processes or machines	SKF, Gothenburg	Large manufacturing company with similar machinery and processes
A company that has experience of conducting production system development and are heavily focus on Lean Production	Autoliv, Vårgårda	Supplier of safety products for the automotive industry with many new production system developments, heavily focused on Lean Production
A company which has a good reputation of using Lean Product Development	SAAB Electronic Defence Systems, Gothenburg	Case-company for demonstrating how to use Lean Product Development for the education described in 2.4.
A company that have integrated Virtual Production in their production system development process (Two different visits)	Volvo Cars Corporation, Gothenburg	Uses Virtual Production in every new development project
	Volvo Group Trucks Technology, Gothenburg	Has the overall responsibility of the virtual manufacturing models, specialised towards Volvo Trucks.
A company which has a well developed process development project model	Volvo Group Trucks Operations, Gothenburg	Information gain first hand by the Project Steering Model process owner.

A questionnaire (see Appendix A) and a description of points of interest (see Appendix B) where created and sent to the company in advanced. This approach made it clear for the contact person what the benchmark visit was focusing on and to avoid that the visit became a traditional company presentation (Andersen & Pettersen, 1997).

The five companies where benchmarked in the same way by finding the answer to the same questions. The point of interest was then evaluated by comparing the result from the different companies in an evaluation matrix (see Appendix C).

2.6 Compilation process

The purpose of the compilation process is to generate one project model that fulfils the overall purpose and goals of the thesis. The project model will be a compilation of three different main areas investigated during the thesis. The three areas are theoretical framework, project models and benchmarking visits, see Figure 2-B.

The compilation of the project models are performed by grouping the project models different phases and gates together according to what purpose the phase/gate have and what activities are to be performed. After the grouping process is finished the information about each phase/gate is evaluated and deciphered into one final phase/gate.

This final phase/gate is then spiced with information obtained from the theoretical framework and benchmarking visits.

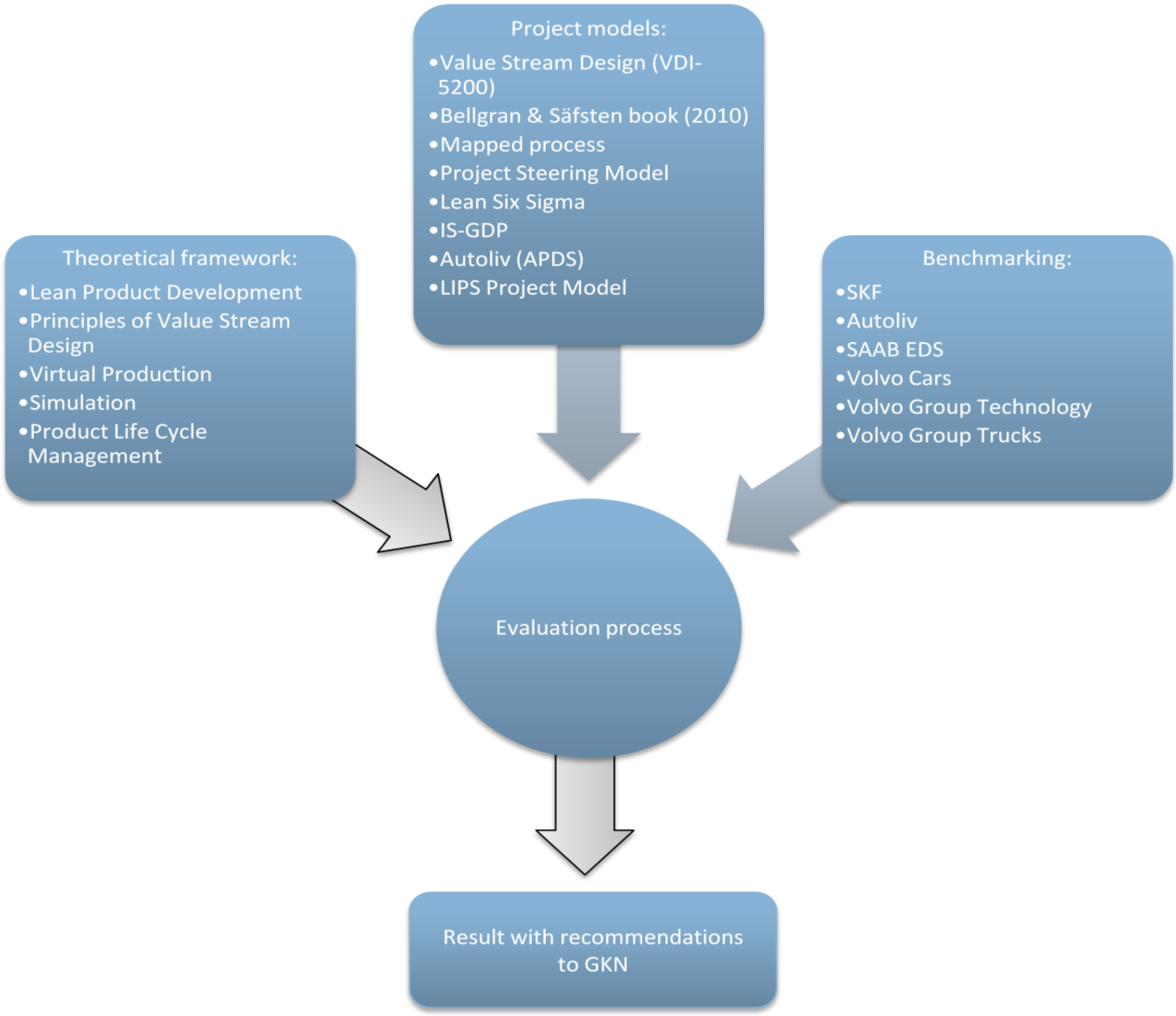


FIGURE 2-B COMPILATION PROCESS

3 THEORETICAL FRAMEWORK

The theoretical framework aims to provide the reader with a deeper understanding in relevant topics connected to the thesis. First, the theory of what a project model is presented and after that lean product development, principles of value stream design, virtual production and simulation and last a brief overview of life cycle management.

3.1 PROJECT MODEL

To understand the purpose of a project model there is a need to understand what a project is. How to define a project can vary from person to person and the definitions are numerous (Svensson & Krysander, 2011). One definition that is quite general and appropriate is:

"A number of project members execute, under the guidance of a project manager, a well-defined task, within a specified time and with given resources. The resources can be people, machines, money or premises. The project must have measureable goals" - (Svensson & Krysander, 2011)

As each project is unique, more or less, and is born out of an idea, planned, executed and then finalised there is a need for an administrative tool to provide guidance and structure to the project (Svensson & Krysander, 2011). This is where the project model comes into play. To provide guidance the project model contains of a collection of rules and aids and includes descriptions of workflows, activities, roles, documents etc. (Svensson & Krysander, 2011). The usage of a project work methodology provide companies with one great advantage, activities can be performed parallel to each other rather than in sequence thus decreasing lead time of the total work (Svensson & Krysander, 2011).

Every project has a customer (also named sponsor, orderer, management group, steering committee, steering committee chairman in different literatures) this person has the responsibility to make the decisions on related costs and approve deliverables such as plans, costs etc.

To create a common understanding of the work needed to be done and identify different phases of the project, project models are often illustrated in a map or flow. This is confirmed by the models presented in theory (Bellgran & Säfsten, 2010; Erlach, 2013; Jugulum & Samuel, 2008) and in benchmarking (Autoliv, 2009; Schauvliege, PSM, 2012). The illustration shows from start to end which phases and gates (decision points) the project team have to go through. The project flow allows the project team to focus on the most important activities at the moment and secures that the steering committee can take the necessary decisions at a certain time.

3.2 LEAN PRODUCT DEVELOPMENT

Lean product development is a structural way of working when developing new products. The method is not as generally perceived, lean production applied on product development project, there are in fact many differences between Lean product development and Lean production development (Holmdahl, 2010). In production development elimination of waste is in focus, in product development on the other hand, documentation and presentation of knowledge is a big success factor. Development work is a learning process and Lean product development emphasises the importance of documenting learning's so that they can be used in the next project or the next phase of the current project. According to Holmdahl (2010) Lean product development is to create the prerequisites needed to be able to produce at least one product, this also includes the design process of a new production system.

3.2.1 SET-BASED DESIGN

Set-based design is a central part of Lean product development, instead of developing one concept (point based design) the team works with many parallel concepts and prototypes at the same time and try to delay decisions concerning specific parameters values as long as possible. By delaying the decisions the project team have the ability to gather more relevant information and thereby increasing the chance of making correct decisions. The idea is to set parameter-spans for design attributes and gradually narrow the design width to eliminate concepts until only one solution is left. The remaining solution is to be considered as the best solution that the company can achieve at the moment and should be chosen as the final concept. Set-based design is based on the following three principles (Holmdahl, 2010):

TABLE 3-A THE PRINCIPLES OF SET-BASE DESIGN

Principle	Description
***Number 1*:** Determine the solution space	The first principle means that the developer should first evaluate every option concerning his own area without taking other areas into consideration. The gathered knowledge is then documented in limit- and trade-off curves
***Number 2*:** Integration overlap	The solutions for the different part-functions are united in the overlapping areas. The combinations of solution that do not overlap are eliminated by narrowing the parameter span
***Number 3*:** Secure the functionality before deciding on the final result	This principle emphasises the importance of only considering solutions within the area where part functions are overlapping. It is also important that the elimination process is not stressed; the project team have to make sure that they have a functional solution before the detailed construction work starts.

Set-based design is considered to be harder and more time consuming than traditional product design, with this in mind it is easy to believe that progress in set-based design projects will be inefficient, slow and expensive. But this is not the reality; according to research, the result of companies applying this method is superior to the result of their competitors (Holmdahl, 2010). One advantage with set-based design is that it is possible to take substantial risks in the individual part-solutions without jeopardising the whole project.

3.2.2 A3-Reports

In Lean product development process, reports in the size of an A3 paper are to a large extent recommended as the documentation standard (Holmdahl, 2010). The A3 size is believed as a manageable and practical dimension to use when presenting information to team members at i.e. meetings. The benefit with an A3 sized report is that it is large enough to contain detailed information and at the same time give a clear overview with space for both pictures and text. In general, there are four different A3-report standards (Holmdahl, 2010): problem solving, suggestions, progress report and competitor analysis report. The main idea with A3-report is to present information in a way that is easy to read and easy to understand in a standardised layout. The A3-report should present the full story of the situation and to enable this, it is important to use pictures and charts which make it easier for the viewer to grasp the essentials in just a short look.

3.2.3 Knowledge Gaps

In the beginning of every development project there are certain lacks of knowledge that needs to be addressed, this lack of knowledge is called knowledge gaps and they are recommended to be documented on A3-reports (Holmdahl, 2010). It is not until all of this knowledge gaps are closed that the final decisions in the project can be determined. The created A3-reports, containing both the knowledge gap and the solution is then saved as lesson learned to be used in future projects. According to Holmdahl (2010), neglecting knowledge gaps are believed to be the most common reason to fire fighting situations in development projects.

3.2.4 LAMDA-Process

The LAMDA-process is an effective tool for the product developer to use in the learning process (Ward, 2007). The tool has the intention to support and guide the practitioner to a better and more effective way of developing new products. According to Ward (2007) LAMDA is short for:

- *Look*- emphasise the importance of going to see the situation yourself. The idea is to replace assumptions with real observations.
- *Ask*- get to the root cause, ask why five times, what am I seeing?

- *Model*- create a model using engineering analysis, simulation or prototypes, the goal is to create a visual presentation of the situation to be able to share your thoughts with others.
- *Discuss*- involve and discuss the matter with all involved parties; this will reveal if there is useful knowledge in the organisation.
- *Act*- tests your idea by conduction experiments.

When the cycle is completed it can sometimes be necessary to start all over again.

3.2.5 Project Room (War Room)

A project room is a dedicated area where all aspects of the project are displayed. By displaying all relevant facts on the walls a clear overview of the project is created, this overview makes the project room an effective tool to visualise and lead the project. The purpose of the project room is to present all aspects in all areas of the project, due to this width all functions (i.e. market department, sale functions, production, logistic etc) have to cooperate within the project room. To enable this cooperation it is important keep the meetings short, focused and productive (Holmdahl, 2010). By using a project room all communication within the project is conducted face to face which prevents the confusion that can lead to postponed decisions.

In the middle of the project room it is recommended to place a prototype presenting the goal of the project. The prototype (i.e. a product or visualisation of the production system being constructed) is a good tool for visualisation to be used in discussions when explaining different problems and other aspects concerning the project. The prototype will help to increase the general project understanding within the project team. Different charts, boards and blueprints can be placed on the walls in the project room, the idea is to have the projects goal in focus and trying to avoid going into more detail that can be presented in a clear and manageable way.

One effective and important planning tool, placed in the project room is the *visual planning board* which is used to present the project team members' individual activities. The board is focused on resources, not activities and the idea is that every resource (personnel) is planned respectively and yellow Post-it notes are used to display what activities have to be completed before the end-result is reached. It is important to point out that the planning board is not a way for the manager to delegate work; it is the team members themselves that write and display the Post-it notes after their name on the board (Holmdahl, 2010).The yellow Post-it notes communicates the most important tasks of the individual team members and in this way the whole team can follow and understand the totality of the project and see what work tasks are left to be done.

The boards and charts in the project room are updated prior to every meeting. During the meeting the team members have approximately three minutes each to present their work area, this leads to a fast and effective meeting structure with a total meeting time less than one hour.

3.2.6 The Lean Product Development Process

Lean product development process is most effective when developing products similar to products developed in the past; this means that the development team has access to material that enables them to make decisions based on experience, this highlights the importance of documenting knowledge gathered in previous projects. The Lean product development process is divided into five phases that are interlinked to each other without gate decisions (Holmdahl, 2010):

TABLE 3-B PHASES OF THE LEAN PRODUCT DEVELOPMENT PROCESS

Phase	Description
Phase 1: Market input	The product development is started and a chef engineer is assigned the project. An existing product needs to be changed or a new business opportunity is identified, the product is described in general, none detailed way.
Phase 2: Concept development	During this concept phase the product specifications are gradually developed into different concept solutions. Knowledge gaps are identified and plans are set for how to close them. New solutions are verified and conflicts are identified and solved. Experiences from prior projects are of great importance in this stage of the project.
Phase 3: Set-based design	The set-based design phase involves a large number of tracks; the large number of tracks dissolves dependence which leads to a solution that is as optimal as possible.
Phase 4: Integration events	The purpose of the integration events is to eliminate the number of parallel tracks by narrowing the parameter span. It is the chief engineer that makes the final decisions.
Phase 5: Detailed construction	The detailed construction should proceed without interference; this is due to the fact that all conflicts and uncertainties have already been resolved before this phase is started.

3.3 Principles of Value Stream Design

The idea with 'value stream design' is to design an optimal production system that operates according to lean production principles right from the start. Customer needs are in focus when designing a value-stream production system and the production takt-time should be based directly on the time between customer deliveries. The most effective way to achieve this optimal solution is to design with the aid of several design guidelines which are based, and expanded from traditional lean production (Erlach, 2013). In optimal solution design, avoidance of waste plays an important role and the main source of waste lies in uneven production. According to Erlach (2013) the ability to design a waste-free, levelled production flow is realised by using the following ten different design guidelines connected to different areas of the development process.

3.3.1 Segmentation of Factory (Production Structuring)

The value-stream under construction must be designed to a specific production section (i.e. product family). This value-stream will have certain resources in the factory that are firmly allocated to this specific value-stream. The goal is to have different value-streams within the factory that are dedicated to a specific product family. This means that a specific product family have one value-stream and will not be distributed by any other production flow or temporary production. After the segmentation is completed the future state idea is developed based on the first eight design guidelines, see Chapters 3.3.2, 3.3.3 and 3.3.4.

3.3.2 Designing Production Process (Dimensioning of Capacity)

In Value stream design, the customer takt-time is the determining factor that sets the capacity level in the production system; all cycle-times in the individual production processes should never exceed customer takt-time. Decreasing the need for buffers is an important aspect when designing the value-stream. This low-buffer approach can be seen as high risk production that will be sensitive to disturbances. On the other hand one piece flow production reveals problems that are not noticeable with large inventory or buffers; it is fundamental to reveal these hidden problems for achieving a low waste, even flow production system. Low inventory creates transparency which highlights the breakdowns to make sure that the problems are really taken seriously. To utilise the full capacity of the operator and minimise transportation it is essential to build the value-stream in a U-shaped flow which also enables the operators to control more aspects of the system.

- **Design guideline 1**: *Pace control by customer takt-time*. Adjust capacity in the value-flow to customer takt-time. This is the most important design guideline, all products in the value-stream must move forward at the same time to prevent buffers and bottlenecks.
- **Design guideline 2**: *Continuous flow production*. The production process must be planned as continuous one piece flow where batch-production is kept at a minimum.

3.3.3 Designing Material Flow (Production Control)

Design of a new production system starts with the production control guidelines, where it is decided how the individual production processes are linked to each other and how the material flow should be planned in the whole value-stream. If a continuous flow is not possible, FIFO (first in-first out) logic is used where orders are pushed through the production system in a pre-determined and unchanged manner. FIFO is especially applicable if parts of the value-stream contains of shared resources[6].

The goal of every value-stream is to be triggered by one resource and this resource acts as a pacemaker for the entire value-stream, all other resources are being controlled accordingly. The pacemaker sets the starting point for push production; all resources prior to the pacemaker are producing according to pull principles.

- **Design guideline 3:** *FIFO approach when continuous flow is not possible*. FIFO planning principles must apply if products have to use resources outside the designated production flow (i.e. technological or organisational reasons).
- **Design guideline 4:** *Kanban control*. Production-rate is controlled by customer demand; this is achieved by using pull principles.
- **Design guideline 5:** *Pacemaker process*. To enable the value flow to follow customer takt-time, it must be triggered accordingly; this is controlled by the pacemaker process.

3.3.4 Designing Information Flow (Production Planning)

Decisions of how production-orders are planned and released in the production system are covered by design guidelines in production planning. Pre-processing of customer demand is important to be able to keep a levelled production and enable a smooth value-stream. This requires the orders to be released in a constant rate and at the same time taking account for restrictions affecting the production process. The most important rule of production planning is that it is not allowed to alter with the planned sequence after it is released; this is important in order to secure a predictable production flow. The production planning goal of a value-stream is reducing the risk of overproduction and inventories that are addressed as unnecessary waste and needs to be avoided. Lower inventories generally equals to shorter production lead times, a lean factory is a fast factory (Erlach, 2013)

- **Design guideline 6:** *Definition of release units*. Start of new production orders must be planned and released in a structured way to enable an even production flow.
- **Design guideline 7:** *Even production mix*. To reach a balanced flow, the production orders concerning variants must be well intermixed.
- **Design guideline 8:** *Bottleneck control*. Release-rate of new orders is controlled by restrictive downstream bottlenecks.

[6] Shared resources: A resource that is shared between two or more product families, could be a machine or process that is complicated with specialized personnel, have a high investment cost or is very space demanding (i.e. quality control, non-destructive testing, hardening)

3.3.5 Implementation (Improvement Measures)

The future state conception based on the first eight design guidelines is documented in a value-stream drawing, the drawing consists of all production processes and their logistic linkages; this includes detailed parameters for cycle time, changeover times, lot size etc. Once the new value stream is defined, it is split up into section for incremental implementation. For every section an action is devised that clearly describes milestones, completion dates and most important, responsibilities. The pacemaker process is the process that has the most influence in the entire value-flow and due to its importance it will be the first to be designed according to the conceptual value-stream drawing. Once the pacemaker process is completed the design work can start with the subordinated downstream processes followed by upstream non customer affected processes. To speed up the implementation process, various sections of the new value-stream may be designed simultaneously. In the ramp-up phase the material supply should be generously designed to enable full attention to the process itself. One important aspect is that the pacemaker process should be the heart of the process and all other processes should be subordinated to this process at all times.

Only after the new production process is design according to the five principles (Production structuring, dimensioning of capacity, production control, production planning and improvement measures) mentioned above does it make sense to proceed with the actual planning of the factory location and layout (Erlach, 2013).

3.3.6 Factory Planning (Value Stream Oriented Planning)

The previously mentioned eight design guidelines focus on design of the factory production processes, in factory planning the physical realisation of the factory production procedure (factory layout and buildings) is addressed and this includes two more areas with design guidelines.

Space planning refers to how the factory area is broken down in different categories depending on the utilisation characteristics, the different utilisation categories are defined as following (Erlach, 2013):

1) **Production space:** Space for processes in the production system including production process related supply areas.
2) **Buffer and storage:** Space for raw material, products in production, finished products, tools etc.
3) **Circulation space:** Space for material and personnel flows.
4) **Functional areas:** Areas for production related office space, i.e. production control, CNC programming, staff information.

5) **Special purpose:** Areas indirectly related to the production but not directly connected to any specific value-stream, i.e. training workshop, technical centre's or tool making.
6) **Social and sanitary areas**: Toilets and break room etc.
7) **Free spaces**: Areas not included in the planned layout.

Space planning in value-flow design is strict when it comes to the division of personnel related separation of production processes and material flow. Production process personnel should only be responsible for value adding actives within the production process; it is the responsibility of the logistic personnel to serve the value adding process with enough material so that the production process personnel can focus on value adding work without disturbances.

- **Design guideline 9*:*** *Separation of production process and material flow*. The value-adding and logistic operations must be separated; this concerns both space and personnel.

Ideal layout is the next step in the factory planning process. Once the resource space requirements have been set, the factory layout can be planned in a way that prevents non-intersecting material flows. The arrangement of recourses in line with the material flow in the value stream is the foundation of flow oriented ideal layout.

- **Design guideline 10:** *Flow-oriented layout*. The production equipment should be organised according to the ideal value-stream and as close together as possible.

3.3.7 Real Layout

In an ideal lean production system design, a prerequisite that prevents the value-stream design is strictly prohibited and should not affect the end result. On the other hand, this ideal result cannot always be achieved, this happens due to the fact that circumstances are not always ideal, certain compromises in real life factory planning are necessary. Building related restrictions, structural conditions, area loads, lighting, air conditioning etc are all factors that can lead to deviations from the ideal solution. This step from ideal solution to real solution will result in different planning variants that have to be evaluated both in a quality and quantity perspective. Evaluation criteria are found in areas of product (material), technology (machine), time (method) and employees (man). Important aspects to consider in real production layout according to Erlach (2013):

- **Variability:** the production layout should be fast and easy to change in case of required modifications.
- **Quality:** the production layout should support a stable production process that assures a high quality level.

- **Speed:** the production layout should be planned in a way that enables clearly structured material flows; short direct transport, material flow oriented layout, short implementation time for projects, ergonomics-friendly and multi machine operation supporting space.

3.3.8 Value Stream Management

The production system manager has an important role in the value-flow production system. Once the value-stream have been planned, designed according to the ten design guidelines and realised, it is the job of the manager to assure that the day to day production is conducted according to value stream production principles and that the customer expectations are fulfilled, this includes both the value adding production and logistic operations. Besides the day to day operations, the manager is also responsible for value stream adjustments due to alterations in product design, compositions of product families and the product mix required by the customer. The value stream needs to be rebalanced and updated on a regular basis to keep its full performance. The conceptual factory design and realisation process are seldom perfect straight away which results in a production system that needs constant improvement work during factory operations. Of most importance in value stream management is the planning task controlling the flexibility and changeability of a lean production system (Erlach, 2013).

The result of Value stream design is a transparent factory which meats customer demand with clear information flow, low inventory and a production process in line with customer takt-time (Erlach, 2013).

3.4 Virtual Production

The digital factory concept has several benefits for the development process; by using virtual production tools a development team have the ability to shorten development time using less resources and achieving a better end result (Kühn, 2006; Schuh, et al., 2011). This is due to the ability to integrate CAD designs and CAE information in the development process, thus conducting the product and process development in parallel and synchronising the information between them (Kühn, 2006; Schuh, et al., 2011). This enables design teams to work seamlessly together and accelerating the product delivery (Kühn, 2006). This is even more apparent when planning high-tech products and production process with the main benefits in increased quality and flexibility of the planning process as well as reduced overall planning costs due to the avoidance of bad planning as pointed out in a company survey (Schuh, et al., 2011).

Optimising a plant design requires the expertise of several different fields (manufacturing, logistics, ergonomics, technology etc.) (Kühn, 2006), this gives the need for a uniform communication platform to ease the cooperation between the specialists. By having a virtual factory model[7] the different specialist could show their own opinions or suggestions in a uniform model that is close to reality (Wiendahl & Harmschristian Fiebig, 2003). This virtual factory model would enable the development team to ‘walk around’ in a mock-up of the future factory and inspecting and animate motion thus manipulate the model interactively without disturbing current production along with keeping the cost down (Kühn, 2006; Wiendahl & Harmschristian Fiebig, 2003). The virtual factory model would also support discrete even simulation tools that can run what-if scenarios to detect problems and optimise the performance of the system before it is even installed (Kühn, 2006).

Using the virtual factory model would also potentially minimise the misunderstandings and communication mishaps over the different technical areas and lead to a better planning result (Wiendahl & Harmschristian Fiebig, 2003). By using virtual factory models a distinguished financial benefit can be achieved because that major problems are recognised early in the development process and dealt with before the company ramps-up for production (Kühn, 2006; Wiendahl & Harmschristian Fiebig, 2003).

In more detail the virtual factory model most important feature is that it is a three-dimensional visualisation that is created very close to reality, which gives a good man-machine interface with virtual presentation and manipulation of 3D data in real time (Wiendahl & Harmschristian Fiebig, 2003). This interface brings many benefits in planning speed, planning cost and planning quality due to the easy handling of complex three-dimensional data and that rough measurements are enough to get a spatial impression of a plant or installation (Wiendahl & Harmschristian Fiebig, 2003).

The three most apparent areas that are benefited by virtual production and particularly virtual models are planning speed, planning cost and planning quality, see Table 3-C.

TABLE 3-C MAIN BENEFITS WITH VIRTUAL PRODUCTION (WIENDAHL & HARMSCHRISTIAN FIEBIG, 2003)

Areas	Outcome
Increased planning speed by	Simplified data administration Handling of high data volumes General intelligibly presentation Intuitive handling of complex data Planning with imprecise data Support of co-operative planning
Decreased planning cost by	Presentation of different planning variants with small time and cost efforts Prevention of redundancies Prevention of change efforts due to early error detection

[7] A 3D-rendered model of a factory, created by scanning the factory and connecting several scans together

Increased planning quality by	Possibility to experience the factory Close to reality presentation Participation of employees Virtual models as a communication platform Interdisciplinary co-operation Planning reliability High degree of acceptance

3.4.1 Discrete Event Simulation

Discrete event simulation is considered as an effective and easy tool to use for manufacturing companies to analyse their complex production systems (Knoll & Heim, 2000). Machines used in production systems are often large, complex and heavy; this means that physical concepts are time consuming and costly to build. Simulation model enables quick modelling of different layout changes without moving the equipment, experimental layouts can easily be created and at the same time keeping track of all the variables involved. This fast way of conduction and testing different concepts enables the company to reject solutions that do not work and thereby decreasing the risk of wasting time and resources in a non profitable way. According to Knoll & Hein (2000); simulation is superior manual calculations in a project involving a system design containing waste amounts of details and variables. The simulation software enables the company to compile and simplify large amounts of data in a way that can be very helpful in the decision support process. The simulation model is based on facts which enables the decisions-makers to have an unbiased source of information that they can base their decisions on; this avoids mixed opinions and eliminates guesswork. The model can i.e. be used to give senior management and executives the information needed to calculation costs associated with taking on a new project. Simulation models also have de benefit of being a good and structural way for documenting information about company processes and decreasing information passed by word of mouth (Knoll & Heim, 2000).

Simulation software is also an effective tool for education and training of the personnel that is going to work in the system that is being constructed (Knoll & Heim, 2000). The model shows how the system works under certain circumstances and provides a visual example of the future process which enables the personnel to gain a better understanding. According to Knoll & Hein (2000) visual simulation is particularly effective when explaining the benefits of one-piece production compared to batch-production, the theories are simple but it can be hard to understand the impact without visualisation.

In the design process of a new production system a simulation model can help the project team to forecast the systems performance in advanced. This approach to find the optimal solution is according to Knoll & Hein (2000) beneficial and the simulation takes many aspects into consideration i.e. variations in distance and travel time between the certain resources and resource characteristics. The simulation model helps the decision-makers to evaluate the project even though there is very little information available. Once the system is finalised the model can be used to see how different improvement changes will affect the production performance.

The simulation model is not just a useful tool in the design phase; it can be used during the production systems whole lifespan. Further, the model creates information that helps to close the knowledge-gaps that every project team encounter and in this way ensuring more accurate predictions concerning the new production system (Knoll & Heim, 2000).

3.4.2 3D-SCANNING

As mentioned above 3D model technology is a good tool for decisions making and can be of great help to bridge the gap between different functions within the company. However, the traditional process of creating the 3D models is considered to be time consuming and often results in simplified models lacking information about critical aspects such as i.e. building- related geometric (Lindskog, et al., 2013). An improved level of detail and accuracy would increase the level of visualisation support in the model and help to increase the understanding gap within the organisation. A way to achieve this level of detail in a fast and manageable way is to combine 3D CAD-models and 3D laser scanning technology (Lindskog, et al., 2013).

Data collected from 3D laser scanning can be used to create a point cloud that presents a photorealistic AS-IS visualisation of factory constraints. The point based visualisation can then be combined with CAD objects to evaluate a future factory layout; the combination of 3D models in a point based cloud is a promising visualisation support tool in the designing process of future production systems (Lindskog, et al., 2013).

The 3D laser scanner technology is used to capture spatial data in 360 degrees by creating a point based cloud. The result of the point based cloud, which consists of millions of data points, is a large dataset. This dataset is constructed in just a few minutes and is described by x, y, z coordinates. The created model can be navigated freely in a close to photo like environment, in this environment the developer could for example evaluate if new equipment will fit into the planned factory area or not (Lindskog, et al., 2012).

It is believed (Lindskog, et al., 2013) that using 3D laser scanning technology to create point cloud models will provide a realistic visualisation that can be used to provide a better understanding throughout the organisation.

3.5 PRODUCT LIFECYCLE MANAGEMENT

The idea of Product Lifecycle Management (PLM) is to manage the product from cradle-to-grave. This approach provides benefits throughout the whole life-cycle, faster introduction to the market in the beginning-of-life, better support during the middle-of-life and better product management in the end-of-life (Stark, 2011). The PLM-process consists of five different phases where the product exists in different shapes. The five stages are Imagine, Define, Realise, Use/Support and Retire/Dispose, a description of each stage is provided in Table 3-D.

TABLE 3-D THE DIFFERENT STAGES IN PRODUCT LIFECYCLE MANAGEMENT

Stage	Description
Imagine	The product is an idea in one person or a number of peoples head
Define	The idea is transcript into a detailed description and developed further
Realise	The idea is making its way from an abstract digital product to an actual physical product and exist in its final form
Use/Support	The product is being used by the customer and could be supported by maintenance
Retire/Dispose	At the end of the lifecycle the product will come to a phase where it is not useful anymore for the company and is retired

The product must be managed throughout the whole lifecycle to make good money for the company, with that being said a company should manage the product 'from cradle to grave' (Stark, 2011). The product responsibility usually changes in the company throughout the lifecycle. At some stage the product responsibility will probably be at the engineering department, marketing, production or maintenance (Stark, 2011). The engineering department will most certainly have the product responsibility during the development process. The development process is called the *Beginning of Life* and is built up with three of the five stages in PLM, imagine, define and realise (Stark, 2011).

4 CURRENT PROJECT MODEL

The chapter provides a description of the current project model used a GKN, the IS-GPD model. This description is a result from the mapping process performed. The description is based on how the model should be used (the 'theory', study of internal documents) and how it is used in practice (interviews) and these two are combined to give the most complete picture on how the work is conducted using the project model. The structure of the description is that every phase is described with its purpose and activities and then the gate ending the phase is explained.

4.1 GENERAL DESCRIPTION OF THE IS-GPD

The current project model used at GKN is a phase-gate model called IS-GPD (Information System Global Development Process). It has seven different phases and nine different gates, see Figure 4-A for a visualisation. All gates are mandatory for a project to clear but can be combined if the project manager and steering committee comes to a consensus that the project is less complicated or mature enough to proceed faster than planned. The project model is very comprehensive and covers all phases from pre-study to follow-up via industrialisation. The purpose of the IS-GPD model is to enable successful management of process, organisation and system change from stating the business value in strategic planning to the deployment and realisation in the user organisation.

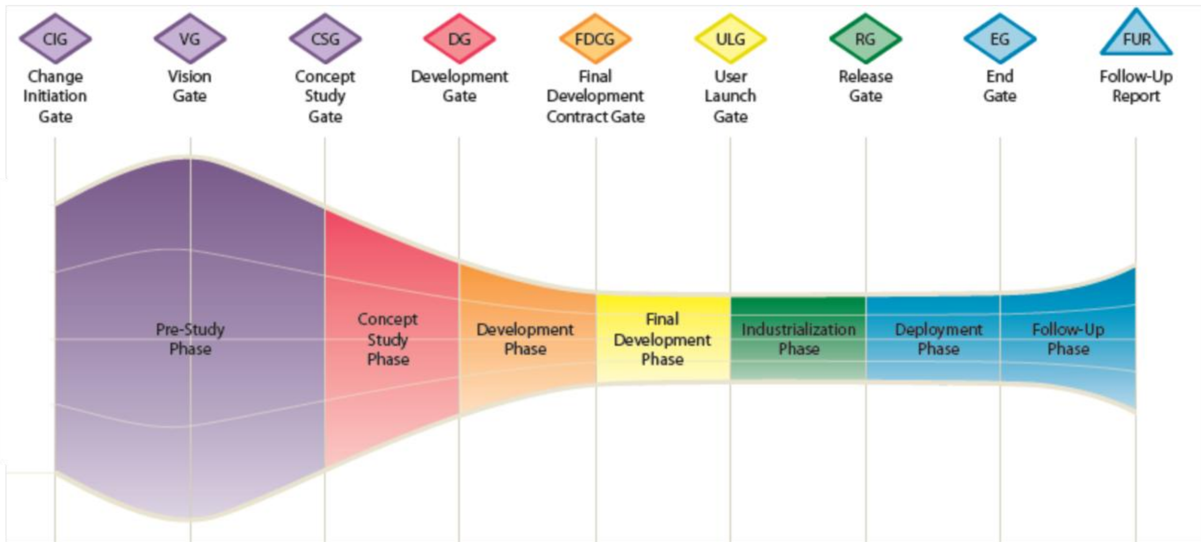


FIGURE 4-A THE VISUALISATION OF IS-GPD

The organisation of an IS-GDP project is build up by three stakeholders, an orderer, and a steering group and one project manager. The project manager has several project members to work together to complete the project. The project members have different work areas assigned to them.

Despite giving the impression of being very rigor with pre-defined steps and phases the actual work performed at GKN, as it came forward after the interviews, is that the phases are overlapping with each other. It also came forward that the actual work can be divided into six different phases instead of the original seven. How these six phases corresponds to the IS-GDP seven is shown in Figure 4-B.

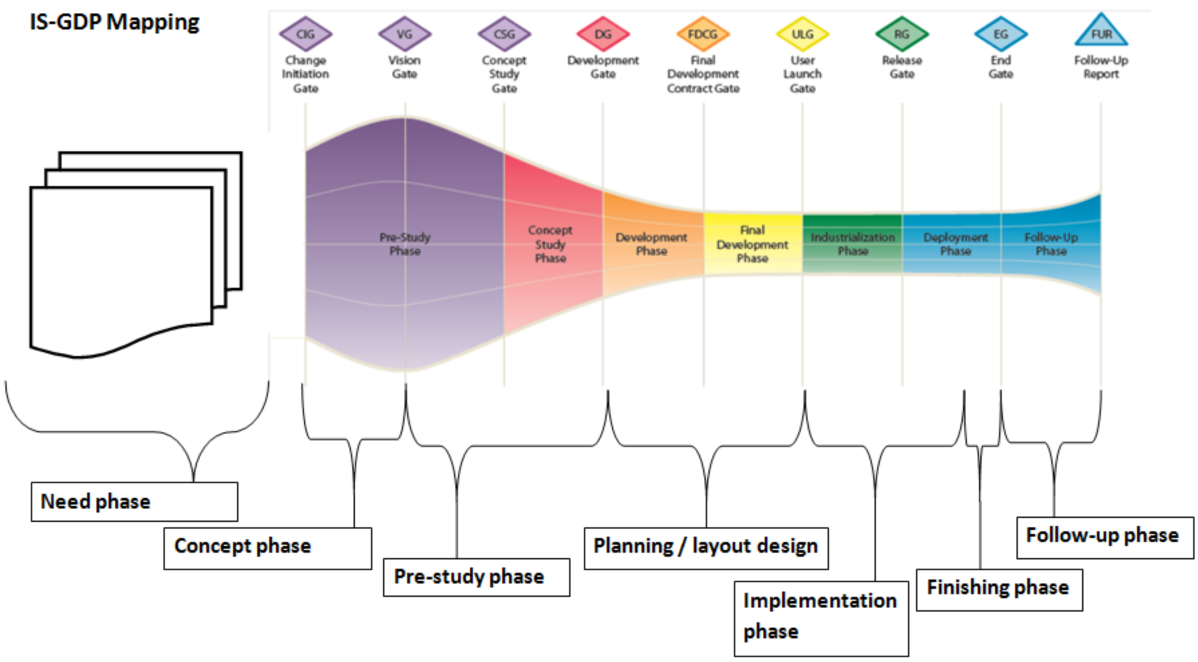


FIGURE 4-B HOW GKN WORKS RELATIVE TO THE IS-GDP, MODIFIED VERSION FIGURE 4-A

As visualised in Figure 4-B the phases of the IS-GDP and how GKN works does not coincide with each other thus complicating the description of the phases. However the description is based on the phases of the IS-GPD and aims to decipher the GKN phases to the appropriate corresponding phase.

4.2 NEED PHASE

The need phase is not an official part of the IS-GPD (as is not present in the visualisation in Figure 4-A) but the need phase describes the starting position and initiates the project. One major part of the need phase is the strategic planning, in which many of the decisions what product to produce, what technologies or methods to use is determined and this is what can start a business case. Depending on the manufacturing capabilities in the present and in the future both in a technology and capacity sense, decisions if a new production system is needed are taken. In basic, the strategic planning identifies the needs of the future and determines how to handle them.

The initiation of a new project starts with the *Change Initiation Gate (CIG)* which purpose is to approve the value of the business case. After the business value is approved, a pre-study is formally started and the appointment of project manager and steering group is carried out.

4.3 PRE-STUDY PHASE

The pre-study phase is intended to be a two part phase, the first part aims to develop a project vision and create a common understanding of the problem or opportunity at hand while the second part aims to define possible solutions. While GKN works in quite the similar way there are some differences to how the work is meant to be performed and how it is actually performed.

At GKN the project vision is created before the *CIG* and is approved in the gate. This is because of a combination of the two first gates in the model, *CIG* and *Vision Gate (VG)*. This combination means that when the project starts there is already a vision and project directives to guide the project forward. So the project starts with searching for possible solutions, aided by rough CAD-models. Different production concepts are also considered, the concept can be flow-layout, parallel flows, functional work shop etc. As the work progress more detailed solutions are created and block layouts (in 2D) are created. The block layouts are used to simulate logistical solutions and material flow for the possible solutions. Any other simulation or visualisation-tools for the production system development are not used to any major extent because it is easier to use block layouts and power-point presentations to visualise possible solutions.

To narrow down the solutions at hand there is a gate called *Concept Study Gate (CSG)* which purpose is to decide which solutions will be investigated further and to close the pre-study phase, thus initiating the actual project.

4.4 CONCEPT STUDY PHASE

The goal is to gather detailed arguments to decide on one solution to develop further. Usually the project manager presents three to five solutions (minimum two solutions is presented) with detailed arguments and a recommendation of which solution the group consider the best to develop further. These detailed arguments consist of block layouts, simulations of logistic and material flow on a more detailed level than in the pre-study phase but also calculations of lead-time, frozen capital and turnover rate. The recommendation of the group is based on these calculations, profitability of the solution and technical and economical risks. But in the end it is the steering committee that decides which solution is chosen. This decision is made in the *Development Gate (DG)*; once this gate is passed the development phase begins.

4.5 DEVELOPMENT PHASE

After the one solution has been chosen the work begins to construct a complete package around the product with "everything that is needed to start to make it real". In other words the project team develop all details necessary to reach the contract to start the industrialisation. This phase contains activities such as getting a technical specification and quotes on machinery, layout plans in high detail, personnel plans and education plans, logistic simulations and transportation solutions and investment plans.

To make sure that the solution is feasible to introduce in the production the *Final Development Contract Gate (FDCG)* must be passed through and its purpose is to freeze the solution and to sign the contract for deployment.

4.6 FINAL DEVELOPMENT PHASE

Focus is on how to deploy the solution on the production floor and that the solution is ready for user validation. The activities is of the same nature as in *4.5 Development phase* but developed into the detail level necessary for creating a deployment plan. The next gate called *User Launch Gate (ULG)* controls and confirms that the solution is ready for user validation test and starts the next phase which handles the industrialisation of the solution.

4.7 INDUSTRIALISATION PHASE

As explained to the authors this is where the physical production system comes to life. This phase is the longest and most expensive of all seven phases. The reason behind this is that all the machinery is obtained and designated factory is prepared with fundaments for machinery, storage spaces and also personnel rooms etc. After this phase the production system will be in place and ready to be used. To make sure a smooth transfer of the production system from the project team to the maintenance and production departments a gate called *Release Gate (RG)* is passed through and its purpose is to approve that the solution is ready for production and the organisation(s) is ready to receive it.

This phase and its activities cannot performed at an earlier stage because of the board must approve the investment plan for the project before the phase even can be begin.

4.8 DEPLOYMENT PHASE

This phase is most about the transfer of the production system. That means the delivery and training of the receiving organisation in how the production system works and logistic plans. During the phase there is also some report writing, closing of accounts and control that all assignments are completed. The *End Gate (EG)* controls that the deployment as been according to the contract and officially hands the production system over to the maintenance and production departments. This gate closes the project.

4.9 FOLLOW-UP PHASE

A follow-up is performed after roughly one year from the hand over and validates if the business case the project had in the beginning is achieved. The last gate, the *Follow-up Report (FUR)*, validates this and if it is needed decides action plans and further change management activities.

5 INVESTIGATED PROJECT MODELS

This chapter gives a brief description of the investigated project models. The focus is to provide a summary of the project model and indicate what approach angles the different project models have and their purpose and goal. One common purpose is to provide a methodology that can be used to improve production system design but the approach angle is different for all the models. The descriptions are intentionally kept short and a more detailed description of each project model will be provided in the coming chapters (the phases in chapter 6 and the gates in chapter 7).

5.1 VALUE STREAM DESIGN

With a focus on the value stream method the value stream design methodology is specific in its purpose and aim. It is a method for production system design and development, its aim is to show the developer the entire value chain visually and enable the developer to find the optimal production design through design guidelines specific for production. Overall the method aims to develop a "value stream-oriented factory".

The usage of the value stream method brings one great advantage to the table, it visualise so much more than a factory layout (Erlach, 2013). A value stream map visualise both the production processes and the material flows but also the information flow in one single illustration. This illustration provides an internal communication platform for both discussion of current state and what a desired future state would look like (Erlach, 2013).

5.2 BELLGRAN & SÄFSTEN

After a research conducted in the 1990's concerning how companies develop production system and the global competition in mind, Bellgran and Säfsten set out to create a structured way of working when develop a production system. The reasoning behind this was that the findings from the research showed that in the design phase the work was done in an *ad hoc* manner (Bellgran & Säfsten, 2010). They argue that a structured way of working provides possibilities to focus on essential tasks and creating a good production system instead of spending time arguing on how to conduct the work.

The structured way of working presented by Bellgran and Säfsten was a model with five clearly defined phases that had parallel running sub-phases within them. The model also contains important milestones that need to be completed before moving on the next phase.

5.3 PROJECT STEERING MODEL

The project steering model (from now on abbreviated PSM) was created and is maintained by the Volvo Group, in particularly Volvo Trucks. The aim is to have a simple project model that is generic but still effective. The PSM is intended to be used for process- and business changes and not for product changes (Schauvliege, 2012).

The organisational structure of the PSM includes a steering committee chairman that holds the responsibility that the project reaches the end effect goals and also acts as a coach for the project manager. There are also steering committee members that are preferably major stakeholders for the project and will be affected by the project outcome. The chairman appoints a project leader that has the responsible to drive the project forward and state project goals that correlates with the end effect goals. The appointment of project members is handled by the project leader who needs to identify and secure the right competences for the team.

The PSM goes through seven different phases and have six gates to control that the project team delivers all the needed facts for the steering committee. In every gate is mandatory to have a status report of what the project team has done in the previous phase and one planning document to show what will be the activities in the next phase.

5.4 DESIGN FOR LEAN SIX SIGMA

To design a product/process with the sought-after function to the lowest cost with six sigma quality, the application of design for lean six sigma (DFLSS) methodology is needed (Jugulum & Samuel, 2008). This DFLSS methodology presents a structured, systematic and disciplined way of achieving the project goals without losing the creativity and intuition of the designer. The Jugulum & Samuel (2008) states that this methodology will ensure the outcome will be fast, reliable, predictable development lead times, robust, reliable, flexible and modular design will be achieved among many other positive things.

Jugulum & Samuel (2008) presents a road map to deploy DFLSS with the aim of helping organisations design processes in a systematic and meaningful manner. The road map is based on an extensive literature review in the subject of DFLSS (Jugulum & Samuel, 2008). The road map with its phases are aligned to DMADV (define, measure, analyse, design and verify) methodology and contains of eight phases.

5.5 Autoliv Product Development System

From the benchmarking visit at Autoliv an understanding was acquired on how Autoliv develops production systems. Their main project model, Autoliv Product Development System, was used for both product development and production system development. Usually these two development processes was driven parallel to each other (Autoliv, 2009). The focuses when developing production system was on takt-time and designing a work place so that the operator(s) did as much value-added work as possible. This is according the concept of lean thinking and lean production, which the company was very profound in. Because of this the development process was concept-driven approach and therefore has the ability to skip conceptual design as many other project models have (Bellgran & Säfsten, 2010).

5.6 LIPS Project Model

The most theoretical project model investigated is the LIPS project model; its original purpose is to facilitate project work within an educational environment. However the model is generic and enables to drive through projects in an effective and controlled manner (Svensson & Krysander, 2011). The greatest advantage of the model is the extensive portfolio of work descriptions and templates.

The actual model is build up on three main phases (Before, During and After) and after each phase there is a decision point to decide that the project moves forward to the next phase. The before-phase is mainly about planning the work to be done, or in other words “what to do”. The during-phase is where all practical work is performed according to the created plan and ends in a system test and delivery to the customer. When the delivery is completed the After-phase begins and the project officially closes and evaluation of the project is performed (Svensson & Krysander, 2011).

6 Compilation of the project models – phases

This chapter aims to describe every phase of each investigated project model. But firstly the compilation matrix is presented. This matrix describes which phases in a project model corresponds to another project model phases. Later in the sub-chapters the description of the phases goes in to more detail.

6.1 The Compilation Matrix – Phases

In Figure 6-A a matrix of the conducted compilation is presented. This is a visualisation of how different phases from different project models correspond to each other. Also in the figure there are milestones visualised (the blue verticals) which is appearing in every project model.

Table of investigated models and its phases

Model name *Project timeline -->*

Model name	Start of project					One chosen design			Final design		Physical production system finished		Production system in full operation	
Value Stream Design		Phase 1: Setting of objectives	Phase 2: Establishment of project basis	Phase 3: Concept planning			Phase 4: Detailed planning			Phase 5: Preliminary implementation steps Phase 6: Implementation supervision		Phase 7: Ramp-up support		
Bellgran and Säfsten		Phase Ax: Prepare investment request Phase Bx: Development planning	Phase A: Background study Phase B: Pre-study	Phase C: Design of conceptual production system	Phase D: Evaluation of prodyction system		Phase E: Detailed design of chosen production system			Phase F: Build production system Phase G: Plan start-up		Phase H: Carry out start up		Phase I: Evaluate the result and the way of working
Mapping		Need phase		Concept phase	Pre-study phase		Planning / layout design phase			Implementation phase		Finishing phase		Follow-up phase
Project Steering Model		Investigation	Feasibility study				Development phase	Final Development phase		Industrialisation phase		Trimming in phase		Follow-up phase
Lean Six Sigma		Phase 1: Voice of customer and strategic intent		Phase 2: Concept phase	Phase 3: Preliminary design		Phase 4: Final design			Phase 5: Product validation Phase 6: Process validation		Phase 7: Product launch		Phase 8: Post-launch
IS-GDP		Pre-study phase 1	Pre-study phase 2	Concept study phase			Development phase	Final Development phase		Industrialisation phase		Deployment phase		Follow-up phase
Autoliv		Phase 0: Project inititiation		Phase 1: Concept definition			Phase 2: Development			Phase 3: Validation		Phase 4: Production launch		Continuous improvements
LIPS Project model		Idea	Pre-study Preparation	Design			Implementation	System test		Installation Acceptance test		Error correction		Evaluation
New model		Project Initiation Phase	Pre-study Phase	Concept Design Phase			Design Phase	Final Design Phase		Realisation phase		Ramp-up phase		Follow-up phase

FIGURE 6-A COMPILATION MATRIX OF THE MODELS AND ITS PHASES (SEE APPENDIX D FOR LARGER PICTURE)

There is a lot of common ground in general between the project models, with phases that are very similar to each other. Particularly the Project Steering Model and the IS-GDP where the commonality is obvious with how the project proceeds and which phases the project goes through. The definition of each phase is almost the same but with the Project Steering Model differ with much more simplicity than the IS-GDP model.

Further on the Value Stream Design model stands out with its heavy focus on value stream design and not so clear descriptions of work content. The LIPS Project Model shines with its lack of practical connection and focuses only on documentation.

6.2 PROJECT INITIATION PHASE

Summary of Table 6-A: Identifying the goals and vision of the project is in focus and also describing the background and problem is important. Creating documentation that summarise this information and also indicating how the work is planned to proceed is another important part along with creating the project organisation with the right competences and resources.

TABLE 6-A PROJECT INITIATION PHASE

Project model name	Description
Value Stream Design	Defining factory goals and making decisions about what framework of the design guidelines should be used in the development process.
Bellgran and Säfsten	Documentation for investment request and also appointing resources, planning for support, creating a project organisation with routines for administration and information.
Mapping	Identify the needs, product changes or new manufacturing technology etc. Constructing the working principles to guide the project.
Project Steering Model	Describing the background and problem and decipher the project request, identify possible links with other projects and also assure the alignment to business plan. Creation of feasibility directive.
Lean Six Sigma	Identifying the expectations of the customer, performing a feasibility study and validating the business case.
IS-GDP	Developing a project vision and creating a common understanding about what the problem is.
Autoliv	Creating a concept idea, performing a feasibility study and defining the cost targets.
LIPS Project model	Writing a project directive that describes the goals and the aim of the project. Creating the project organisation, choosing a project manager and establish a project group.

6.3 PRE-STUDY PHASE

Summary of Table 6-B: Performing an in-house study to know the prerequisites and the existing production systems are common to do, in other words creating the AS-IS process. Also performing analysis of stakeholders and the problem is important.

TABLE 6-B PRE-STUDY PHASE

Project model name	Description
Value Stream Design	Conducting a value-stream analysis that depicts the entire current state of the factory, need potentially be complemented with more detailed analysis such as space analysis or material analysis.
Bellgran and Säfsten	Analysis of existing production system in-house and benchmarking for best-practice. Indentifying demands from stakeholders, analysis of the development and business

	potential.
Mapping	*Not applicable.*
Project Steering Model	Perform stakeholder and problem analysis, define prerequisites, project goals, time, cost and project organisation. Make up a business case and create the AS-IS process.
Lean Six Sigma	*Not applicable.*
IS-GDP	Defining possible solutions to the problem.
Autoliv	*Not applicable.*
LIPS Project model	Write a requirement specification, make a system drawing and write a project plan.

6.4 Concept Design Phase

Summary of Table 6-C: Development of different concepts and evaluating them against each other is a big part of the Concept Design Phase. The detailed level of each concept differs and how the developer acquires the details is different but one common thread is the layout focus when developing concepts.

TABLE 6-C CONCEPT DESIGN PHASE

Project model name	Description
Value Stream Design	Dimensioning the capacity according to the customer takt-time and also designing a value stream-oriented factory with the help of design guidelines.
Bellgran and Säfsten	Developing different concepts by iterations. Choose the tools, methods, layout, material flow, level of automation, machines, equipment and more. Evaluation of the different concepts, estimate costs. Compile and share the results from the evaluation and choose one solution.
Mapping	Look at alternative solutions, rough CAD-models and discuss different principles such as flow layout or parallel production lines. Create block-layouts, calculate costs, risk, lead times and economical stats. Choose one solution.
Project Steering Model	Identify and evaluate different solutions, recommend one solution, plan development activities. Create a project directive that describes how the project will proceed to reach end gate
Lean Six Sigma	Customer expectations are turned into actionable and measureable functional requirements. The expectations are decomposition to lower levels to create a better understanding about the design requirements and therefore creating better concepts. A detailed design is identified by evaluating various design alternatives.
IS-GDP	Gather the detailed arguments to decide ways of working and to choose one solution.
Autoliv	Validating the concept, trying it out in mock ups.
LIPS Project model	Create a design specification that is detailed description of how to reach the project end result

6.5 Design Phase

Summary of Table 6-D: The chosen solution is developed in further detail, to that extent that a steering committee can make a decision wheatear to go for the solution or not. Technical specifications are drawn up and quotes on machines are acquired.

TABLE 6-D DESIGN PHASE

Project model name	Description
Value Stream Design	Focus on developing the detailed plans that match the value stream map created before and differ between value-creating and supporting activities.
Bellgran and Säfsten	Develop and determine a detailed design for the chosen solution. Preliminary work place design. The developed material should be detailed enough so that the steering committee can take a decision.
Mapping	Creating a detailed plan containing technical specification on machines, quotes on machines and equipment, detailed layouts, personnel plans, logistic simulations.
Project Steering Model	Design solution on detailed level; define (long lead time) tools, equipment, layout changes. Develop necessary documentation for Investment Request and plan final development activities.
Lean Six Sigma	The development of the design is focused from a productivity and quality point of view.
IS-GDP	Develop all details necessary to freeze the overall solution and reach the contract.
Autoliv	More detailed development, in full scale models with simulated work load. A part of the design verification process.
LIPS Project model	Complete design specification, make plans for resources and time, and write different manuals and plans.

6.6 Final Design Phase

Summary of Table 6-E: The work from the design phase is continued but on an even more detailed level. Preparing for deployment is one new aspect.

TABLE 6-E FINAL DESIGN PHASE

Project model name	Description
Value Stream Design	See Table 6-D.
Bellgran and Säfsten	See Table 6-D.
Mapping	Develop all details necessary for the steering committee to make a decision if the investment is approved.
Project Steering Model	Design solution on detailed level (TO-BE process), plan industrialisation activities and create communication and training strategy. Define tools, equipment, layout changes

	and but long lead time tools, equipment etc... Fine tune the project time and budget.
Lean Six Sigma	Development of transfer function and optimisation of the design solution.
IS-GDP	Develop the technical solution and prepare for deployment.
Autoliv	See Table 6-D.
LIPS Project model	See Table 6-D.

6.7 Realisation Phase

Summary of Table 6-F: The main activities in this phase according to all the above models are the investment of tools, machines, equipment and layout changes and the deployment and verification of these.

TABLE 6-F REALISATION PHASE

Project model name	Description
Value Stream Design	A responsible *value stream manager* will step-by-step introduce the designed value-stream in structured sequences while re-configure it if needed.
Bellgran and Säfsten	Installation of equipment and machines, verifying the education of personnel and prepare the organisation for the transition with responsible persons.
Mapping	Investment in machines, installation of the machines. The work shop is build up.
Project Steering Model	Buy and install equipment, training of people, plan trimming in activities.
Lean Six Sigma	Final design is tested against requirement specification and the development process is validated and measured.
IS-GDP	Perform the user validation tests and finalise the preparations for deployment.
Autoliv	Validating and qualification of the process.
LIPS Project model	Demonstrate the result and present it. Deliver and install all the equipment at the customer site.

6.8 Ramp-Up Phase

Summary of Table 6-G: Producing prototypes and pre-series are vital; the ramp-up is performed according to the plans drawn up in the earlier phase. Preparing the delivery to the receiving organisation is one main activity.

TABLE 6-G RAMP-UP PHASE

Project model name	Description
Value Stream Design	The ramp-up process is taken care of through continuous evaluation of the value stream performance.
Bellgran and Säfsten	Work according to the plan created in earlier phase and start producing prototypes to fine-tune the production system.
Mapping	Prototypes and pre-series are produced along with ending reports of the work conducted.
Project Steering Model	Implementation of the solution in full scale, delivery of the production system and getting the approval from the customer. Prepare to hand over the responsibility to the line organisation.
Lean Six Sigma	The final design is put in to practice and the results of earlier work are implemented fully.
IS-GDP	Deliver the solution and train the organisation.
Autoliv	Full-speed production runs.
LIPS Project model	Execute acceptance test, deliver the project result to operational unit.

6.9 FOLLOW-UP PHASE

Summary of Table 6-H: Basically evaluating the result of the delivered production system and document the lessons learned.

TABLE 6-H FOLLOW-UP PHASE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Evaluate the result of the final physical production system and document lessons learned.
Mapping	How did it go? What is positive and/or negative with the result?
Project Steering Model	Measure and set up an action plan to reach the end effects.
Lean Six Sigma	The end result is verified.
IS-GDP	Validate that the business objectives are reached.
Autoliv	Continuous improvements.
LIPS Project model	Evaluate the experience gained and improve the project model and the work model. Follow up on the quality.

7 Compilation of the Project Models – Gates

This chapter aims to describe every gate of each investigated project model. But firstly the compilation matrix is presented. This matrix describes which gate in a project model corresponds to another project model gate. Later in the sub-chapters the description of the gates goes in to more detail.

7.1 The Compilation Matrix – Gates

In Figure 7-A a matrix of the conducted compilation is presented. This is a visualisation of how different gates from different project models correspond to each other. Also in the figure there are milestones visualised (the blue verticals) which is appearing in every project model.

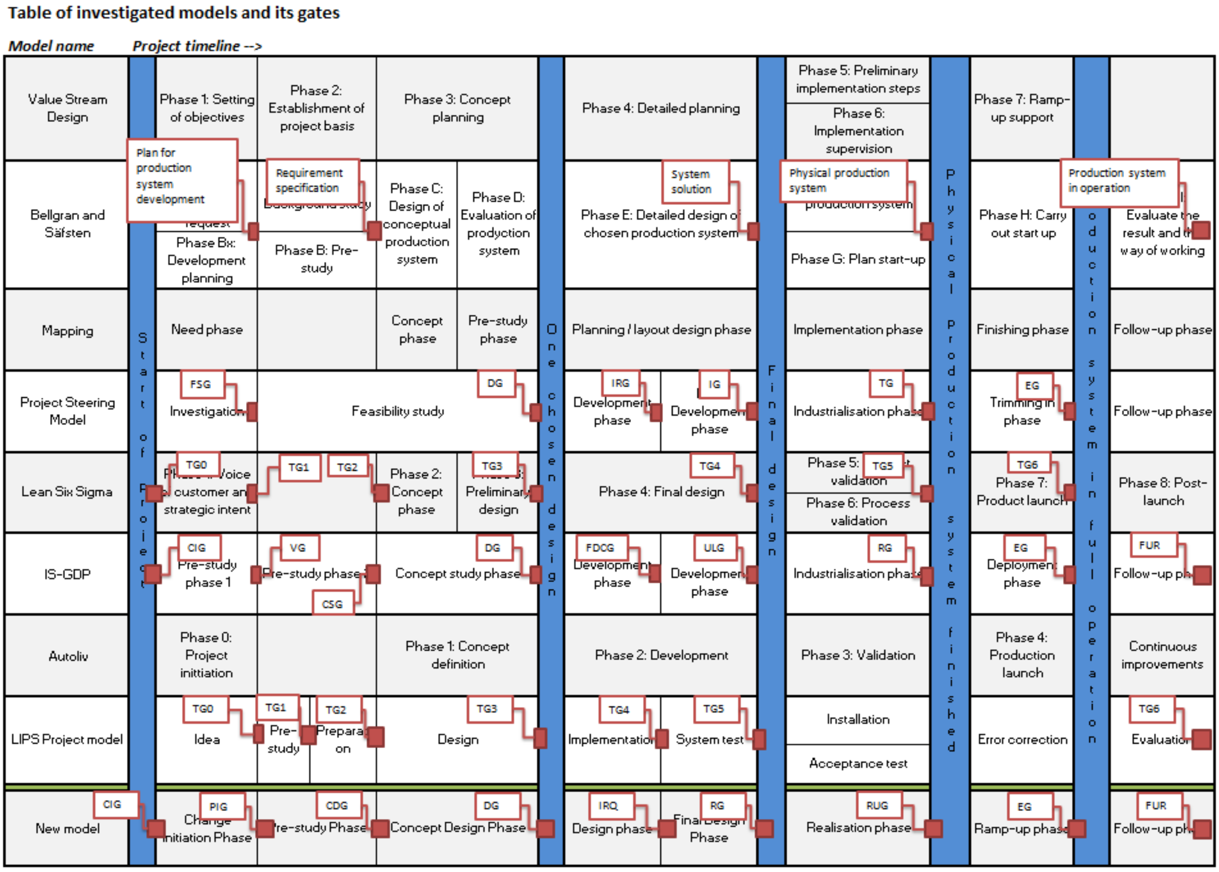


Figure 7-A Compilation matrix of the models and its gates (see Appendix E for larger picture)

The project models are quite similar in some cases to each other but in other parts they differ a lot. The IS-GDP and Lean Six Sigma corresponds the most to each other with the Project Steering Model being close by but with another focus in the pre-study and concept design phases. Bellgran and Säfsten do not really have any gates but still has some main checkpoints which has been analysed as gates. The Value Stream Design model does not have any gates and does not give any indication of gates either.

7.2 Change Initiation Gate

Summary: of Table 7-A The three applicable gates of the investigated models are quite similar and clear on what the decision in the gate is concerning. The change initiation gate discuss if the business case (or need for change) presented is valid and that there are potential winnings by proceeding with the business case in a project.

TABLE 7-A CHANGE INITIATION GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	*Not applicable.*
Mapping	To approve the need for change and formally start up a project.
Project Steering Model	*Not applicable.*
Lean Six Sigma	Researching if the project should be initiated, needs to be re-worked or rejected. This is based on a high level business case, customer needs and potential offerings coming from the project.
IS-GDP	The overall purpose is to approve the business value of the request and formally start a pre-study.
Autoliv	*Not applicable.*
LIPS Project model	*Not applicable.*

7.3 Project Initiation Gate

Summary of Table 7-B: Stating how the project organisation should be like and what resources that are assigned to the project are key aspect in the project initiation gate. This is most common handled in a project directive.

TABLE 7-B PROJECT INITIATION GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Drawing up the plans for the future work including project management, resources, time plan, administration, outlines for requirement specification and system solution. Mainly creating the input for a project directive.
Mapping	Not applicable.

Project Steering Model	The main purpose is to approve the project directive and agree upon starting a feasibility study, officially starting up the project.
Lean Six Sigma	The decision if the business case is valid is the main focus but also that the customer needs are well defined and that feasibility is likely. In the description is an indication of creating a project directive.
IS-GDP	Approve the project vision and confirm that everyone has a common understanding of the problem or opportunity.
Autoliv	Defining the project targets, schedule and further development is the main focus. Also taking up customer requirements and quotation. Similar to approving a project directive.
LIPS Project model	Approve the project directive and assign resources to the project.

7.4 Concept Design Gate

Summary of Table 7-C: What the decision that is made in the concept design gate is based on have a high variety. Although one main characteristic in the descriptions is to investigate and decide which solutions to develop further and determine if the solutions is technically feasible.

TABLE 7-C CONCEPT DESIGN GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Setting the principles and important aspects to consider for the development work and also defining what exist in-house (machines, good solutions etc.). Take care of what the background study brought forward and learn from lessons learned from other projects. Develop different concept.
Mapping	*Not applicable.*
Project Steering Model	*Not applicable.*
Lean Six Sigma	Discuss and decide if the project has a technically feasible solution that meets customer and business expectations.
IS-GDP	To decide which solutions to investigate further.
Autoliv	*Not applicable.*
LIPS Project model	The plans for future work have been specified and a decision to continue with the project has to be made.

7.5 Design Gate

Summary of Table 7-D: Evaluation and the approval to develop one concept solution further.

TABLE 7-D DESIGN GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Evaluate the different concept solutions and decide which concept solution to develop further.
Mapping	Decide one concept which will be developed further.
Project Steering Model	Approve one concept to develop in further detail. Create a project directive that will replace the feasibility directive.
Lean Six Sigma	Decide if the proposed preliminary design that meets the requirements and is technically feasible. Investigate if the project plan is viable and that technical, financial and customers risk are acceptable.
IS-GDP	Choose one solution and approve the ways of working in combination with technical concept.
Autoliv	Define the basic design of the process (production system) and release the prototypes.
LIPS Project model	An extra check to see if the project time plan and workload are correct or needs to be updated.

7.6 Investment Request Gate

Summary of Table 7-E: The overall solution should be detailed enough so the project team and steering committee can freeze the overall solution and request investments for the rest of the project, especially for long lead time tools, machines, equipment etc.

TABLE 7-E INVESTMENT REQUEST GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	*Not applicable.*
Mapping	Freeze the overall solution and start collecting in quotes from suppliers.
Project Steering Model	Decision point to request investments, request for releasing money for the rest of the project. Approval to buy long lead time tools, machines, equipment etc.
Lean Six Sigma	*Not applicable.*
IS-GDP	The purpose is to freeze the overall solution and sign the contract.

Autoliv	*Not applicable.*
LIPS Project model	The purpose is to track the progress of the project and the quality of the work conducted.

7.7 Realisation Gate

Summary of Table 7-F: A detailed solution is presented to the steering committee and the decision if the solution is complete and lives up to the requirements are taken. If approve the solution is taken into full industrialization.

TABLE 7-F REALISATION GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Present a detailed production system solution.
Mapping	Present the detailed production system solution and request investment from the steering committee.
Project Steering Model	Approve to go for full industrialisation.
Lean Six Sigma	To decide if the stakeholders accept the proposed solution and see if it reaches all requirements stated earlier.
IS-GDP	Approve that the solution is ready for user validation test.
Autoliv	The design is finalised and the production system is approved to be released.
LIPS Project model	The decision if whether the result will be used or not is taken here.

7.8 Ramp-Up Gate

Summary of Table 7-G: After the production system is realised and in physical form the ramp-up gate is there to check if the production system lives up to the expectations and if it is ready for full serial production.

TABLE 7-G RAMP-UP GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Investigate how the physical production system performs and if it is ready for full implementation.
Mapping	Decide if the industrialisation as gone according to plan and if the production system is ready for serial production.

Project Steering Model	Approve to go for serial production/full implementation
Lean Six Sigma	Decide if the stakeholders are satisfied how the production system has been performing, relevant to the requirements.
IS-GDP	To approve that the solution is ready for deployment and the organisation is ready to receive it.
Autoliv	Check if the production system is ready for full serial production.
LIPS Project model	*Not applicable.*

7.9 End Gate

Summary of Table 7-H: The end result of the development process is reached and the transition of the ownership is completed. Project team is dismantled and the organisation takes over the responsibility of the production system.

TABLE 7-H END GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	*Not applicable.*
Mapping	End the project and hand over the production system to the receiving organisation.
Project Steering Model	Approve the take-over directive. Decide to close the project (project organisation is dismantled.)
Lean Six Sigma	Decide if the hand over process is established and that the development process is finished.
IS-GDP	To approve that the solution contents and deployment are achieved according to the contract, hand over the responsibility to the organisation and close the contract.
Autoliv	Check if the project targets are met and that the customer is satisfied.
LIPS Project model	Decision to finalise the project and dismantled the project organisation.

7.10 Follow-Up Report

Summary of Table 7-I: Decide if the production system achieved the business objectives and investigate if further work is needed to reach them.

TABLE 7-I FOLLOW-UP GATE

Project model name	Description
Value Stream Design	*Not applicable.*
Bellgran and Säfsten	Evaluation of the physical production system and how well it fulfilled the requirement specification. Also investigate how the development process was conducted.
Mapping	Check if the production system reached the target goals set up.
Project Steering Model	*Not applicable.*
Lean Six Sigma	*Not applicable.*
IS-GDP	To validate that the business objectives have been achieved and, if needed, decide action plans and further change management activities.
Autoliv	*Not applicable.*
LIPS Project model	*Not applicable.*

8 Result

This chapter present the results of the thesis starting off with an introduction to the proposed project model and the project organisation behind it. To provide a more detailed description of how the work will be performed in development process a description is then provided on the work methodology in the development process. To round the result up a presentation of how to apply simulation in the development process is presented.

8.1 Introduction

The project model that is created during the research is a stage-gate model with phases in each stage. The model consists of five stages with eight phases and nine gates; see Figure 8-A for the project model flow. The five different stages in the model are Start, Measure and Analyse, Design, Realise and Verify inspired by the LAMDA-process described in Chapter 3.2, Lifecycle Management described in Chapter 3.5 and the Design for Lean Six Sigma model described in chapter 5.4. The different phases and gates were created during the compilation process (Chapter 2.6, Chapter 6 and Chapter 7).

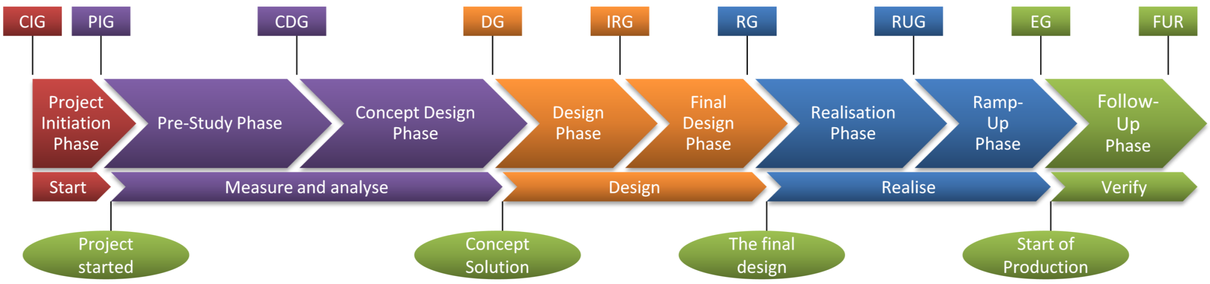


FIGURE 8-A THE PROJECT MODEL FLOW, SEE APPENDIX F FOR LARGER PICTURE

The milestones that are present at the bottom of the model, see Figure 8-A the green circles, exist in all the investigated models and provide guidance of what the expected result of each stage is, see the relation between stages and milestones in Table 8-A.

TABLE 8-A DESCRIPTION OF THE MILESTONES WITHIN EACH STAGE

Stage	Milestone description
Start	*Project started:* The project is officially started and the project organisation is in place
Measure and Analyse	*Concept solution:* The process of generating concepts and evaluating them against each other is completed and one (recommended) concept solution is chosen for further development
Design	*The final design:* The chosen concept solution is developed

	in detailed and investments of long lead time items have been made.
Realise	*Start of production:* The production system has been installed and handed over to the production organisation, the start of full production
Verify	Evaluate and follow-up about how the final production system corresponds to the final design

The purpose of each phase and gate is stated in Table 8-B in chronological order to the project model. The work methodology will be explained more comprehensively in chapter 8.3. To give a more detailed insight to the project model see The Handbook in Appendix G.

TABLE 8-B THE PURPOSE OF THE PHASES AND GATES

Phase or gate	Purpose
Change Initiation Gate	To decide whether to proceed, re-work or reject the need for change
Project Initiation Phase	To create a project organisation and secure resources for pre-study phase
Project Initiation Gate	To approve the concept development directive. Decide if the need for change is valid, the customer needs are well defined and feasibility is likely
Pre-Study Phase	To conduct a green-field scenario study and state the factory constraints independently of each other
Concept Design Gate	To decide if the green-field scenario meets project goals and customer demands and that the factory constraints study is performed on a high detail level. To decide if the necessary resources are available to generate on solution
Concept Design Phase	Merging the green-field scenario study with the factory constraints to develop conceptual solutions that will be evaluated and then one recommended solution should be presented
Design Gate	To decide if there is a design solution that is technically sound and feasible and have a project directive that is viable and that describes how the work will be conducted to reach end gate
Design Phase	To develop all details necessary to freeze the overall solution and reach the contract with focus on long lead time items[8]. The material should be detailed on a level that makes it possible for the steering committee to make a decision
Investment Request Gate	To freeze the overall solution and request investment for long lead time items. To decide if the stakeholders accept that the detailed design is technically sound and feasible, meets customer, business, regulatory and environmental requirements
Final Design Phase	Develop the final solution so it is ready for deployment and prepare for the deployment
Realisation Gate	Approve to go for full industrialisation
Realisation Phase	Investment of tools, machines, equipment, layout changes and the deployment and verification of the final production system

[8] Long lead time items: Tools, machines, equipment, layout changes that have a long lead time from first contact to installation in the factory.

Ramp-Up Gate	Approve to go for serial production/full implementation
Ramp-Up Phase	Perform according to the ramp-up plan and go to serial production/full implementation. Create documentation of lessons learned from the project
End Gate	To decide if the development process is completed and transition ownership is established. Approve the take-over directive, decide to close the project
Follow-Up Phase	To evaluate the result and the way of working. Evaluate the result of the developed production system
Follow-Up Report	To validate that the business objectives have been achieved and, if needed, decide action plans and further change management activities

8.2 PROJECT ORGANISATION

Management group appoints the steering committee chairman, who in turn collaborates with the management group to form a strong and motivated steering committee. The ideal situation is a smaller team (4-6 people) that have high power within the company and that are highly affected by the result of the project; see the circle in Figure 8-B.

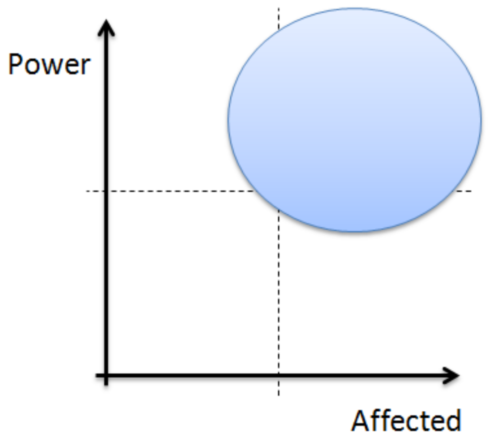


FIGURE 8-B GRAPH OF HOW TO CHOOSE STERRING COMMITTEE

To form a project team the steering committee headed by the chairman appoints one project manager. This project manager can be a visionary person that has the responsibility of the project for the measure and analyse stage of the project and a new get-the-job-done manager could be appointed to manage the project through the later stages. Although there can be one project manager that can have the responsibility throughout the whole project.

The appointed project manager identifies the needed competences to complete the project, specific stage or specific phase (when appropriate) and request these competences from the organisation. When a specific competence is acquired, a time estimation of the workload needs to be done for that specific competence. This time estimation (preferably in percentages) needs to be informed to the competence and the competence manager and agreed upon that the competence will be ‘lend’ to the project organisation for a certain percentage of the workday for a certain time.

The project manager has the responsibility to achieve the desired goals that exist at the End Gate and after the project has passed the End Gate the project team is dismantled. This means that it is the responsibility of the steering committee to perform the Follow-Up Report and evaluate how the production system performs compared to the final design system. This responsibility is placed on the steering committee to ensure their commitment to the project throughout the timeline and motivate them to provide guidance and coaching to the project team.

8.3 Work Methodology

The most important part of the proposed project model in the sense of work methodology is to understand the development process under the stage of Measure and Analyse to reach one concept solution. From set-base design (Chapter 3.2) it is proposed that a developer should move away from point-based design and start designing with parameters and trade-off-curves etc. This is quite complicated to perform in a development project that handles production systems. However the thought of not lock yourselves to one solution in the beginning (point-base design) is appealing. Therefore the proposed work methodology in Measure and Analyse is to conduct a green-field scenario[9] study and in parallel but independently conduct a factory constraints study.

The green-field scenario study will be heavily focused on the use of simulation- and visualisation tools (more on that in Chapter 8.4). With the aid of simulation tools, the design guidelines (presented in Chapter 3.3) and the company strategy, a developer should design the optimal production system digitally, creating a model in the context of virtual production (Chapter 3.4). The green-field should show how the company can produce certain products in the best and most efficient way possible, thus creating the optimal value-flow.

As mention beforehand parallel to the green-field scenario study a factory constraints study should be performed independently. This study should bring forward possible workshops that the production system could be installed in, with all the constraints adjacent to them, e.g. floor, walls, ceiling, existing material flow, existing value-flows, ventilation, facilities etc. As the factory constraint study progresses one or more potential workshops should be scanned to create the base model for a Virtual factory model (Chapter 3.4). This Virtual factory model will be used in the concept generating process along with the green-field scenario study. The green-field scenario study and factory constraints study is conducted during the Pre-Study Phase.

In the Concept Design Phase the green-field scenario study and the factory constraint study is merged together to create different concepts. The group that conducted the factory constraints study have the responsibility to motivate why the green-field production system should be altered and why the production system should not be the optimal anymore. At the end of the Concept Design Phase at least two concept solutions should be presented and one (exactly one) concept solution should be recommended for further development. This approach is proposed to combine

[9] Green-field scenario: Design of a production flow according to the optimal scenario without any prerequisites, e.g. having an empty field to design and build whatever you want the best you can.

the benefits of set-base design and virtual production, which is mainly to achieve a better product quality with less resources spent on a shorter time.

At this time the project will have come in to the Design stage and one concept solution is chosen to develop further, in the Design Phase the focus should be on defining and designing the long lead time items and create a detailed enough production system to freeze the overall solution[10]. To decrease the development lead time it is proposed to have an Investment Request Gate in the Design stage that approves the investment of long lead time items and also to freeze the overall solution. This gate can save time by conducting the investment of a long lead time items earlier in the process thus shortening the lead time.

To steer the project in the right direction two different directives are necessary, one concept development directive and one project directive. The difference between the two directives is that the concept development directive is used from the Start stage and throughout the Measure and Analyse stage, thus describing how the project will reach one concept solution. The project directive is used from the Design stage and all the way to End Gate thus describing how the project team will develop the concept solution to be a physical production system. Another benefit with this approach is that it creates a natural transition point if a project manager has to hand over the project responsibility to new project manager, as discussed in Chapter 8.2.

8.4 How to Use Virtual Production

To aid the development and achieve a quality result using fewer resources in less time, simulation is an important part. This chapter aims to describe how and when simulation can be used in the proposed model. As the development progresses in the Measure and Analyse stage the aim is to create a Virtual Production Model that can be used in the actual development but also in the future when improving the production system, thus trying out the proposed improvements virtually before implementation. To get an overview of different simulation activities in the model see Figure 8-C.

[10] Freeze the overall solution: Design key-items to detailed level that ensures that item will be according to the specifications in the physical production system.

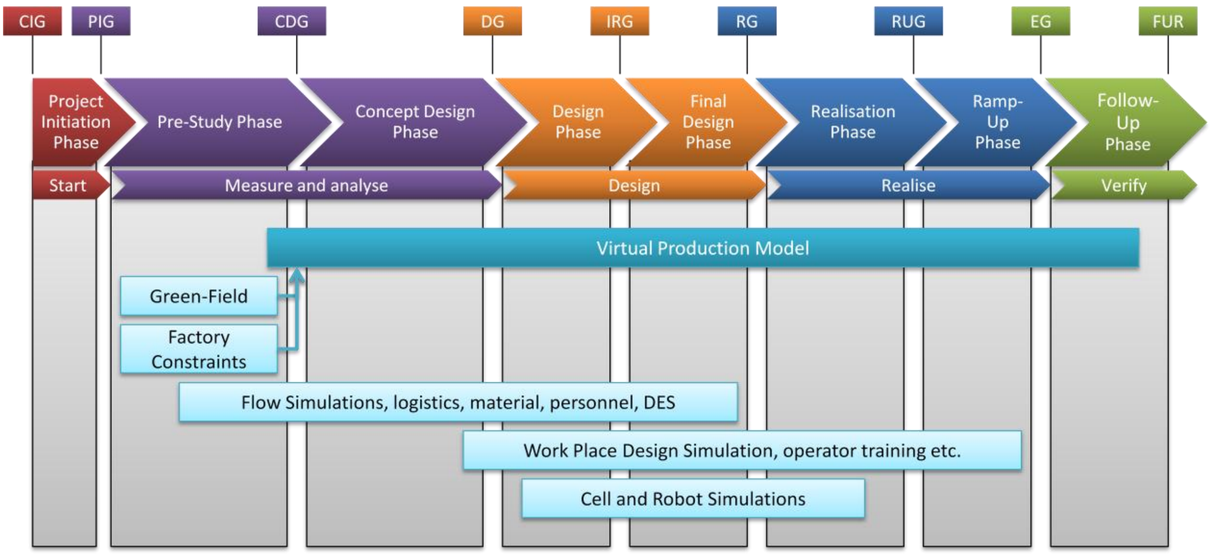


FIGURE 8-C THE PROJECT MODEL WITH THE DIFFERENT SIMULATION ACTIVITIES

To give a more detailed description of the methodology behind the simulation the 'Green Field' (Chapter 8.4.1), 'Factory Constraints' (Chapter 8.4.2) and 'Virtual Production Model' (Chapter 8.4.3) will be further described.

8.4.1 Green-Field Scenario Study

The beginning of the green-field scenario study starts with constructing a value-stream map. This map shows the material flow, information flow, buffers and all processes and more in only one picture. The value-stream map should be the absolute desired state of the production, in short the optimal production system, see Figure 8-D for an example. When designing the value-stream map the developer should be using the design guidelines explained in Chapter 3.3.

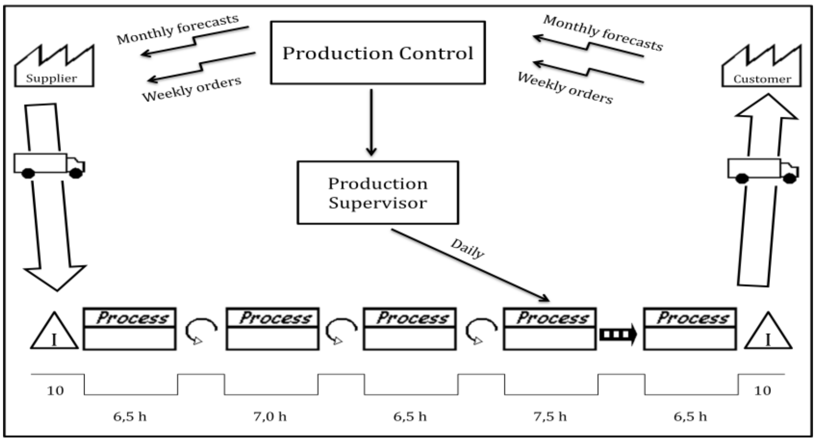


FIGURE 8-D GREEN-FIELD SCENARIO STUDY VALUE-STREAM MAP

From the value-stream map the developer should start constructing an optimal layout for the value-stream. This layout should aim to optimise the logistics distances in the layout, space utilisation and simplicity of the value-flow. In the optimal layout the logistics flow can also be illustrated, see Figure 8-E for an example.

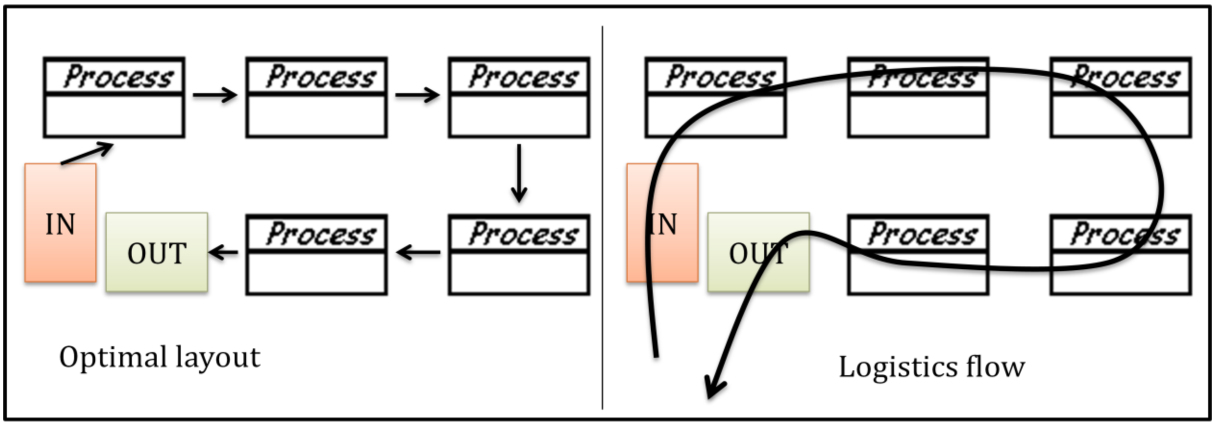


FIGURE 8-E TO THE LEFT: THE OPTIMAL LAYOUT FROM THE VALUE-STREAM MAP; TO THE RIGHT: THE LOGISTICS FLOW IN THE OPTIMAL LAYOUT

These three different maps (Figure 8-D and Figure 8-E) should be compiled into one virtual model to start building towards a virtual production model. Further on, the developer should make sure that the proposed green-field scenario stands up to the requirements on the production system. Therefore a Discrete Event Simulation (see Figure 8-F) of the value-flow should be performed for proper analysing the performance of the green-field scenario. The benefits of performing a Discrete Event Simulation are described in Chapter 3.4.

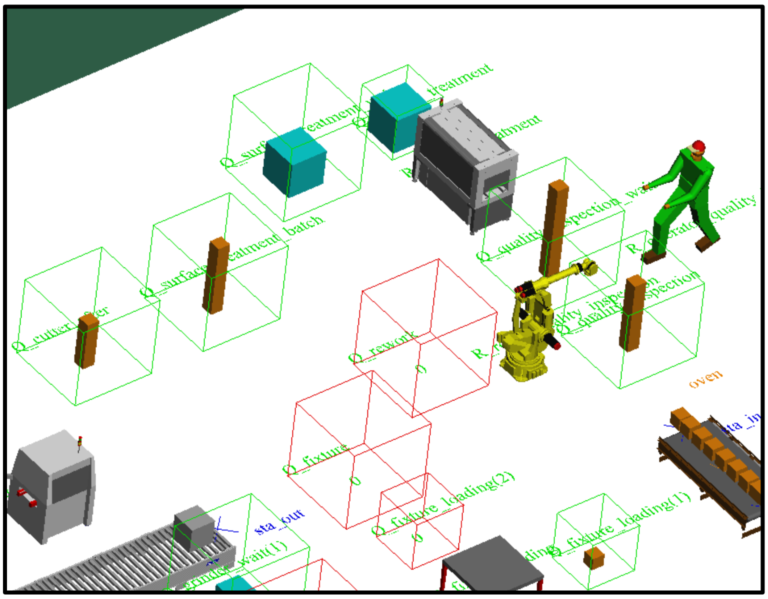


FIGURE 8-F AN EXAMPLE OF A DISCRETE EVENT SIMULATION

8.4.2 Factory Constraints Study

The importance in the factory constraints study is to gather information about possible factory locations for the production system. Some aspects that are the most noticeable is where the walls, ceiling, windows, ventilation structures, facilities, existing machines or production system are located, this can be visualised with a 3D-scan of the factory, see Figure 8-G An example picture of a 3d-scan model for an example of how a 3D-scan model can look like.

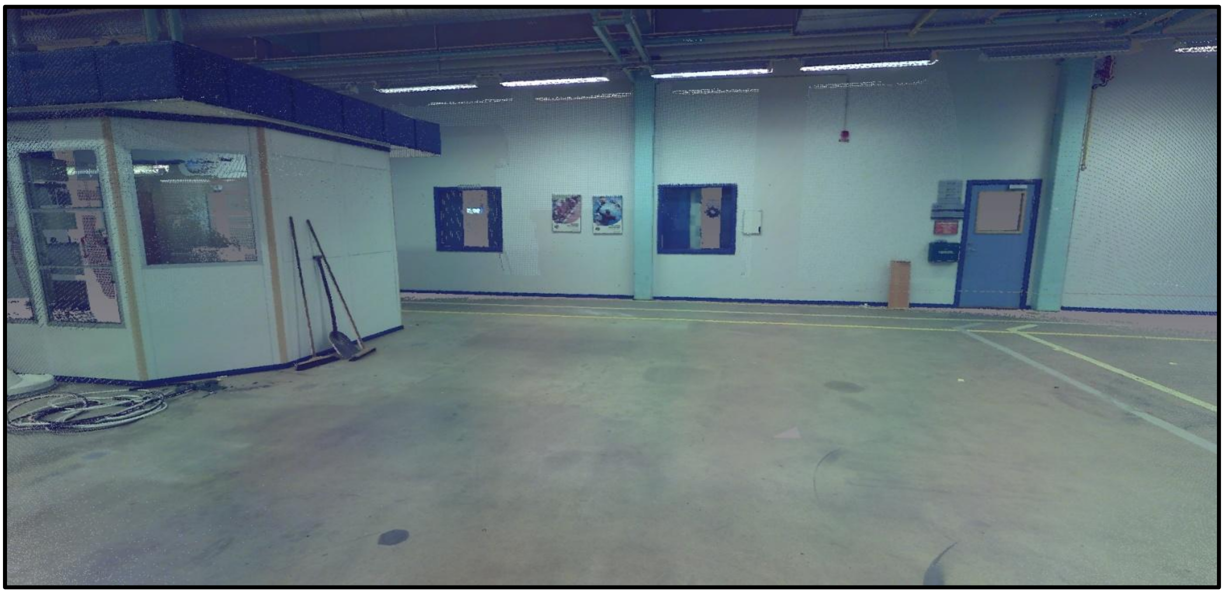


FIGURE 8-G AN EXAMPLE PICTURE OF A 3D-SCAN MODEL

The 3D-scan model along with a layout map of the possible locations for the production system, see Figure 8-H for an example, the factory constraints study should give a clear picture of the different constraints that is present in the factory. On example of a constraint present in Figure 8-H is the process nr 5 that is a shared process between two or more value-flows. This resource can be shared because of a number of reasons, e.g. investment cost, space requirement and/or specialised personnel.

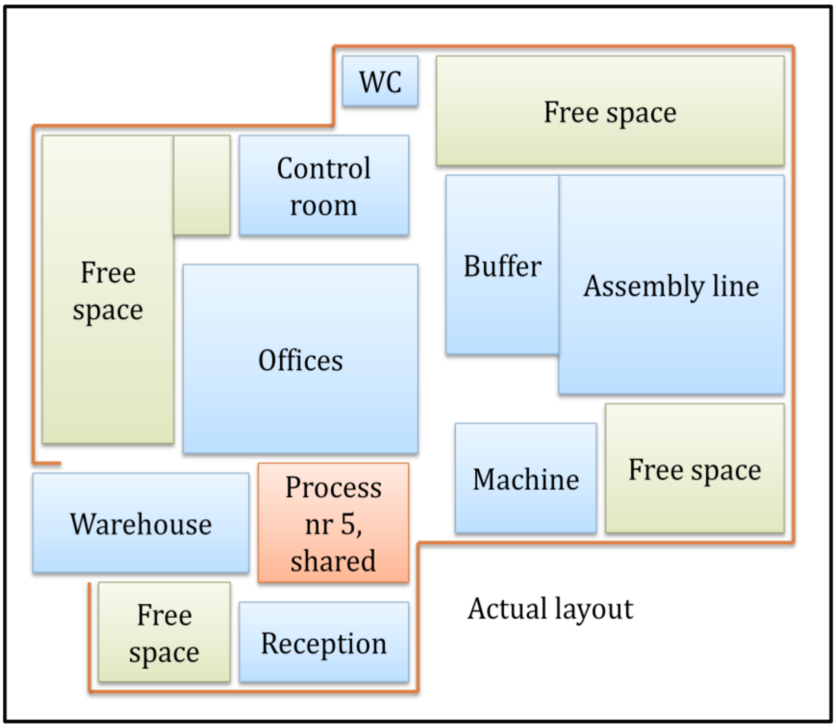


FIGURE 8-H AN EXAMPLE PICTURE OF A FACTORY LAYOUT

8.4.3 Virtual Production Model

To create the Virtual Production Model a merging of the Green-field scenario study and the factory constraints study is necessary. This starts with an updated value stream map that corresponds to how the constraints are in the factory. This can be affected by the need for using a shared process for example, as described in Figure 8-H. In accordance with the value-stream map in Figure 8-D an updated version could for example look like the Figure 8-I. Here the shared process applies FIFO and the pacemaker process is the same but with a Kanban-coupling to process number two with a push system between process number two and process number three thus corresponding with the design guidelines. When the value-stream is completed the methodology from the green-field scenario study applies again with forming an optimal layout and visualising the value-flow in the layout. This for instance can be performed as in Figure 8-K for the layout and in Figure 8-J for the flow.

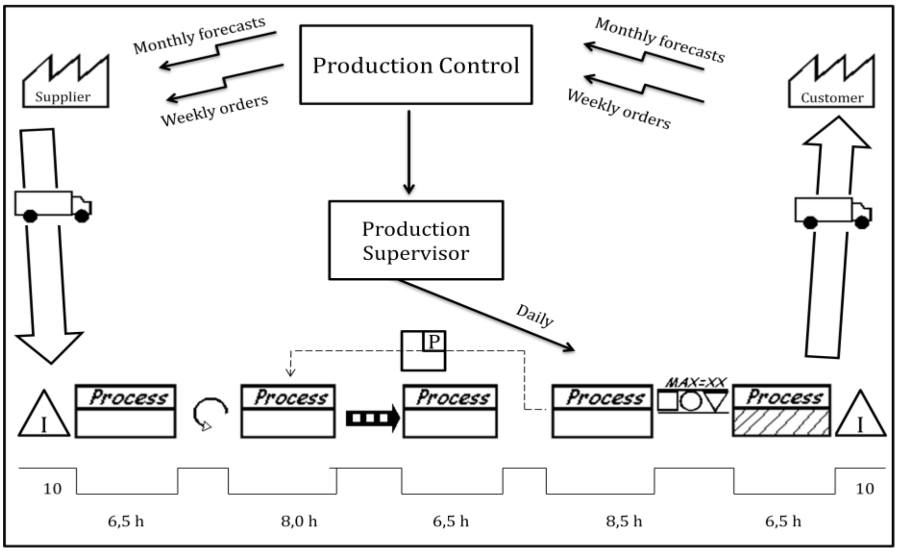


FIGURE 8-I UPDATED VALUE-STREAM MAP

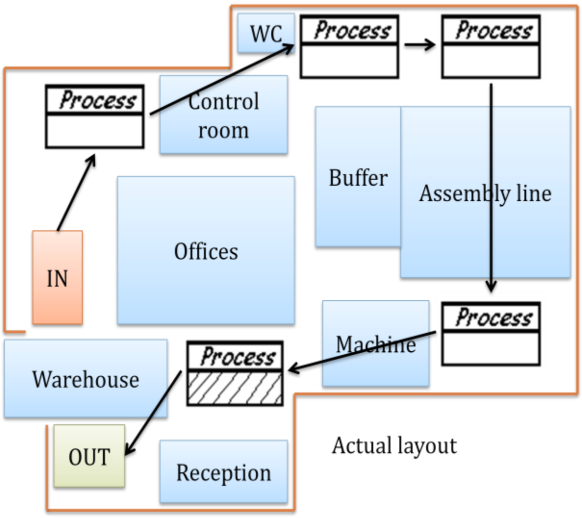


FIGURE 8-K AN EXAMPLE OF MERGED LAYOUT

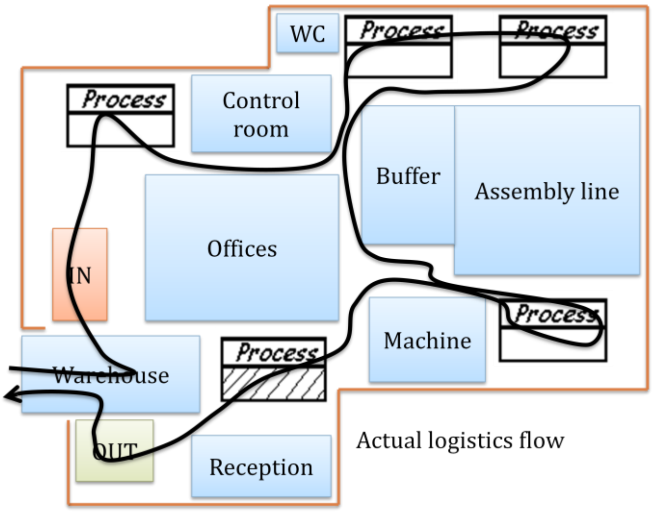


FIGURE 8-J AN EXAMPLE OF MERGED LAYOUT WITH THE VALUE-FLOW

To evaluate different concept of how the layout should be and if it physically fits in the factory the virtual factory model can be used by importing CAD-models into the model, see Figure 8-L for example.

Further simulations to be performed in the Virtual Production Model are work place design simulations that aim to create an efficient and ergonomically correct work place for the operators. Beside these simulations more detailed simulations on robots and cell workstations should be performed to optimise the work sequence, speed and quality of the machines and robots.

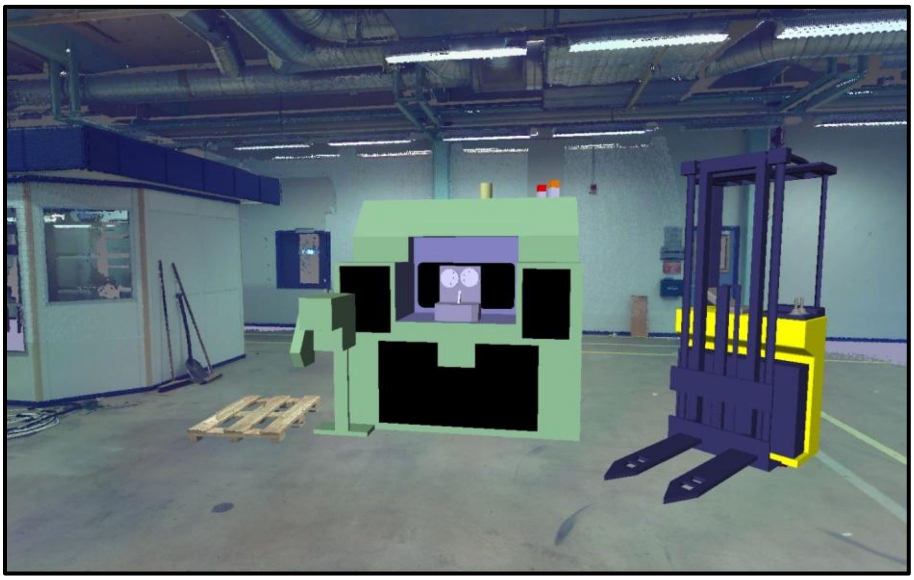


FIGURE 8-L VIRTUAL FACTORY MODEL WITH CAD-MODELS INSERTED

9 DISCUSSION

This chapter discuss three different areas that have been of importance for the thesis. The areas are; how the IS-GDP model compares to the other investigate project models, the result from the benchmarking, the use of Virtual Production and the reasoning behind Lean Product Development.

9.1 DIFFERENT PROJECT MODELS

From the start it was perceived that the IS-GDP model was inappropriate to use when designing production systems. This was also one of the research questions of the thesis, investigating if the current project model is suitable for production system development. In the analysis of the thesis (Chapter 6 and Chapter 7) it became apparent that the IS-GDP does not differ as much as first perceived. The purpose and methodology in the model was quite similar to the rest of the project models. However, the IS-GDP does differ on a more detailed level which is really the main problem. It does have a heavy focus on IT-system development and is not a generic system development model.

Another thing that was fascinating about all the project models is that they are quite similar to each other in their fundamentals, but covers this up at first glance taking on a specialised approach, e.g. Lean Six Sigma or Value-Stream Design. So taking it all in one model did not revolutionise the project model due to the fundamentals. However the aim was create a project model that focuses on the design for a lean production using virtual production tools to achieve a better solution with better result, in less time and using fewer resources.

9.2 BENCHMARKING

The intention of the benchmarking process was to get an insight into how different companies develop production systems. This purpose was fulfilled to some extent but not to the that extent that was planned at first. Although the benchmarking did not give the expected result; it did provide information useful for the thesis. From the visit at Volvo Trucks important insight in project management and project organisation and SKF confirmed the way of working, to name two. Another advantage that came from the benchmarking visits was verification that the author's ideas, methodology and proposed model were on the right track.

The intention from the beginning was to compile these different benchmarking visits and discuss similarities in the development process, however the visits did not provide the same information and were on a wide spread area. A reason behind this can be found the literature about benchmarking, that a company wishing to practice benchmarking should create a long-term collaboration with the other company to get the best results (Andersen & Pettersen, 1997).

9.3 Virtual Production

Using a virtual production model in the development process, especially for new production systems, have many benefits as described in Chapter 3.4. But one of the greatest benefits that are not that apparent is that a virtual production model will provide the development team a unified understanding of the production system during the design phase. This unified understanding will aid and promote the other benefits presented in Chapter 3.4 because of all the developers get a better insight and understanding for other areas than their own, thus closing knowledge gaps in lean product development terms.

The proposed methodology will provide a more effective and simple way of creating the AS-IS process in a factory by making a 3D-scan model instead of constructing the whole factory in a CAD-model. The 3D-scan model will provide a virtual model that a development team can ‘walk’ around in and test different scenarios, such as place a machine in a new place or simulate the consequences of introducing a new product into a production flow. In this way a development team can solve a lot of problems even before they appear in the real world, thus creating a better production system to a lower cost in shorter time.

Simulations in the virtual production model can be useful in many other ways than just development of a production system, a discrete event simulation could be used when re-planning flows or adding new flows into the existing production system. Depending on how detailed the simulation is, it can tell how the lead-time will be affected, buffers needed, any change in bottlenecks etc. This would be very beneficial, to know the consequences before a change is made and have the possibility to make the correct adjustment before applying the change.

9.4 Lean Product Development

As the thesis started the intention was to propose a project model based on the methodology in Lean Product Development. This intention was based on Mr. Holmdahl’s comparison between a stage-and-gate model and the use of Integration Events according to Lean Product Development methodology. This comparison points out great advantages towards Lean Product Development such as that they focus on visible results, does not allow wishful thinking, varied project methodology for each project and aims to optimise the whole instead of sub-optimisation. Although these advantages seems wonderful to have in a production system development project, the author’s reason that introducing Lean Product Development right from the start would be to visionary and would not come to any use. This does not mean that GKN should not use Lean Product Development but the author’s thinks it is easier to introduce the methodology in actual product development first and then take inspiration from the product development department in future production system development projects.

On the other hand, for this type of development project GKN can start using visual management and more specifically a war room to keep everyone updated on the progress of the development team is doing. A certain tool that can be very beneficial is the visual planning that allows all team members to present what they are doing and also see what the other member's works with, as described in Chapter 3.2.

10 CONCLUSION

In this chapter, the research questions are answered and are followed by a suggestion of future studies within the area.

10.1 RESEARCH QUESTION

The purpose of this thesis was to propose a new and improved project model to GKN that is specialised for production system development with the focus of how, when and to what purpose simulation and visualisation tools can be used in the process. This was presented in Chapter 8 and was done through comparing several different project models and conducting benchmarking visits. During the thesis work four different research questions has been answered;

How does GKN develop a production system and how does the current project model work?

The current situation is characterised by using a project model that is not specialised for production system development, the model contains a lot of irrelevant information for this type of project. This causes the development work at GKN drift away from the project model and they work in their own unique way, which is not documented, and tries to fit their way of working into the project models way of working. To conclude there is a need for structuring the work and work according to a more suitable project model.

Is the current project model suitable for production system development and are there better alternatives?

The answer to this question is both yes and no. The current project model is suitable for production system development, as seen from the benchmarking visits where they use it for this specific purpose. However their work was performed from an IT system standpoint, which the current project model is specialised for. To use the current project model from another standpoint would not be as effective, therefore the current project model is not suitable for GKN to use for production system development.

Can the current project model used at GKN be improved to be more suitable for production system development?

The project model can certainly be improved to be more suitable for production system development. In fact, as the analysis brought forward was that the current project does not differ on a more abstract level from the other investigated project models. It is just the specialisation and the complications that come with it that makes the current project model unsuitable for production system development. An improved project model that is inspired by the current project model has been presented in Chapter 8.

How can visualisation and simulation tools be used is production system development?

Visualisation and simulation tools can be used in the development process to create a virtual production model. The purpose of the virtual production model is to decrease cost and increase the quality of the system by identifying problems and complications early in the development process and fixing them to a cheaper price. This will most certainly also lead to a decrease in development time because of the problems and complications are more easily fixed. The proposed method for creating the virtual production model is to conduct a green-field scenario study independently of a factory constraints study and then merge them together to create the best possible solution.

10.2 Recommendation to GKN

One topic that was uncovered during the thesis work and identified to have several benefits if used by GKN is Lean Product Development. The author's recommendation to GKN is to gradually introduce Lean Product Development as a methodology to be used in a production system development project. Of course it would also be beneficial to use Lean Product Development in the actually product development process also, however this is an area the author's have minimal knowledge about the work methodology that is being used.

REFERENCES

Andersen, B., & Pettersen, P.-G. (1997). *Benchmarking - En praktisk handbok.* Studentlitteratur.

Autoliv. (October 2009). APDS. *APDS Training Module*. Autoliv Inc.

Bellgran, M., & Säfsten, E. K. (2010). *Production System Development.* Springer.

Chryssolouris, G. (2006). *Manufacturing Systems: Theory and Practice.* Springer.

DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical Education*, Vol: 40 p. 314-321.

Erlach, K. (2013). *Value Stream Design: The Way Towards a Lean Factory.* Springer-Verlag Berlin Heidelberg.

GKN. (den 14 January 2013). *Introduction - Commerical aero engine components*. Hämtat från GKN Aerospace Engine Systems: http://www.gknaerospaceenginesystems.com/AERO/GLOBAL/EN-GB/PRODUCTS/ENGINE%20COMPONENTS/COMMERCIAL_ENGINES/PAGES/COMMERCIAL%20ENGINES.ASPX

Holmdahl, L. (2010). *Lean Product Development På Svenska.* DigitaltryckNu.

Hutchinson, S. A., & Wilson, H. S. (2006). Research Interviews (Qualitatve). *Encyclopedia of Nursing Research*, 2nd ed. p. 521-522.

Jugulum, R., & Samuel, P. (2008). *Design for Lean Six Sigma: A Holistic Approach to Design and Innovation.* John Wiley & Sons, Inc.

Knoll, J. M., & Heim, A. J. (2000). Ensuring the Successful Adoption of Discrete Event Simulation in a Manufacturing Environment. *Proceeding of teh 2000 Winter Simulation Conference*, (ss. 1297-1304).

Kühn, W. (2006). Digital factory - simulation enhancing the product and production engineering process. *Winter Simulation Conference*, (ss. 1899-1906).

Levy, Y., & Ellis, T. J. (2006). A Systems Approach to Conduct an Effective Literature Review in Support of Information System Research. *Informing Science Journal*, Vol. 9 p. 181-212.

Lindskog, E., Berglund, J., Vallhagen, J., & Johansson, B. (2013). Visualiszation Support for Virtual Redesign of Manufacturing Systems. *Forty Six CIRP Conference on Manufacturing Systems.*

Lindskog, E., Berglund, J., Vallhagen, J., Berlin, R., & Johansson, B. (2012). Combining Point Cloud Technologies with Discrete Event Simulation. *Winter Simulation Conference.*

Rowley, J. (2012). Conducting research interviews. *Management Research Review*, Vol: 35 p. 260-271.

Rösiö, C. (2012). *Supporting the Design of Reconfigurable Production Systems.* Mälardalen University.

Sandy, Q. Q., & Dumay, J. (2011). The qualitative research interview. *Qualitative Research in Accounting & Management*, Vol: 8 Iss: 3 p. 238-264.

Schauvliege, E. (October 2012). PSM. *Project Steering Committee Course: Project Sterring Model Course Material*. Volvo Trucks Operations.

Schuh, G., Aghassi, S., Orilski, S., Schubert, J., Bambach, M., Freudenberg, R., . . . Schiffer, M. (2011). Technology roadmapping for the production in high-wage countries. *German Academic Society for Production Engineering*, 5:463-473.

Stark, J. (2011). *Product Lifecycle Management.* Springer.

Svensson, T., & Krysander, C. (2011). *Project model: LIPS.* Studentlitteratur.

Taylor, D. (den 11 January 2012). *The Literature Review: A Few Tips on Conducting It*. Hämtat från University of Toronto: http://www.writing.utoronto.ca/advice/specific-types-of-writing/literature-review

Trost, J. (2005). *Kvalitativa Intervjuer.* Studentlitteratur.

Vallhagen, J., Stahre, J., & Johansson, B. (2011). Visual Production - strategic manufacturing system development tools for aerospace industry. *ISABE-2011-1620*, (ss. 1-10).

Ward, A. C. (2007). *Lean Product and Process Development.* The Lean Enterprise Institute, Inc.

Westkämper, E. (2006). New Trends in Production. i A. I. Dashchenko, *Reconfigurable Manufacturing Systems and Transformable Factories* (ss. p.15-26). Springer Berlin Heidelberg.

Wiendahl, H.-P., & Harmschristian Fiebig, T. (2003). Virtual factory design - a new tool for a co-operative planning approach. *International Journal of Computer Intergrated Manufacturing*, Vol. 16 No. 7-8 P. 535-540.

APPENDICES

APPENDIX A - BENCHMARKING QUESTIONS

Questioner for production system development		
	Every question is connected to production system development	
	Translated from the original in Swedish	
	Project model	
1.1	**Do you use a project model when developing a production system?**	
1.1.1	What type of project model do you use? (E.g. a gate-model)	
1.1.2	What purpose does the project model have for your development project? (E.g. guiding, visualisation)	
1.2	**What initiate a development project for you?**	
1.2.1	What phases do you have?	
1.3	**How do you perform your pre-study?**	
1.3.1	What is the result from the pre-study?	
1.3.2	How wide do you work in the pre-study?	
1.3.3	What is important to think about in the pre-study?	
1.4	**How do you make sure that the decisions made in the project align with the company's manufacturing strategy and long-term goals?**	
1.5	**How do you take care of lessons learned from earlier projects? (E.g. documentation, mouth to mouth)**	
1.6	**Do you use any KPI:s in the project?**	
1.6.1	How do you use the KPI:s?	

1.7	**What is your time-frame to develop a production system?**	
1.8	**How do you evaluate the final result and compare it to what was planned?**	
	Work methodology	
2.1	**What is important to include in the project to ease the introduction of lean production in the final production system?**	
2.1.1	When is lean introduced in the project phases?	
2.1.2	How is lean introduced in the project phases?	
2.2	**Have you had any project with the goal of develop a new production system / cell?**	
2.2.1	How many concept solutions do you generate before a solution is freeze?	
2.2.2	How do you compare and evaluate different concept solutions?	
2.2.3	What prerequisites are there when generating a concept?	
2.3	**When do you start construct different layout solutions?**	
2.3.1	At what point do you start evaluate different layout solutions?	
2.4	**When do you start construct different logistics solutions?**	
2.4.1	At what point do you start evaluate different logistics solutions?	
2.5	**Do you use visualisation tools in the development process?**	
2.5.1	Where do you use visualisation tools?	
2.5.2	How do you use visualisation tools?	

2.6	**Do you use simulation tools in the development process?**	
2.6.1	Where do you use simulation tools?	
2.6.2	How do you use simulation tools?	
2.6.3	To what detail level do you perform the simulations?	
2.6.4	Do you use different detail levels in different phases of the development work?	
	Project steering	
3.1	**Do you use visual management to steer the project?**	
3.1.1	How do you use visual management?	
3.1.2	Do you have a project room (war room) to steer the project?	
3.1.3	What purpose do your project room serve?	
3.2	**How do you confirm that lean principles are used in the final production system?**	
3.2.1	Do you follow the company's strategy even though short term winnings might appear?	
3.3	**How do you steer the project?**	
3.3.1	How do the competences divide on them who steer the project?	
3.3.2	To what extent are they who steer the project involved in project?	
3.4	**What decision points exist that must be approve during the project?**	

3.5	**What economical calculations are made to evaluate the project?**	

APPENDIX B - POINTS OF INTEREST BENCHAMRING

Discussion points – Visit from master thesis students

The master thesis focuses on the project model that is used for developing and implementing production systems. The goal of the thesis is to develop a project model specific for production system development with design guidelines and description what tasks needs to be performed in each phase. Special attention is given to tools for visualization and simulation of production systems and the usage of them in the development process.

Areas of interest:

- The project model that your company are using for the development of a new (or modified) production system
- How your company ensure that the production system meets the overall goals and are aligned with the overall manufacturing strategy of the company
- How the evaluation of the production system is conducted during the development process (from start -> finish)
- What design parameters are the most important ones to consider when designing the production system
- How your company use visualisation and simulation tools in the development process
- How relevant project information is shared / distributed in the company
- How the development process is controlled/guided/steered by project leader
- How the development process is controlled/guided/steered by higher management

Thank you for taking your time to meet us,

Carl Därnemyr & Marcus Lindell

APPENDIX C - EVALUATE MATRIX BENCHMARKING COMPANIES

Matrix of the benchmarking							
	Question:	**Benchmarking company nr 1**	**Benchmarking company nr 2**	**Benchmarking company nr 3**	**Benchmarking company nr 4a**	**Benchmarking company nr 4b**	**Benchmarking company nr 5**
	Project model	**SKF**	**Autoliv**	**SAAB EDS**	**Volvo Cars**	**Volvo Group Technology**	**Volvo Group Trucks**
1.1	**Do you use a project model when developing a production system?**	GPM (Group Project Management). The Project model is based on best practice and the project steering principles of Prince 2	Yes, APDS. A new production system is always developed with the product development. Product development has the responsibility for the whole process from blueprint to production system.	N/A	Global product development system (GPDS). The model covers research & development, purchasing and manufacturing	Yes, IS-GDP	Yes, the PSM.
1.1.1	What type of project model do you use? (E.g. a gate-model)	Group Project Management model is a Gate model	Phase-gate model, three variants.	N/A	The model is based on milestones	Phase-gate	Phase-gate model
1.1.2	What purpose does the project model have for your development project? (E.g. guiding, visualisation)	The project model is used to steer the project time and keep track of the activities. It is important to have one project model that covers the whole concern. "One SKF, One project management method". The most important thing is according to SKF that the model is a tool for guidance and not steering	To steer the project, each project is unique.	N/A	The project model is used to steer the project time and keep track of the activities. It is important to have one project model that covers the whole concern.	N/A	To steer the project, each project is unique

1.2	**What initiate a development project for you?**	The PPM committee (Factory management team) prioritise a number of projects that are important enough to be started	OEM or Research department	N/A	Management team decides	N/A	Management group sees a need
1.2.1	What phases do you have?	5 phases. Pre-project, Initiation stage, Delivery stage, Final delivery stage, Post-project	See APDS in report.	N/A	Pre-study phase, concept phase, industrialization 1 phase, Industrialization 2 phase	N/A	
1.3	**How do you perform your pre-study?**	Wide investigation, try to see what is new on the market before deciding the concept.	Pre-study not performed at the production system, only on the product.	N/A	N/A	N/A	Wide scope, looks at a lot of solutions, front loading
1.3.1	What is the result from the pre-study?	N/A	N/A	N/A	N/A	N/A	One solution
1.3.2	How wide do you work in the pre-study?	N/A	N/A	N/A	N/A	N/A	Very wide
1.3.3	What is important to think about in the pre-study?	Environmental aspect must be included in the pre-study	N/A	N/A	N/A	N/A	Let it take its time to come to a good solution
1.4	**How do you make sure that the decisions made in the project align with the company's manufacturing strategy and long-term goals?**	The Factory management team initiates the project	Highest management takes the decisions of which business opportunities to take	N/A	Initiated by top management	N/A	End effect correlate to the manufacturing strategy. Project goals to end effects etc.

1.5	**How do you take care of lessons learned from earlier projects? (E.g. documentation, mouth to mouth)**	Lessons learned are documented on the project intranet site	Store in a database, uses cross-functional teams	N/A	Lessons learned are documented in the end of every phase and summarised after the project is closed	N/A	Compilation in a database, indexed
1.6	**Do you use any KPI:s in the project?**	N/A	Yes, cost, quality and time	N/A	Yes	N/A	Yes, for each specific project
1.6.1	How do you use the KPI:s?	N/A	To steer the project	N/A	KPI:s are included in the gates	N/A	Keep the project on track and see that everything is under control
1.7	**What is your time-frame to develop a production system?**	Is depended on the projects size	In line with the OEM	N/A	30 months	N/A	Does not exist
1.8	**How do you evaluate the final result and compare it to what was planned?**	N/A	Customer verification test	N/A	N/A	N/A	See 1.4
	Work methodology						
2.1	**What is important to include in the project to ease the introduction of lean production in the final production system?**	N/A	Concept base thinking from the beginning, one-piece flow, operators only do value-added work.	N/A	Principles for Lean production must be included in the manufacturing strategy	N/A	N/A

2.1.1	When is lean introduced in the project phases?	N/A	One-piece flow, U-cells, Kanban system, need flexibility, operator only do value-added work	N/A	N/A	N/A	N/A
2.1.2	How is lean introduced in the project phases?	N/A	Concept thinking	N/A	N/A	N/A	N/A
2.2	**Have you had any project with the goal of develop a new production system / cell?**	N/A	Almost every time, specific products and volumes	N/A	The China plant	N/A	Yes
2.2.1	How many concept solutions do you generate before a solution is freeze?	N/A	Freeze the concept early	N/A	N/A	N/A	N/A
2.2.2	How do you compare and evaluate different concept solutions?	N/A	N/A	N/A	Use simulation tools for this purpose	N/A	N/A
2.2.3	What prerequisites are there when generating a concept?	N/A	Minimise the used floor space	N/A		N/A	N/A
2.3	**When do you start construct different layout solutions?**	N/A	Only U-cell, concept thinking	N/A	Volvo Cars have a standardized layout solution that they improve	Virtually, line processes	N/A

2.3.1	At what point do you start evaluate different layout solutions?	N/A	Early, physical real size models	N/A	N/A	N/A	N/A
2.4	**When do you start construct different logistics solutions?**	N/A	Early, takt time requirements	N/A	N/A	As early as possible	N/A
2.4.1	At what point do you start evaluate different logistics solutions?	N/A	Adjust to take time	N/A	N/A	See 2.4	N/A
2.5	**Do you use visualisation tools in the development process?**	Yes	Physical models only	N/A	Yes	Yes, extensively	N/A
2.5.1	Where do you use visualisation tools?		Pilot with iterations	N/A	Assembly worker training	Virtual production	N/A
2.5.2	How do you use visualisation tools?	Use sketch-up to present different layout solutions	Real world testing	N/A	To drill the assembly workers before the actual physical system exists	To know before we go	N/A
2.6	**Do you use simulation tools in the development process?**	Yes	No	N/A	Yes, FACTS is recommended, Högskolan in Skövde has developed the tool. Easy enough so that the project leader can use it.	Yes, extensively	N/A

2.6.1	Where do you use simulation tools?	Simulate production flow	N/A	N/A		Virtual production	N/A
2.6.2	How do you use simulation tools?	N/A	N/A	N/A	At Volvo Cars they simulate the following areas: Assembly, ergonomics, production flow,	To simulate so many different aspects as possible	N/A
2.6.3	To what detail level do you perform the simulations?	N/A	N/A	N/A		Differ	N/A
2.6.4	Do you use different detail levels in different phases of the development work?	N/A	N/A	N/A		Yes	N/A
	Project steering						
3.1	**Do you use visual management to steer the project?**	N/A	PULS-room (Management control room), and sub rooms for specific projects	Yes, extensively	N/A	N/A	Yes for bigger project, can exist for smaller to
3.1.1	How do you use visual management?	N/A	See above	Visual boards	N/A	N/A	N/A
3.1.2	Do you have a project room (war room) to steer the project?	N/A	Yes	Yes, larger projects	N/A	N/A	See 3.1
3.1.3	What purpose do your project room serve?	N/A	Steer the project	To steer, control and give information of the project	N/A	N/A	Steering and control

3.2	**How do you confirm that lean principles are used in the final production system?**	N/A	Concept driven development	N/A	Is included in the manufacturing strategy	N/A	N/A
3.2.1	Do you follow the company's strategy even though short term winnings might appear?	N/A	Monthly meetings with the high management	N/A	N/A	N/A	N/A
3.3	**How do you steer the project?**	Use the project model for this purpose. The machine acquisition process is controlled by a project handbook.	The highest managers from different departments, logistics, production, economy, market etc.	Visual management	The project model is used for this purpose	N/A	Gates, active coaching
3.3.1	How do the competences divide on them who steer the project?	Sponsor and steering group. 3 persons, The sponsor is the steering group leader and is a stakeholder i.e. production manager. His responsibility is to establish the project and lead the way. The steering group members are people with power in the company	Updated with information at least once a month	N/A	N/A	N/A	High power - highly affected - high knowledge
3.3.2	To what extent are they who steer the project involved in project?	N/A	Mail	N/A	N/A	N/A	Should be coaching and help the project manager steer the project
3.4	**What decision points exist that must be approve during the project?**	N/A	Takt-time	N/a	N/A	N/A	The gates

3.5	**What economical calculations are made to evaluate the project?**	SKF compare investment cost for different suppliers. The const is not the most important aspect, quality, cost for spare parts, and service are also important	N/A	N/A	N/A	N/A	N/A

APPENDIX D - LARGER PICTURE OF THE TABLE OF INVESTIGATED MODELS AND ITS PHASES

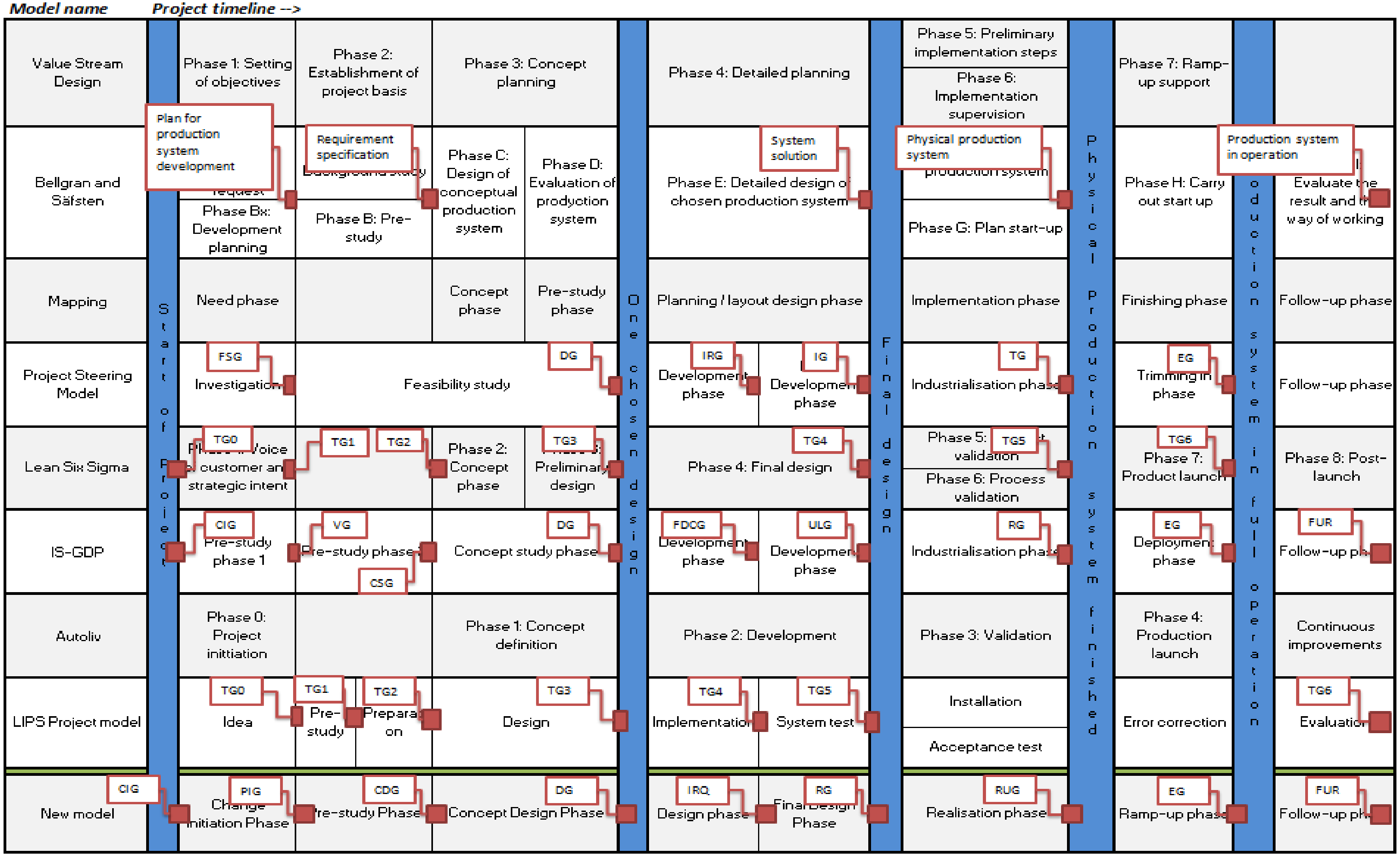
Table of investigated models and its phases

Model name	*Project timeline -->*													
	Start of project					One chosen design			Final design		Physical production system finished		Production system in full operation	
Value Stream Design		Phase 1: Setting of objectives	Phase 2: Establishment of project basis	Phase 3: Concept planning			Phase 4: Detailed planning			Phase 5: Preliminary implementation steps Phase 6: Implementation supervision		Phase 7: Ramp-up support		
Bellgran and Säfsten		Phase Ax: Prepare investment request Phase Bx: Development planning	Phase A: Background study Phase B: Pre-study	Phase C: Design of conceptual production system	Phase D: Evaluation of prodyction system		Phase E: Detailed design of chosen production system			Phase F: Build production system Phase G: Plan start-up		Phase H: Carry out start up		Phase I: Evaluate the result and the way of working
Mapping		Need phase		Concept phase	Pre-study phase		Planning / layout design phase			Implementation phase		Finishing phase		Follow-up phase
Project Steering Model		Investigation	Feasibility study				Development phase	Final Development phase		Industrialisation phase		Trimming in phase		Follow-up phase
Lean Six Sigma		Phase 1: Voice of customer and strategic intent		Phase 2: Concept phase	Phase 3: Preliminary design		Phase 4: Final design			Phase 5: Product validation Phase 6: Process validation		Phase 7: Product launch		Phase 8: Post-launch
IS-GDP		Pre-study phase 1	Pre-study phase 2	Concept study phase			Development phase	Final Development phase		Industrialisation phase		Deployment phase		Follow-up phase
Autoliv		Phase 0: Project inittiation		Phase 1: Concept definition			Phase 2: Development			Phase 3: Validation		Phase 4: Production launch		Continuous improvements
LIPS Project model		Idea	Pre-study | Preparation	Design			Implementation	System test		Installation Acceptance test		Error correction		Evaluation
New model		Project Initiation Phase	Pre-study Phase	Concept Design Phase			Design Phase	Final Design Phase		Realisation phase		Ramp-up phase		Follow-up phase

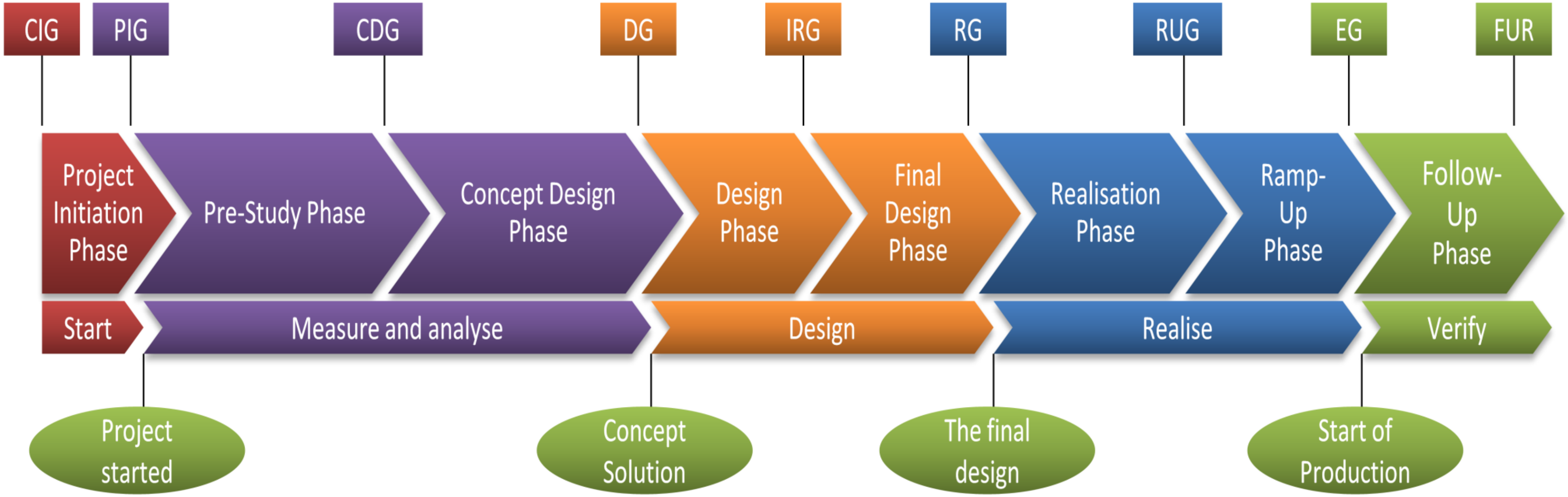
APPENDIX E - LARGER PICTURE OF THE TABLE OF INVESTIGATED MODELS AND ITS GATE

Table of investigated models and its gates

Model name ***Project timeline -->***



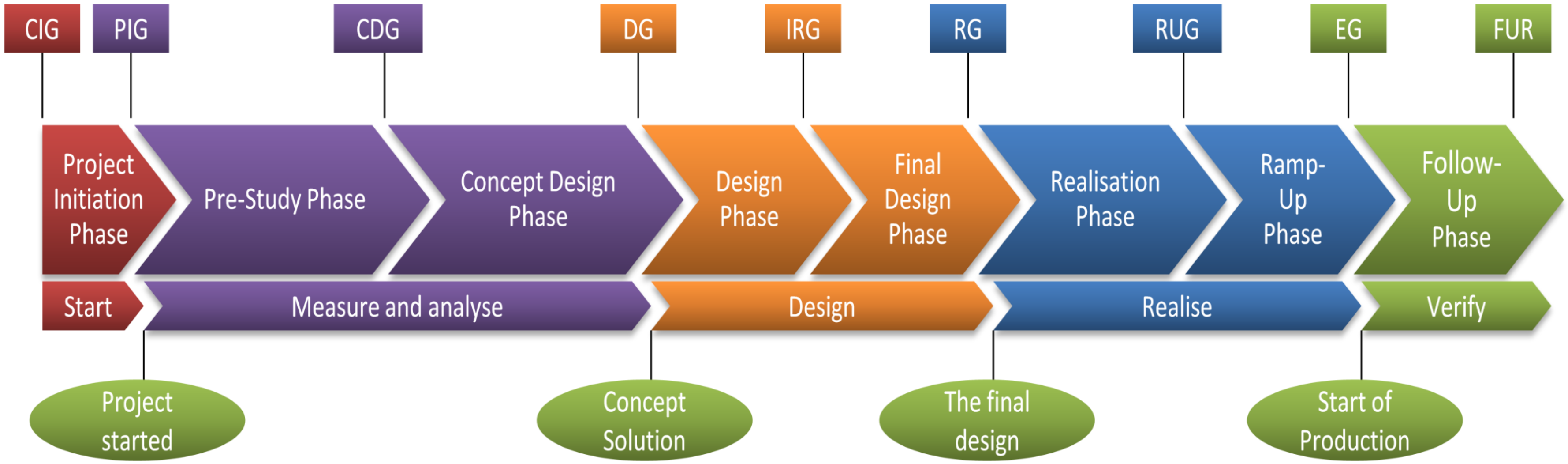
APPENDIX F - LARGER PICTURE OF THE PROJECT MODEL



APPENDIX G - THE HANDBOOK

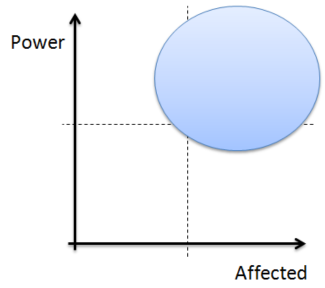
Project Model - Production system development

Handbook



PROJECT ORGANISATION

Management group appoints the steering committee chairman, who in turn collaborates with the management group to form a strong and motivated steering committee. The ideal situation is a smaller team (4-6 people) that have high power within the company and that are highly affected by the result of the project.



GRAPH OF HOW TO CHOOSE STERRING COMMITTEE

To form a project team, the steering committee headed by the chairman appoints one project manager. This project manager can be a visionary person that has the responsibility of the project for the measure and analyse stage of the project and a new get-the-job-done manager could be appointed to manage the project through the later stages. Although there can be one project manager that can have the responsibility throughout the whole project.

The appointed project manager identifies the needed competences to complete the project, specific stage or specific phase (when appropriate) and request these competences from the organisation. When a specific competence is acquired, a time estimation of the workload needs to be done for that specific competence. This time estimation (preferably in percentages) needs to be informed to the competence and the competence manager and agreed upon that the competence will be 'lend' to the project organisation for a certain percentage of the workday for a certain time.

The project manager has the responsibility to achieve the desired goals that exist at the End Gate and after the project has passed the End Gate the project team is dismantled. This means that it is the responsibility of the steering committee to perform the Follow-Up Report and evaluate how the production system performs compared to the final design system. This responsibility is placed on the steering committee to ensure their commitment to the project throughout the timeline and motivate them to provide guidance and coaching to the project team.

WORK METHODOLOGY

The proposed work methodology in Measure and Analyse is to conduct a green-field scenario study and in parallel but independently conduct a factory constraints study.

The green-field scenario study will be heavily focused on the use of simulation- and visualisation tools. With the aid of simulation tools, the design guidelines (presented below) and the company strategy, a developer should design the optimal production system digitally, creating a model in the context of virtual production. The green-field should show how the company can produce certain products in the best and most efficient way possible, thus creating the optimal value-flow.

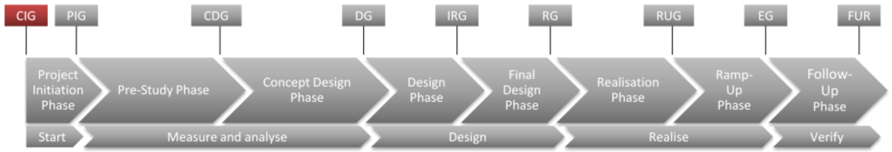
Parallel to the green-field scenario study a factory constraints study should be performed independently. This study should bring forward possible workshops that the production system could be installed in, with all the constraints adjacent to them, e.g. floor, walls, ceiling, existing material flow, existing value-flows, ventilation, facilities etc. As the factory constraint study progresses one or more potential workshops should be scanned to create the base model for a Virtual Reality model. This Virtual Reality model will be used in the concept generating process along with the green-field scenario study.

In the Concept Design Phase the green-field scenario study and the factory constraint study is merged together to create different concepts. The group that conducted the factory constraints study have the responsibility to motivate why the green-field production system should be altered and why the production system should not be the optimal anymore. At the end of the Concept Design Phase at least two concept solutions should be presented and one concept solution should be recommended for further development. This approach is proposed to combine the benefits of set-base design and virtual production, which is mainly to achieve a better product quality with less resources spent on a shorter time.

At this time the project will have come in to the Design stage and one concept solution is chosen to develop further, in the Design Phase the focus should be on defining and designing the long lead time items and create a detailed enough production system to freeze the overall solution. To decrease the development lead time it is proposed to have an Investment Request Gate in the Design stage that approves the investment of long lead time items and also to freeze the overall solution. This gate can save time by conducting the investment of a long lead time items earlier in the process thus shortening the lead time.

To steer the project in the right direction two different directives are necessary, one concept development directive and one project directive. The difference between the two directives is that the concept development directive is used from the Start stage and throughout the Measure and Analyse stage, thus describing how the project will reach one concept solution. The project directive is used from the Design stage and all the way to End Gate thus describing how the project team will develop the concept solution to be a physical production system. Another benefit with this approach is that it creates a natural transition point when a project manager has to hand over the project responsibility to new project manager.

Change Initiation Gate (CIG)



Objective: To decide whether to proceed, re-work or reject the need for change

Decision points:

- Approve the need for change
- Whether or not to formally start a project with its organisation

Input: Request from management group

Output:

- Need for change documentation
- Customer needs
- Potential offerings

Key questions:

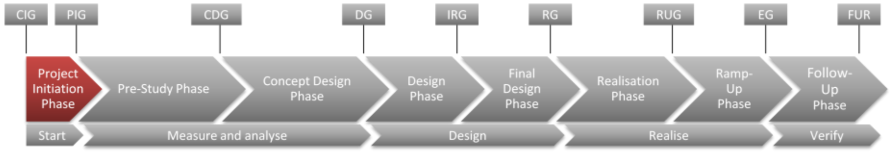
- What is the potential market opportunity, and why?
- Who are the customers for the proposed solution?
- Is the program sponsored by the business leadership?
- Does the proposed program align with business strategy?
- What is competitive environment in the marketplace?
- Is there a technology or business capability available for generating the solution?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: A project is formally started and a project organisation is established

All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gates are closed, you must deliver to open them

Project Initiation Phase



Objective: To create a project organisation and secure resources for pre-study phase

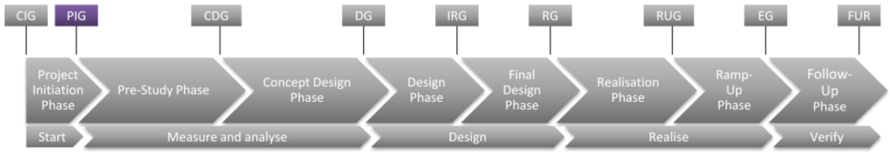
Main activities:

- Work out the project request (Business case)
- Create a project organisation (Steering Committee Chairman, Steering Committee, Project manager, Project team)
- Secure resources and competences needed for pre-study phase
- Define the responsibilities in the group
- Create a concept development directive
- Decide framework of the design guidelines and what principle(s) is going to be used

Outcome:

- Project organisation
- Concept development directive
    - Description of the aim of the project
    - Description of the project goals
    - Develop a project vision
    - Define customer needs
    - Describe business case
    - Plan on how to reach one solution

Project Initiation Gate (PIG)



Objective: To approve the concept development directive. Decide if the need for change is valid, the customer needs are well defined and feasibility is likely.

Decision points:

- Approve the concept development directive
- Decide if feasibility is likely with the business case
- Are the necessary resources secured for the next phase?
- Approve the project organisation

Input:

- Clearly defined project organisation with defined responsibilities
- Concept development directive that explains how the project team aims to reach one solution

Output:

- Updated business case
- Identified customer needs
- Technology and business capability assessment
- Concept development directive

Key questions:

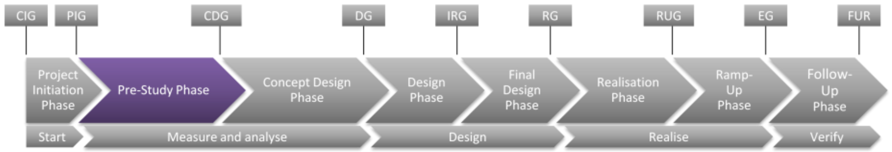
- What are the unmet customers needs (jobs to be done)?
- Who are the customers?
- Who are the stakeholders for the project?
- What is the strategic importance of this project?
- Time to market?
- Financial viability?
- Technology feasibility?
- What are prioritised customer needs?
- What are business requirements?
- Lessons learned identified?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: The investigation work is started with a pre-study and follows the plan established to reach one solution

All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gates are closed, you must deliver to open them

Pre-Study Phase



Objectives: To conduct a green-field* scenario and stating the factory constraints independently of each other.

*Green-field: Design of a production-flow according to the optimal scenario without any factory constraints.

Main activities:

- Green-field scenario (Purpose: Achieve optimal value-flow)
    - Realise the company's strategic planes
    - Based on the 10 design guidelines
    - Value stream mapping, optimal case
    - Simulation model, optimal case
    - Material flows, optimal case
    - Block layout, optimal case
    - Rough estimations of equipment size
    - Warehouse, buffers
- Factory constraints study
    - Analysis of current production systems and products
    - Identify requirements from involved interests
    - Define prerequisites (factory, floor, walls, material flows etc.)
    - Define important design aspects to consider
    - Perform stakeholder analysis
    - Perform a problem analysis
    - Define measureable goals

Outcome:

- One optimal green-field scenario
- Clear defined factory constraints

Simulation:

The Green-field study shall include a flow simulation (Discrete event) to demonstrate the optimal value flow:

- Calculate the amount of machinery necessary to meet the requested capacity
- Generate different concepts and conduct continuous evaluations to achieve the optimal solution
- Create logistic flow
- Create information flow
- Show the potential performance the system can deliver

Factory constraints study

- 3D scan of alternative work shops
- Simulations of existing material flows

Machine and equipment supply (Need Phase):

To conduct a rough preliminary examination of the business potential based on a concern or an idea.

- Describe the background and investigative business potential of the idea
- Identify risks at a general level, and plan activities for the next phase
- Decide if the idea have an option solution (subcontractor, purchase / manufacture, or production methods)
- Set up a Pre-study directive

Principles and guidelines to value stream design (Green-field scenario)

When designing a production system it is important to set the prerequisites for Lean-production right from the start. Before the actual planning of the factory layout the following principles and guidelines have to be taken into consideration:

Design guideline 1: Pace control by customer takt-time. Adjust capacity in the value flow to customer takt-time. This is the most important design guideline, all products in the value chain must move forward at the same time to prevent bottlenecks and buffers.

Design guideline 2: Continuous flow production. The production process must be planned as continuous one piece flow where batch-production is kept at a minimum.

Design guideline 3: FIFO approach when continuous flow is not possible. FIFO planning principles must apply if products have to use resources outside the designated production flow (i.e. technological or organisational reasons).

Design guideline 4: Kanban control. Production rate is controlled by customer demand; this is achieved by using pull principles.

Design guideline 5: Pacemaker process. To enable the value flow to follow customer takt-time, it must be triggered accordingly; this is controlled by the pacemaker process.

Design guideline 6: Definition of release units. Start of new production orders must be planned and released in a structured way to enable an even production flow.

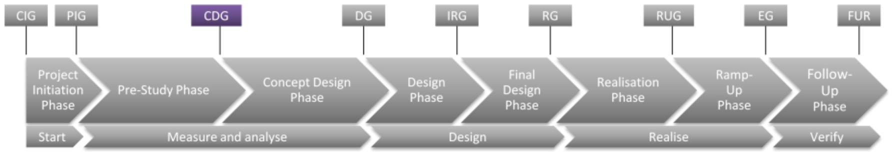
Design guideline 7: Even production mix. To reach a balanced flow, the production orders concerning variants must be well intermixed.

Design guideline 8: Bottleneck control. Release-rate of new orders is controlled by restrictive downstream bottlenecks.

Design guideline 9: Separation of production process and material flow. The value-adding and logistic operations must be separated; this concerns both space and personnel.

Design guideline 10: Flow-oriented layout. The production equipment should be organised according to the ideal value-stream and as close together as possible.

Concept Design Gate (CDG)



Objective: To decide if the green-field scenario meets project goals and customer demands and that the factory constraints study is performed on a high detail level. To decide if the necessary resources are available to choose one solution

Decision points:

- Does the green-field scenario fulfil project goals and customer demands?
- Are the necessary resources available and secured for reaching one solution?
- Is the green-field scenario technically feasible?
- Are there any potential production system solutions in-house?
- Do the factory constraints meet the desired detail level?
- Are there any risk other factory constraints will be uncovered in later phases?

Input:

- Green-field scenario solution
- Factory constraints results

Output:

- Details for conceptual solutions (green field and factory constraints)
  - Flow simulation and 3D scan
- Functional requirements
- Preliminary project directive

Key questions:

- What key functions will the solution address?
- What are the most suitable conceptual designs?
- Are the concepts technically feasible?
- How well will the solution perform against customer expectations?
- What is the business impact?
- What are potential design options to support the concepts?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: Work begins to merge the green-field scenario and factory constraints to generate different concept solutions.

All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

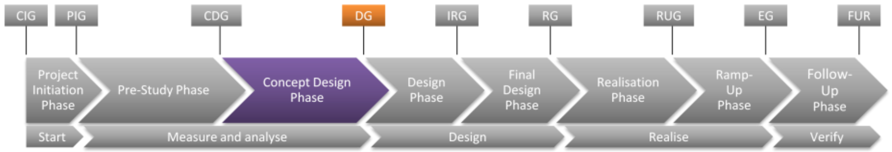
- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gate are closed, you must deliver to open them

Machine and equipment supply (Pre-study Gate):

The steering committee decides by the proposed Prestudy directive if the feasibility study should be initiated and thus allocate resources for this

- The owner (project manager in this case) presents his case for the steering committee, the case is based on the material developed in need phase.

Concept Design Phase



Objective: Merging the green-field scenario and the factory constraints to develop conceptual solutions that will be evaluated and then one recommended solution should be presented

Main activities:

- Merging green-field scenario with factory constraints
  - Block layout + Scans + Simulation = Different concepts
  - The factory constraints study has to argue to why the green-field study is not workable.
- Deliver different concept solutions with evaluation criteria's presented and one recommended solution
- Plans on conceptual solutions
  - Type of tool, method, process, layout
  - Material flow, Level of automation, level of technology, type of machines, equipment
  - Pre-plans for investment, estimated costs
- Create a project directive that clearly shows how the project will reach End Gate
- Risk analysis for unplanned future changes

Outcome:

- One recommended solution among several conceptual solutions
- Plans on the chosen concept solutions
  - Value stream maps (Value added portion, lead-time, process-time etc.)
  - Material-, process- and layout-flowcharts
  - Block layout, plan for material supply
  - Economical calculations, risk analysis in technical and economical terms
  - A model that presents the systems different functions and their mutual relationships
- A value-stream factory plan that can be realised based on design guidelines established in project initiation phase
- Project directive

Simulation:

- A visualisation and updated flow-simulation of different concepts based on the green-field scenario adapted to the factory constraints
- The simulation is used as a decision support tool
- The purpose of the flow-simulation is to show if the planned production system can meet customer requirements.
- What if scenario based in the risk analysis

Machine and equipment supply (Pre-study Phase):

The material from the need phase is further evaluated and supported. The output is a defined project with business opportunities. The Prestudy will result in one recommended proposal for a solution

- Requests equipment quotations
- Identify and evaluate different solutions
- Set up requirements document i.e. requirements specification, technical specification, test instructions, business spreadsheet, directive for continued work etc
- Make risk analysis

Design Gate (DG)

Objective: To decide if there is a design solution that is technically sound and feasible and have a project directive that is viable and that describes how the work will be conducted to reach end gate.

Decision points:

- Is the recommended solution technically sound and feasible?
- Is the project directive viable?
- Are the technical, financial, future changes and customer risk within acceptable limits?
- Are the necessary resources and competences secured for reaching end gate?

Input:

- One recommended solution among at least two conceptual solutions; The recommended solution is based on:
    - The company's overall strategy and goals
    - How well it concur with the requirement specification
    - How well it concur with chosen competitive factors the company have
- Plans on the chosen concept solutions
    - Value stream maps (Value added portion, lead-time, process-time etc.)
    - Material-, process- and layout-flowcharts
    - Block layout, plan for material supply
    - Economical calculations, risk analysis in technical and economical terms
    - A model that presents the systems different functions and their mutual relationships

Output:

- Value stream maps, simulation results, visualisation results
- Project risk assessment reports
- System and subsystem design architecture
- Design of the supply chain configurations and technology assessment
- Project directive

Key questions:

- What is expected performance of the design?
- What is the design of the system and subsystem architecture?
- What are the results from model/simulation prototypes?
- Are new activities assigned resources?
- Are there any potential long lead time tools/machines/equipment? Are there a need for a gate 4 (investment request for long lead time tools/machines/equipment)?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: Opens design phase which aims at developing all details necessary to freeze the overall solution and reach the contract.

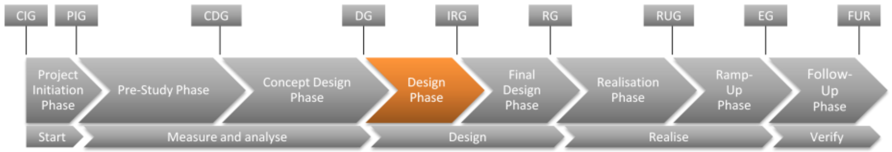
All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman's responsibility to plan gates
- The gates are closed, you must deliver to open them

Machine and equipment supply (Development Gate):

The steering committee decide if the project development phase can begin according to the fulfilment of the proposed directive and thus allocate resources for this.

Design Phase



Objective: To develop all details necessary to freeze the overall solution and reach the contract with focus on long lead time items (tools, machines, equipment and layout changes etc.). The material should be detailed on a level that makes it possible for the steering committee to make a decision.

Main activities:

- Start up development activities, design solution on detailed level
- Work place design
  - Include blue collar workers, safety representative, logistic personnel etc at this stage
- Develop necessary documentation for Investment Request
- Define long lead time items
  - Request quotes on tools, machines, equipment, layout changes
  - Evaluate different suppliers
- Plan final design activities
- Fine tune project lead time
- Optimise business case
- Perform a risk analysis

Outcome:

- List of long lead time items
  - Investment plan
- Detailed solution to freeze the overall solution

Simulation:

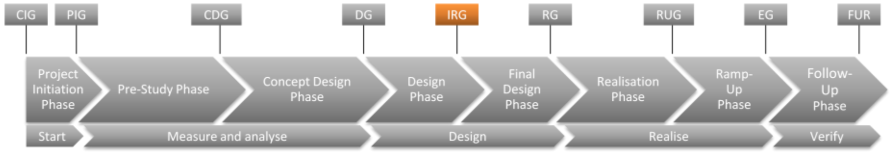
- Updated flow simulation, more detailed
  - If possible, include rough CAD-models of machines and equipment at this stage

Machine and equipment supply (Development Phase):

Finishing the technical requirements for the chosen solution and prepare for the investment

- An Investment Request is created
- The proposed solution is developed at a more detailed level; defines the tools, equipment and layout changes
- Make risk analysis.
- Create TSU (Tillstånd Särskild Utgift) for equipment

Investment Request Gate (IRG)



Objective: To freeze the overall solution and request investment for long lead time items. To decide if the stakeholders accept that the detailed design is technically sound and feasible, meets customer, business, regulatory and environmental requirements.

Decision points:

- The overall solution is detailed enough to freeze
- Decide if the investment plan is approved for long lead time items.
- Are the necessary resources and competences secured?
- Is the project directive updated and relevant?

Input:

- Investment request of long lead time items.
- Detailed solution
- Updated project directive

Output:

- Approved investment request
- Freeze overall system solution
- Updated flow simulation and visualisation

Key questions:

- Are all long lead time items identified?
- Have all long lead time items been requested for investment?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: Finalise all the necessary details of the system solution and prepare for deployment

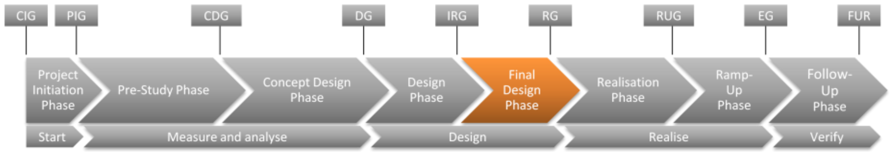
All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gate are closed, you must deliver to open them

Machine and equipment supply (Investment request Gate):

Approved TSU-/ investment request results and secured resources for the continued project

Final Design Phase



Objective: Develop the final solution ready for deployment and prepare for deployment

Main activities:

- Design solution on the detailed level that is required for deployment
    - Plans for facilities and transport
- Plan realisation phase activities
    - Request quotes on short lead time items
    - Evaluate different suppliers
- Create communication and training strategy
- Define tools, equipment, machines and layout change
- Buy long lead time items; tools, machines, equipment, layout changes
- Perform a risk analysis
- Work organisation plans
- Work place design
- Installation plans
- Fine tune project lead time and budget

Outcome:

- Final solution ready for deployment
- Updated project directive
- Plan for deployment and installation plans
- Training plans for personnel
- Work organisation plans

Simulation:

The goal is to have a simulation model that is good enough to give everyone a common view of the value-flow

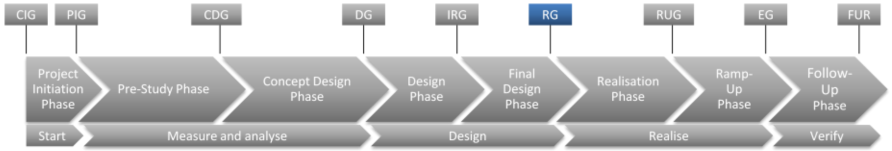
- Updated flow simulation, more detailed
    - The purpose of the flow-simulation is to show if the planned production system can meet customer requirements
- Simulation of work-place design
    - Ergonomic analysis
    - Robot performance
    - Machine performance
    - Manual work

Machine and equipment supply (Transaction Phase):

Resources are available and the solution is prepared at a detailed level and procurement activities are conducted

- Alternative suppliers are called for final negotiations
- Prepare solution proposal at a detailed level for final negotiation
- Define tools, equipment and layout changes and acquire long lead-time items (LLI)
- Create a plan for the installation phase and a communication and education strategy
- Conducting Factory Approval Test (FAT)

Realisation Gate (RG)



Objective: Approve to go for full industrialisation and request investment for short lead time items

Decision points:

- Detailed production system solution that include these areas:
    - Layout plan with flows, installation plans
    - Technical specification and quotes on short lead time items
    - Technology used and linked through systems
    - Work organisation
    - Work environment with ergonomics
    - Training plans, personnel plans
    - Investment plan for short lead time items

Input:

- Final solution ready for deployment
- Project directive
- Installation plans
- Deployment plans
- Investment plan
- Work organisation and training plans

Output:

- Production system ready for deployment
- Updated flow simulation and visualisation
- Simulation results of work-place design

Key questions:

- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: The gate opens the industrialisation phase which aims at finalising the preparations for deployment

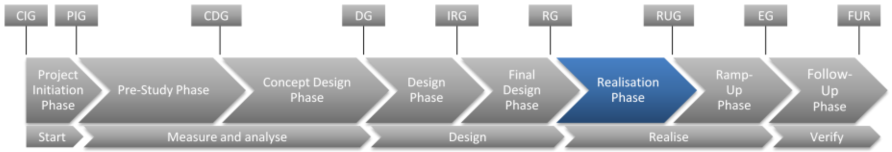
All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gate are closed, you must deliver to open them

Machine and equipment supply (Installation Gate):

Passing the Factory Approval Test (FAT) clears the supplier to deliver the agreed equipment

Realisation Phase



Objective: Buy short lead time items; tools, machines, equipment, layout changes and the deployment and verification of the final production system

Main activities:

- Step-by-step realisation of a structured sequence of *value stream sections*
- Install tools, machines, equipment, layout changes and facilities
- Verify tools, machines, equipment, layout changes and facilities
- Train personnel according to plan
- Prepare the organisation for hand over and elect responsible persons
- Finalise the risk analysis
- Test the production system against predicted performance and capability
    - Pre-series, prototype production, forerunner
- Measure and verify the process that was used to develop the production system
- Plan ramp-up

Outcome:

- A physical production system
- Educated personnel
- Responsible persons to hand over the production system to
- Plan for ramp-up

Simulation:

At this stage the virtual production system is transformed to a physical production system

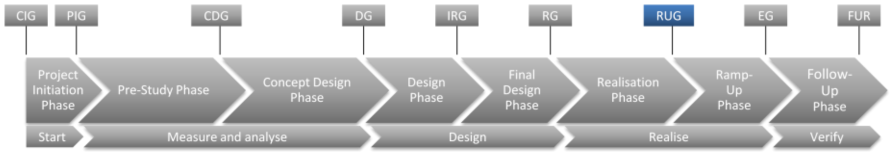
- Verify that the physical system corresponds to the virtual system
- Virtual training of manual work

Machine and equipment supply (Installation Phase):

The equipment is approved for delivery and must be installed and tested in accordance with Installation Approval Test (IAT)

- Acquire short lead time items and install equipment
- Finish work place realisation and perform safety inspection
- Train operators and maintenance personnel
- Finish the risk analysis

Ramp-Up Gate (RUG)



Objective: Approve to go for serial production/full implementation

Decision points:

- Does the production system perform according to the requirements
- Are there design optimisations available
- How did the pre-series and prototypes production go
- How is the process capability
- Is the personnel educated

Input:

- Result from pre-series, prototype production and forerunner
- Physical production system
- Educated personnel

Output:

- Pre-series, forerunner and prototype production results

Key questions:

- What are the results of pre-series, forerunner or prototype production?
- Have the objectives of the design been demonstrated and validated?
- Are there further opportunities for optimisation based on the test or prototypes?
- Is the pre-series meeting customer and stakeholder expectations?
- Have all business, functional and service concerns been addressed?
- Are validation plans ready?
- Is the supply chain ready and capable?
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: Start the process to train the receiving organisation, performing the user validation test and deliver the solution.

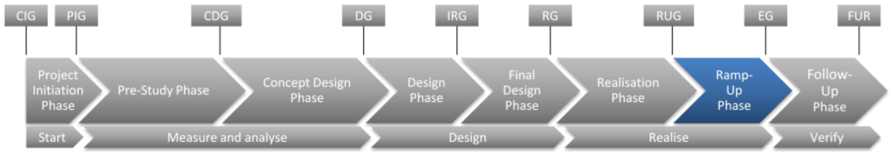
All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gate are closed, you must deliver to open them

Machine and equipment supply (Trimming-in Gate):

Installation Approval Test (IAT) is approved and safety inspections are performed and approved. The equipment is handed over to the line for qualification activities.

Ramp-Up Phase



Objective: Perform according to the ramp up plan and go to serial production/full implementation. Create documentation of lessons learned from the project.

Main activities:

- Continuous evaluation of the value stream performance by way of value stream monitoring
- Execute the ramp-up plan
- Implement solution in full scale
- Deliver the results and make sure to get customer approval
- Perform hand over to line organisation
- Plan follow up activities
- Create take over directive

Outcome:

- Fully implemented production system in serial production
- Take over directive

Simulation:

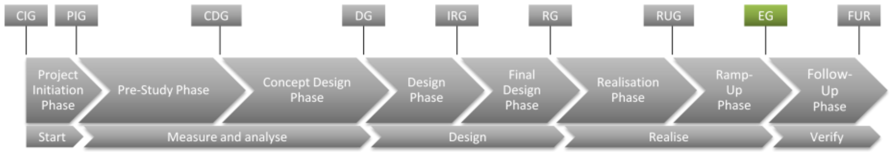
- Verify that the physical system corresponds to the virtual system
- Update the simulation model

Machine and equipment supply (Trimming-in Phase):

The equipment is formally handed over to the line and the warranty period has started.

- Introduction of products
- Adjustments or repairs are monitored during the warranty period where control is done by the supplier on a regular basis
- The project account is closed in the beginning of this phase
- Plan and conduct a full guarantee follow-up

End Gate (EG)



Objective: To decide if the development process is completed and transition ownership is established. Approve the take-over directive, decide to close the project.

Decision points:

- Is the development process completed
- Is ownership established
- Decide to close the project
- Dismantle the project team

Input:

- Take-over directive
- Test result of the production system

Output:

- Final report
- Final net present value and financial report
- Close risk management
- Dismantled the project team
- Updated simulation model that corresponds to the real production system

Key questions:

- What are the obstacles for transitioning to production and launch?
- Is the transition plan completed?
- Has the plan been communicated to the production team?
- Has functional support been established?
- Is the solution profitable
- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned

After decision to open gate: The project is closed and the project team is dismantled. The responsibility is handed over to the line organisation and the steering committee have the responsibility to carry out the follow-up report.

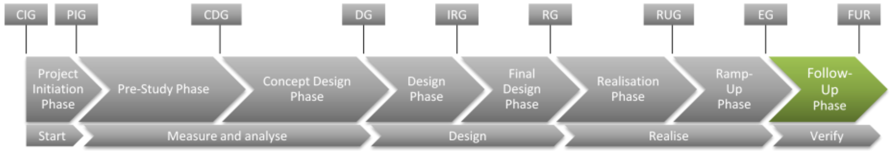
All gate criteria covered by means of two mandatory documents: Status or final report, Project directive/concept development directive

- Verify if the objectives of the previous phases have been reached
- Forward-looking future oriented decision points
- Decision whether to: Go on with the project, adjust its direction or close it down
- It is the steering committee chairman’s responsibility to plan gates
- The gate are closed, you must deliver to open them

Machine and equipment supply (Using Gate):

Guarantee reconciliation with the supplier

Follow-Up Phase



Objective: To evaluate the result and the way of working. Evaluate the result of the developed production system.

Main activities:

- Evaluate the developed production system
- Compare to goals and vision
- Does the production system fulfil the requirements?

Outcome:

- Follow up report
- Probability and financial report

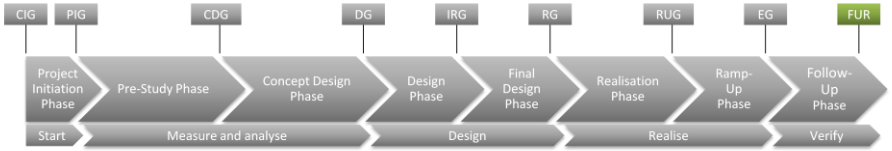
Simulation:

- Verify that the physical system corresponds to the virtual system

Machine and equipment supply (Using Phase):

The warranty period has expired, Trimming-In is complete and the equipment meets the Business Case

Follow-Up Report Gate



Objective: To validate that the business objectives have been achieved and, if needed, decide action plans and further change management activities

Decision points:

- Evaluation concerning:
    - The physical production system
    - The success to fulfil the proposed system solution and requirement specification
    - How the development process was performed
    - Dismantle the steering group

Input:

- Follow up report
- Probability and financial report

Key questions:

- Is the project on track?
- Phase deliverables for next phase known & accepted?
- Resources for next phase secured?
- Budget under control?
- Risks under control?
- Specific project items/issues solved?
- Document lessons-learned
- Final profitability calculations