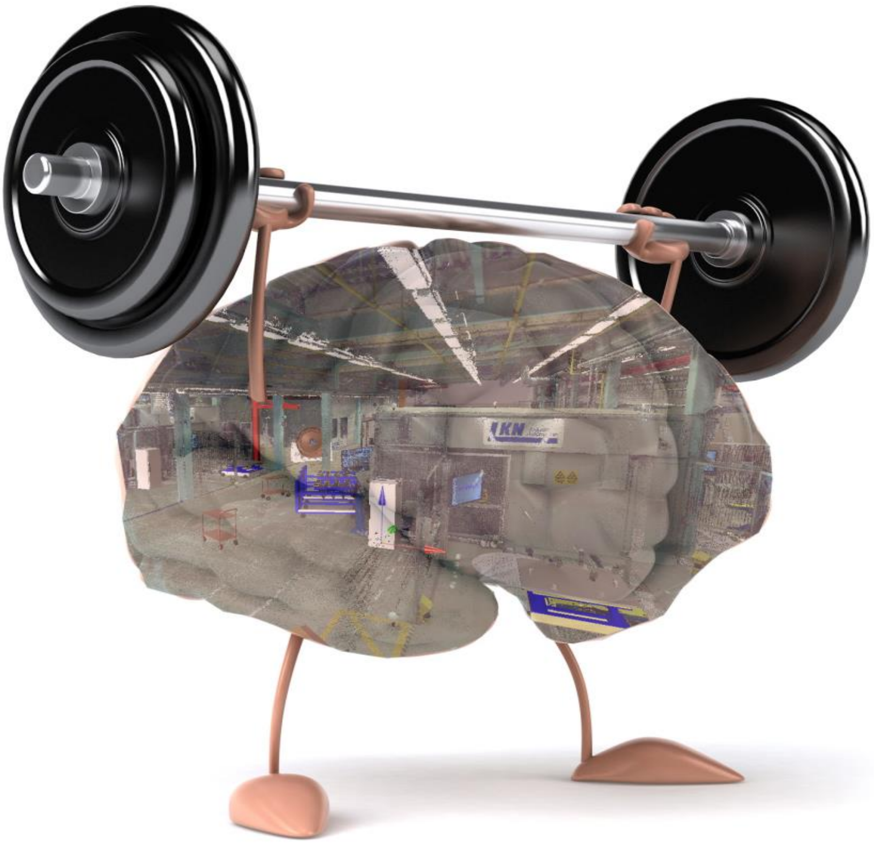
CHALMERS



ANALYZE OF POSSIBILITIES FOR VIRTUAL TOOLS FOR VISUALIZATION OF PRODUCTION ENVIRONMENTS

Visualization study of X-ray unit at GKN Aerospace Engine Systems

Master of Science Thesis in the Master Degree Program Production Engineering

Gustav Jansson
Sebastian Roos

Department of Product and Production Development
Division of Production System
CHALMERS UNIVERISTY OF TECHNOLOGY
Gothenburg, Sweden, 2013

ANALYZE OF POSSIBILITIES FOR VIRTUAL TOOLS FOR VISUALIZATION OF PRODUCTION ENVIRONMENTS

Visualization study of X-ray unit at GKN Aerospace Engine Systems

GUSTAV JANSSON
SEBASTIAN ROOS

Supervisor: Erik Lindskog

Examiner: Björn Johansson

Department of Product and Production Development

Division of Production System

CHALMERS UNIVERISTY OF TECHNOLOGY

Gothenburg, Sweden 2013

Analyze of possibilities for virtual tools for production visualization environments

GUSTAV JANSSON

SEBASTIAN ROOS

Master thesis 2013:

Department of Product and Production Development

Division of Production Systems

Chalmers University of Technology

SE-412 96 Gothenburg

Sweden

Phone: + 46 (0)31-772 1000

Cover:

Visual model of the X-ray cell and the surrounding environment

Source: (Mortensen, 2012)

Gothenburg, Sweden 2013

Sammanfattning

Genomförandet av denna studie har utförts som ett komplement till forskningsprojektet Visuell Produktion, ett forskningsprojekt som bedrivs på institutionen för Produkt och Produktionsutveckling på Chalmers tekniska högskola. I projektet Visuell Produktion medverkar även GKN Aerospace Engine Systems som samarbetspartner, vilket är anledningen till att en stor del av arbetet med denna examensuppsats utgått från GKN Aerospace Engine Systems produktionsanläggning i Trollhättan.

Syftet med genomförandet av denna studie är att bidra till forskningsprojektet Visuell Produktion genom att finna nya användningsområden för virtuella visualiseringsverktyg relaterat till produktionsutveckling och därigenom beskriva dess nytta. Resultatet delas in i två delar där den ena främjar att stödja forskningsprojektet genom att presentera identifierade nyttor uppkomna genom att använda virtuella visualiseringsverktyg i produktionsutveckling och den andra att leverera ett förslag på hur verktygen skulle kunna användas på GKN Aerospace Engine Systems. I den första delen av resultatet presenteras allmänna nyttor som konkluderats under genomförandefasen av projektet. I den andra delen appliceras dessa allmänna nyttor på den föreslagna projektmodellen för produktionsutveckling hos GKN Aerospace Engine Systems, vilken nyligen togs fram i ett examenarbete som även det grundade sig i forskningsprojektet Visuell Produktion.

Några av de fördelar som kan gynna produktionsutvecklingsprocesser ur ett allmänt perspektiv, som beskrivs i denna rapport, är att användandet av virtuella visuella modeller av produktionsmiljöer leder till bättre kommunikation mellan olika funktioner aktiva i produktionsutvecklingsprocessen, det kan väsentligt förbättra möjligheten för projektledare att presentera förståbara investeringsförslag för beslutsfattare samt underlätta för projektgruppen att tidigare upptäcka problem i produktionssystem under utveckling.

Studien som ligger till grund för denna rapport har huvudsakligen utförts i tre delar, som vävts samman i resultatet. Dels har en litteraturstudie genomförts, där gällande forskning har analyserats och använts för att öka förståelsen för allmänna principer vid simuleringsprojekt samt understödja argumentation vid slutsatser. Nästa del har varit en fallstudie där en produktionsenhet på GKN Aerospace Engine Systems i Trollhättan byggts upp i en virtuell miljö, bestående av punktmoln, en simulerad arbetsgång och kompletterande CAD-modeller. De delar som konstruerats under denna fas har använts som byggstenar till den virtuella visuella modell som skapats. Del tre bestod av att den konstruerade modellen användes som underlag till fyra intervjutillfällen där olika funktioner, relaterade till produktionsutvecklingsprojekt, fick chansen att delge åsikter om föreslagna användningsområden för modellen.

Keywords: Visualisering, produktionsutveckling, 3d-scanning, punktmoln, simulering

Abstract

This master thesis is part of a research project at the Department of Product and Production Development at Chalmers University of Technology in Gothenburg. The project, called Visual Production, aims to find new areas of usage for virtual visualization tools for production and production devolopment. The project also includes researchers at GKN Aerospace Engine Systems in Trollhättan as partner, which is why a large part of the work of this master's thesis have been performed at GKN Aerospace Engine system's plant in Trollhättan.

The aim of the master thesis work described in this report is to contribute to the research project by finding new areas, in which virtual visualization tools can be used advantageously in production and production development activities and thus describe their benefits. The results can be divided into two parts, the first is focused on describing characteristics and properties of virtual tools for production visualization. By further developing the ideas, these general characteristics are applied to production and production development and analyzes have been conducted to discover benefits that can be achieved in these areas. The second part of the result is a further application of the noticed strengths of the tools, where the newly developed project model for production development project at GKN Aerospace Engine Systems is supplemented with details on how to work with virtual tools to manage development projects in a more efficient manner. Some of the benefits that have been identified during the project that is described in this report, is that the virtual visual models of production environments can lead to better communication between the different functions that are active in the production development projects, significantly improving the ability of project managers to present understandable investment proposals to decision makers and to facilitate the project team to earlier detect problems in the production systems that are under development.

The methods used in the work to substantiate the results of this project consisted of three parts. First, a literature review was carried out, in which current research has been analyzed and used to develop understanding of general principles in simulation projects, and to support conclusion of the project. The next part has been a case study, in which a production unit at GKN Aerospace Engine Systems in Trollhättan was constructed in a virtual environment, consisting of a point cloud model of the surroundings, a simulated workflow and various additional CAD models to complete the model. The model was then used as base in four interview sessions, where employees at GKN Aerospace Engine Systems was able to share their thoughts on the tools used in the design process of the model. The inputs and reflections gained from these three phases of the project has then served as a base for the results and conclusions in this master´s thesis report.

Keywords: Visualization, production development, 3d scanning, point cloud, simulation

Acknowledgment

During this master thesis work we have had help from a lot of knowledgeable, committed and inspiring people. We would like to thank our supervisors Erik Lindskog, Chalmers, Johan Vallhagen, GKN Aerospace Engine Systems, and examiner Björn Johansson, Chalmers, for their support and inputs from start to finish of this thesis study.

Moreover, during the time spent at the GKN Aerospace Engine Systems production facilities in Trollhättan we have experienced meetings with enthusiastic and interested individuals, who have been helpful and contributing to the success of this study. We would also like to thank the persons participated at the interviews providing superb and very honest input on how to make the best of the future developing process.

Regards

Sebastian Roos & Gustav Jansson

This work is funded by VINNOVA (Swedish Agency for Innovation Systems), and the NFFP5 program. This work has been carried out within the Sustainable Production Initiative and the Production Area of Advance at Chalmers. The support is gratefully acknowledged.

Contents

1 Introduction

The first chapter of this master´s thesis report aims to provide an overview of reasons and the organizations that initiated the project. Moreover, the focus and purpose of the project will be explained. The project has been carried out during the spring semester 2013.

1.1 Terminology

In this Master of Science thesis report, the concepts "visual production", "visual simulation", "visual virtual tools" and "virtual production" will be used frequently. These concepts have room for interpretation; therefore they will be explained in this section, in the context of this report.

Visual production means a visual representation of a production system, often created using a computer software. The visual production environments that may be created in computer software products can be used as illustrations of already existing production environments or production systems under development. It is important to note is that visual production models does not necessarily include exact replicas of all functions and characteristics of a production system, only the visual parts and it is not always possible to gain knowledge of the capacity of a production system by analyzing visual production models.

Visual simulations can be performed in order to analyze a workflow. In this report, the term will refer to a computer made visual model of the work around a certain process, for example manual handling of products.

Virtual visual tools are the computer software products (and in some cases hardware equipment, such as cameras or scanning devises can be used to as a complement to these virtual products) used to create the visual representations. It could also be named as computer based models for visualizing certain processes.

Virtual production is a wider concept that visual production and includes all computer based representations of production systems. Besides the area of visual production, the term also includes computer based capacity models etc.

1.2 Background

The objective of the research project called Visual Production at the department of product and production development at Chalmers University of Technology is to investigate possible areas of usage for virtual and visual tools, related to production development. The main industrial partner, supporting this project is GKN Aerospace Engine Systems Sweden.

GKN Aerospace Engine Systems Sweden is a sub supplier for the aerospace industry, producing high precision components for jet engines. As a part of a project dedicated to building a new fabrication shop, a fully automated X-ray cell has been constructed. Evaluations indicate that the future demand on the products needed to be processed in the cell will increase and additional products will be redirected through the process from less efficient manual X-ray units. As a consequence of increased pressure on the equipment, management plans to build one or several additional similar X-ray cells to support the product flow.

The focus of this master's thesis project is to contribute to the research project Visual Production and the process of production system development at GKN Aerospace Engine Systems Sweden. The starting point of the contribution from this thesis project has been to perform a case study related to the X-ray cell and using findings from this study to complement the project model for production system development at GKN Aerospace Engine Systems, as well as the research material related to the Visual Production project.

During the time between October 2012 and Mars 2013 a project model for production system development was developed at GKN Aerospace Engine Systems, as a result of a master´s thesis project. The structure of this project model proposes the use of virtual production tools at different stages in the production development process. However, there is room of clarification and specification regarding specific virtual tools in this production system development project model.

1.3 Purpose

The purpose of this project is to support the research project "Visual Production" by investigating possible benefits of using virtual tools in the context of production development projects. In addition, the project outcome will include suggestions for how the production development process at GKN Aerospace Engine Systems can be advantageous supported by the use of virtual tools.

1.4 Problem definition

During the last decade new tools for visual production have been developed and the possibility to create qualitative representations of production systems, in shorter time, has improved. This master's thesis have the objective to investigate opportunities for how to implement these tools in a production development context and increase the understandings of how production development projects can be performed more efficiently by the use of visual virtual tools, and to do so by answering the following questions:

- In what way can virtual visual production models be useful for the employees and the production development process at GKN Aerospace Engine Systems?
- What benefits can be achieved by the use of visual virtual tools related to generic production development processes?
- How can virtual production models be of use as a competitive tool in a business situation?

1.5 Goals

The project has two organizations as main stakeholders and in order to contribute to both of them the goals are divided. The goals are:

- To find and ensure new areas where virtual visual production tools can be of use.
- To contribute to the success of the production development projects at GKN Aerospace Engine Systems, the second goal of this project is to supplement the recently developed model for production system development with suggestions on how to work with virtual visual tools during production development projects.

1.6 Delimitations

The study will include the production area and the stations closed linked to the X-ray process. The models that will be created of the cells will not be performing measurements of performances in a way that can be used for mapping utilization, values of efficiency related to different input data like a Discrete event simulation model. Since the study is a part of a research project investigating the possibilities of visual tools related to production development, this will limit the study to prioritize to explain how visual methods can be used, which benefits there are benefits are and how to perform these theories on the case with current and future state of the X-ray station. When applying the found benefits of using virtual tools for visualization onto the suggested production development model at GKN Aerospace Engine System, it will be a suggested additional section based on the already suggested project phases.

1.7 Methodology

The methodology used can be divided into three main parts: creation of a visual model of the X-ray unit and its surroundings, interviews of employees that are connected to production development projects at GKN Aerospace Engine Systems and literature studies.

As a starting point for this study, with the objective of finding new areas for usage for virtual tools for visualization related to production development, a case study with the aim to build a virtual pilot model of a production unit will be performed. The aim of this case study is partly to introduce the members of the team of this master´s thesis project to the software products that can be used in the creation of such a visual virtual model. And by using these software products gain the base knowledge needed in order to reflect on possible benefits of using these virtual tools. The second objective of this case study is to use the created model, to use as an illustrative base for discussion within focus groups of employees at GKN Aerospace Engine Systems that are related to production development processes.

The interviews at GKN Aerospace Engine Systems will be performed as an important step towards learning the actual needs for tools of this kind in real production development situations. During the interview sessions, the model will be presented and different scenarios, where the tools may be of use, will be suggested and discussed. In addition, the interviewees will have the opportunity share their thoughts regarding the virtual visual models and the general idea of using such tools in their profession.

The third part of the methods used in this project is a literature study. Since the usage of virtual visual tools in the context presented in this study is fairly new to the industry, academic publications on the topic are also limited. Therefore the literature that will be investigated is related to similar areas of research, Discrete Event Simulation, running simulation projects in general and 3D-scaning projects. The methodology used when running projects in these areas has been considered (by the team of this master´s thesis project members) to be similar to the one used when running virtual visualization projects and the methods are therefore applicable in this field to a large extent.

The methodology of the project will be presented more thoroughly in chapter

Implementation chapter. The result will consist of two parts, in the first part the gained knowledge from the study will be will be presented as general benefits, which can be achieved by using virtual tools for visualization in production development projects. To realize this part of the result, the outcome from the three parts of the methodology will be merged. In the second part of the result suggestions will be provided for how to use virtual tools to support the GKN Aerospace Engine Systems production development project model. A chart of the included methods used and in what order is described in *figure 1-1*.

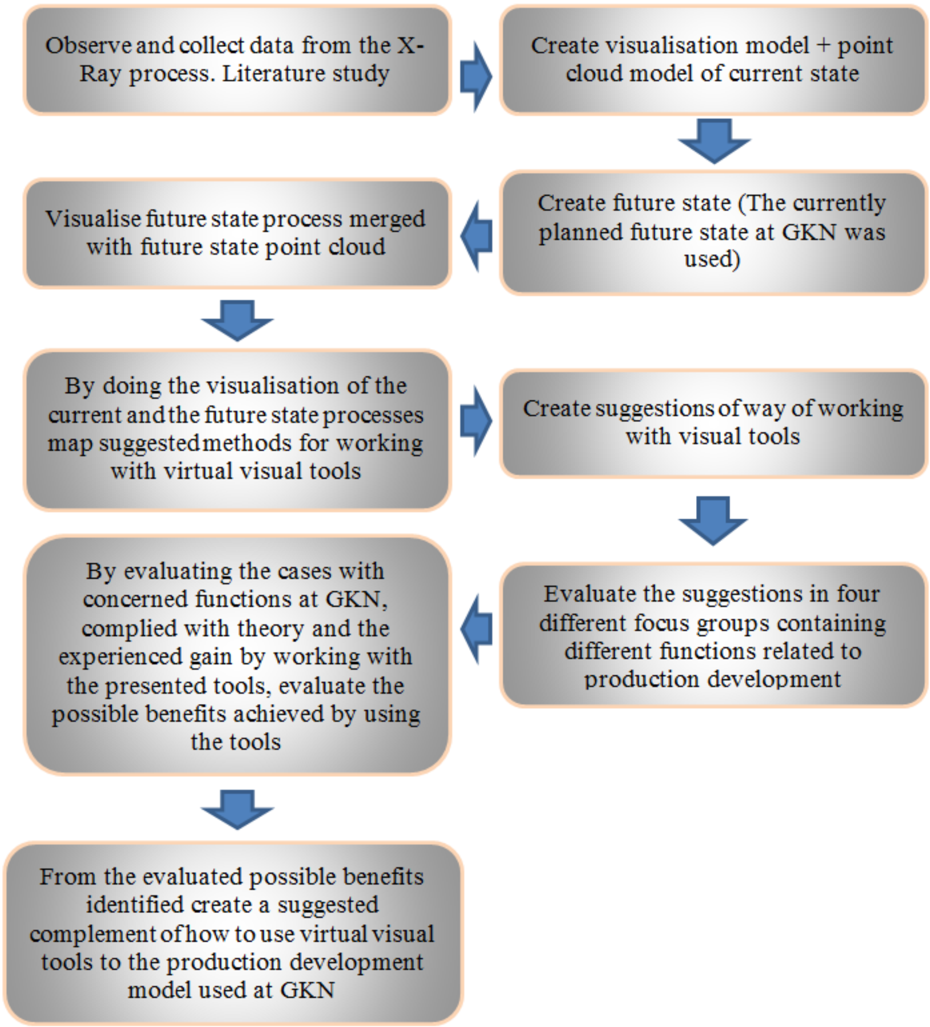


Figure 1-1 Flow chart of the methods used

2 Theory

In this chapter, theory connected to the areas of interest for understanding the method and result chapters will be presented.

2.1 3D laser scanning

A common way of creating representative 3D models of specific equipment and its surrounding environment is to use computer aided design (CAD) software products, to define and visualize the real situation (Lindskog, et al., 2012). The problem of constructing CAD models of complex industrial facilities is that it can be very time consuming. In addition, there is a risk that the reconstruction is simplified and that the measurements are incorrect, due to the amount of measurements that needs to be in order. A relatively new alternative to CAD modeling, to create models of existing equipment is to create point cloud models (environments consisting of large amount of very small points, placed at specific coordinates in relation to a common center, that together appears as illustrations of real environments), which are generated from 3D-scans. In the same way as for CAD modeling, 3D-scan can be used to create computer based representative reproductions of real environments. The procedure of creating a point cloud model is most often more time efficient than it would be to reconstruct a factory using CAD tools (Lindskog, et al., 2012).

There are a few different types of equipment, or types of techniques, which can realize laser measurements for scanning activities, examples are "Time of flight", "Triangulation" and "Phase Shift". To create the model illustrated in Figure 2-1, the phase shift technique was used.

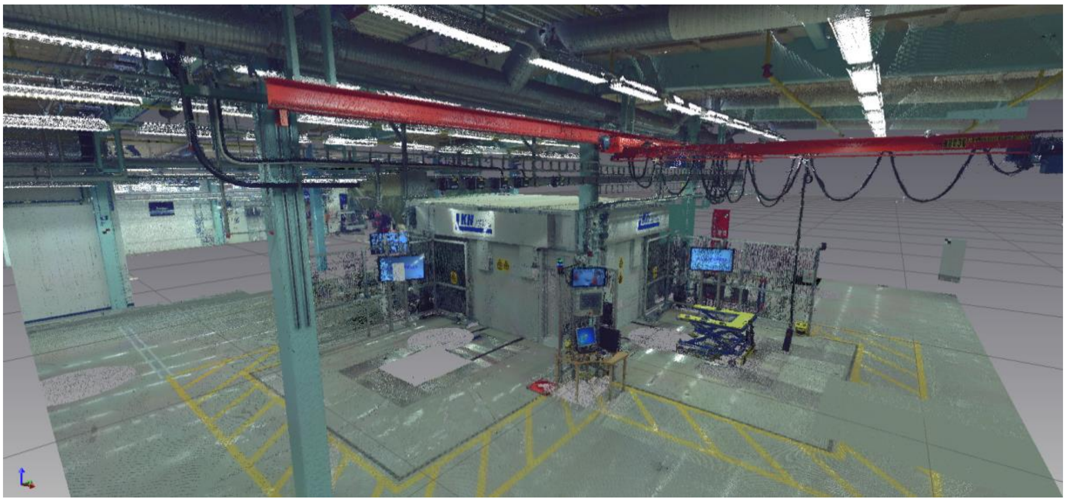


Figure 2-1 Example picture from a point cloud model

Phase shift 3D-scan is a non-contact measurement technique that is performed by collecting data of the surrounding environment by emitting laser beams from a scanning device, the reflected laser beam contains information that can be analyzed and compared to the emitted beam in order to calculate the distance to the point of reflection (Lindskog, et al., 2012). During a scanning session, the scanner rotates around its own x- and z-axis in small increments and performs one measurement in each position. When the scanning session is finished, enough information is gathered to create a spherical view with the center at the point where the scanning device was placed. A spherical view creates the opportunity to observe the surroundings from one point, but all details are only illustrated from one angle. So in order to create a model of an object, where it is possible to observe the item from all directions and “walk around it” in a virtual world, several scans are needed to cover the object from all directions of interest. When several scans are to be assembled there is a need for common reference points, visible in more than one of the scans. These reference points should remain still until all scans are completed successfully, at least three reference objects should be visible in two scans if they are to be integrated in a realistic way (Lindskog, et al., 2012).

A point cloud consists of a large amount of points, that are defined as distances from a certain scan origin, some scanning equipment also support color recognition in which case all points will be defined in terms of distance and color. Each scan takes approximately two minutes for non-color scans and five minutes for scans including color registration.

When several scans are combined, a highly realistic factory environment can be created in a virtual environment. In the virtual model it is possible to produce measurements, with the accuracy of 1.2 millimeters (FARO, 2013), in a simple way using software functions without having to enter the real factory. Furthermore, many CAD software products provide the opportunity to import point cloud models, which makes it possible to create virtual environments where point cloud models are integrated with CAD objects, se example in Figure 2-2. In Figure 2-2, the carts, crane and cupper detail are constructed in a CAD-software, while the rest of the visualized environment are point cloud objects.

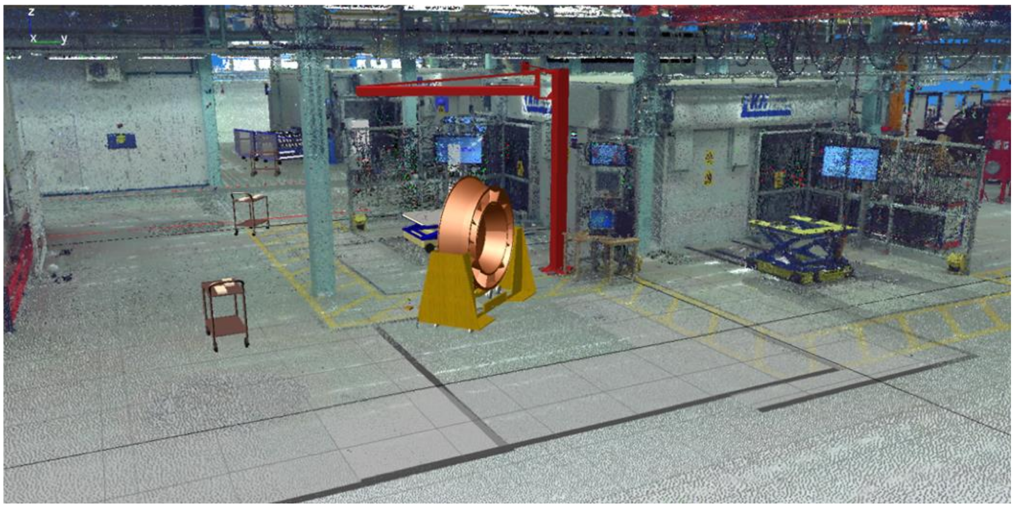


Figure 2-2 Illustration of point cloud in combination with CAD-objects

The areas of usage for 3D point cloud models have become wider according to the level of accuracy, and the possibilities of integrating point cloud models with models created in other software products, such as CAD objects. Compatibility with additional software products can lead to a larger area of usage, and quality improvement of imported point clouds in current software would provide opportunities to create more realistic, integrated, CAD and point cloud models. One scan consist of millions of points (FARO, 2013), which are all defined in distance from the scanning source and color, this means that these files often become large. When several scans are integrated, and maybe even combined with CAD objects or Discrete event simulation models (DES), models can be very sizable and hard to manage by generic computer equipment; this is a limitation for the widespread use of this technology.

There are a few companies that actively work with point cloud models today and one of them is Volvo Cars Corporation. In their production plant in Torslanda (Sweden) they have been using this technique to some extent during the last ten years (Alpman, 2013). According to Volvo Cars benefits can be achieved as the virtual world can be used to run simulations to analyze how to manage production of new cars. As the virtual world is very close to the real production environment, it is possible to see if new models will be able to run smoothly through the assembly lines, or if adjustments are needed to be made in order to produce the new models. In this way they can avoid downtime at start of production due to car bodies bumping in to the production equipment, down time that are extremely costly in assembly lines for car manufacturing (Pröckl, 2003). Other benefits that have been noticed by the simulation experts related to Volvo Cars Corporation are:

- Time efficient, to measure or create a similar world manually would take much longer time.
- Increased flexibility in the development phase.
- Great precision in the virtual word compared to manual measurement activities.

2.2 Virtual factory in general

Virtual factory is referring to a computer based environment that aims to simulate or visualize a real factory environment or a possible future state. Common usage of virtual factory models is often linked to different planning and foresights scenarios and to visualize and simulate alternative solutions (Kuhn, 2006). Virtual factories may consist of different techniques combined such as visual models, point clouds (from 3D scanning) and CAD models as exemplified in Figure 2-3 below.

By integrating CAD models and CAE (Computer Aided Engineering) in general into a virtual factory it is possible to reduce the development time by working with product development and at the same time working with the associated production development. (Kühn, 2006). Also, utilizing a virtual factory can lead to a common ground for communication between different departments which in turn will lead to reduced risk of misunderstandings when it is possible to use the same model to discuss different matters (Wiendahl & Harmschristian Fiebig, 2003).

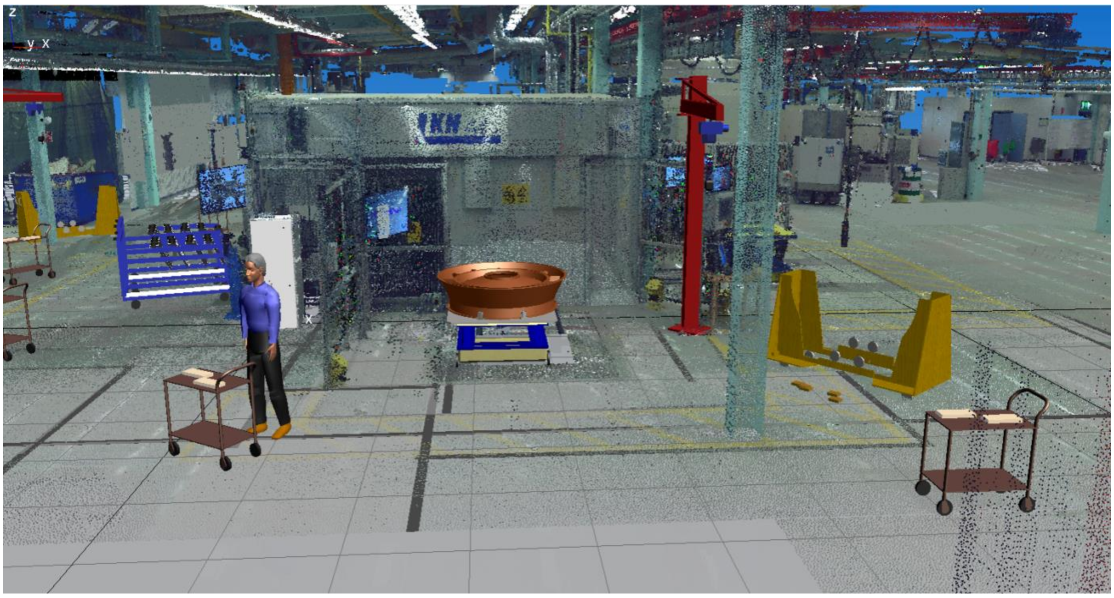


Figure 2-3 Virtual factory exemplified

Virtual models of reality can improve time-to-competence in an amount of critical decisions (Rovaglio & Scheele, 2011) and provides a more detailed basis for decisions when different solutions are evaluated. This is due to both the realistic visual appearance that can be achieved in virtual models and also that 3D models are more understandable on an intuitive level compared to for example information tables or 2D layouts in different compositions (Rovaglio & Scheele, 2011).

A visual simulation model can be used for creating workflows where the different work tasks are programmed and the result is performed as an animation in a virtual environment. A visual simulation model can include different aspects depending on which software that is being used and what is meant to visualize, for example human ergonomic situations, workflow design and material handling. A virtual factory focuses on the integration of different tools available for planning and testing the products, the production system and the operative control of the factory (Kühn, 2006).

Depending what to focus on in a virtual environment different extent of details can be used for different subsystem. If material handling is of highest interest in factory visualization then the CAD models used to visualize the different products can have a lower level of detail and more effort can be put in describing the exact routes of operators and products. For more accurate virtual factory models, it is possible to load the real movements of machines into the model, cycle times of transportation and operations can be included and CAD models that are real designing documents could be used to visualize the physical objects included in the factory (Pröckl, 2003).

2.2.1 Discrete event simulation (DES)

Discrete event simulation models are calculated computer models used to analyze system performances based on different input values and probability events. Output values can for example be cycle times required for a certain system, queue sizes and batch sizes (Ingalls, 2002).

DES modeling is based on logic programming where different parts of a system are treated with individual parameters and then linked together with its surroundings and programmed to operate by the same start, stop and wait signals as the real system does. It is event based which means that whenever a new event occurs in the simulation a new state for rest of the model is calculated (Vallhagen, et al., 2011).

DES models are considered to be a good tool when complex production systems are to be analyzed since the models can be programmed on an overall in-out level as well as highly detailed where every part of a machine is registered with its own cycle time to create a complete highly detailed computer model of the production system. DES models usually require a large amount of knowledge and input data about the process. Despite the need of extensive information gathering DES modeling is considered to be an effective and easy tool for analyzing complex production systems (Knoll & Heim, 2000). DES routing is exemplified in figure 2-4.

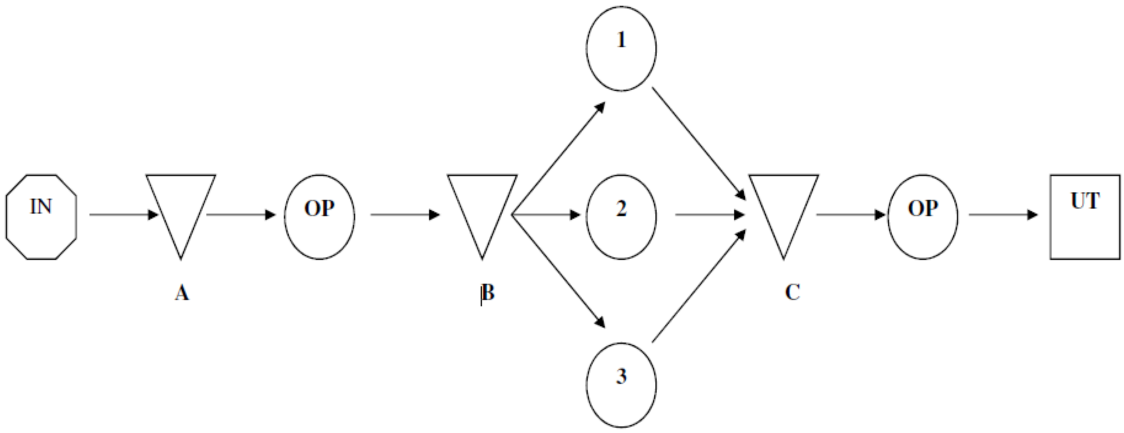


Figure 2-4 Schematic image of DES model (Johansson, 2011)

DES is a tool that fits both in a planning phase of the design of production systems as well as a tool for working with improvements and to evaluate different suggested design changes (Knoll & Heim, 2000). Identified usage outcome of DES models are shown in table 2-1.

Table 2-1 Benefits of DES modeling

Virtual tool	Benefits
DES	Making correct choices
	Compressing and expanding time
	Understanding "Why?"
	Visualizing the plan
	Building consensus
	Preparing for change
	Making wise investments

2.3 Virtual manufacturing in a project context

The use of simulation and visualization tools can be of great use, as a part of a production development project. The initiative for starting a simulation model construction work may lead to both cost and time savings in a project; it can also lead to high costs without useful results if prerequisites for modeling are poor (Knoll & Heim, 2000). In this section issues regarding simulation and the possibilities of producing a useful simulation/visualization model of a production system will be handled.

A successful simulation model is the one that deliver useful information, at the right time and can support decisions (Sadowski, 2007), an illustration of the concept is illustrated in Figure 2-5.

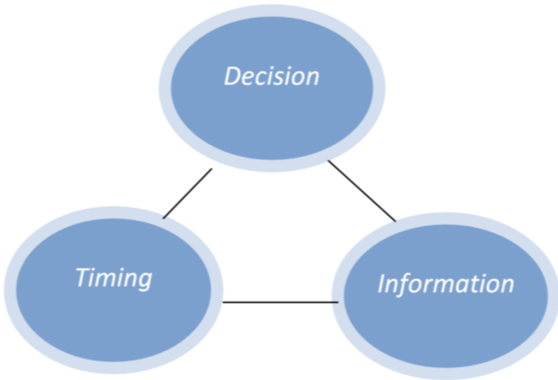


Figure 2-5 Symbolic illustration of the important attributes of a successful simulation model

2.3.1 Pitfalls and precautions

In order to be able to use a simulation or visualization model to support the decision making process it is crucial that it is finished on time. If a model is presented afterwards, it will be useless regardless of the quality of the model itself. Therefore it is always better to be able to deliver a model, explaining the production system roughly (on time) than it is to deliver a more detailed model too late (Sadowski, 2007). There are many reasons why the time for delivery may be delayed, but the risk of delivering the useful model to late can be heavily reduced if precautions are considered and carefully planning of the simulation/ visualization project are conducted in an early phase. In this section typical pitfalls will be addressed.

2.3.2 Data handling

Data handling is a common problem in simulation projects. Often the data handling phase in simulation/visualization projects stands for a considerable part of the entire project time (Sadowski, 2007), and therefore it is important not to underestimate the time needed when scheduling projects. In some project the problem is that the amount of available data is too extensive. In these cases the data might be stored in large databases along with other information; the trouble is how to extract right data that is useful for the project. In some cases the simulation expert does not even have the competence needed, and may therefore need help from IT experts. When special competence is needed, it is important to express the need for help early, in order to secure that the help can be provided without delaying the project.

Another more obvious situation can occur when the information needed to complete the model is incomplete (Sadowski, 2007). This situation can be problematic and extremely time consuming. Activities such as time studies and other additional measurements may be necessary, which can have a great effect on the possibilities to deliver a useful model on time. In order to avoid this situation, the information needed for the project should be stated and available information should be investigated early, so that a the possibilities for making a realistic time plan can be conducted at the start of the simulation/visualization project.

The third data related issue is when the available amount of data suits the project but the data is hard to understand and interpret (Sadowski, 2007). The use of generic words related to production is not always consequent in different organizations. To be able to use the information at hand, it is important that the communication between the information provider and the model constructer is clear.

2.3.3 Project initiation

As described earlier, simulation and visualization models can provide the decision makers with useful information, information that can be very helpful in the process of making the right decisions (Knoll & Heim, 2000). At the same time as this fact can be considered to be the most important applications of the models, this may also be the reason why many simulation projects fail. This has to do with the reason why the project is initiated at the first time. Imagine a situation where a project manager for a production system development project hires a simulation expert with the intention to be provided with a model that supports the already generated ideas and to use the model to convince the management of the greatness of specific new investments. In such a case, the prerequisites for construction of a realistic simulation model that can contribute to the business goals of the company are poor compared with a situation where the simulation project will be delivered to a team of open minded individuals (Sadowski, 2007).

One of the downsides of simulation projects is that it is time consuming and costly, but at the same time as they can save both time and money for the project and be a helpful in the process of creating the best possible production system. Due to these reasons it is important to analyze the problem before deciding that the best way to analyze the problem at hand is to construct a simulation/ visualization model. In some cases, the production system that are under consideration may be analyzed and improved to an appropriate level by less time consuming analyze methods, such as queuing analysis or spreadsheet calculations (Sadowski, 2007).

2.3.4 Animations

Animations can be very effective when the objective is to use a simulation model as a communication tool (Sadowski, 2007). Often simulation models are used to convince top management that certain investments will be beneficial for the company; in these cases it is very important that the project team is able to communicate their ideas to the decision makers. In these cases well executed animations can be of great use (Lindskog, et al., 2012). One example where the simulation constructers have been working with very different levels of animations can be seen in Figure 2-6 and Figure 2-7, both of the simulation models are constructed in the DES software called AutoMod. It is obvious that the model illustrated in Figure 2-6 provides a more complete view of the simulated production system. Due to the additional work on animations, it will probably help non simulation experts to get a clearer view of the meaning with the proposed improvements and investments.

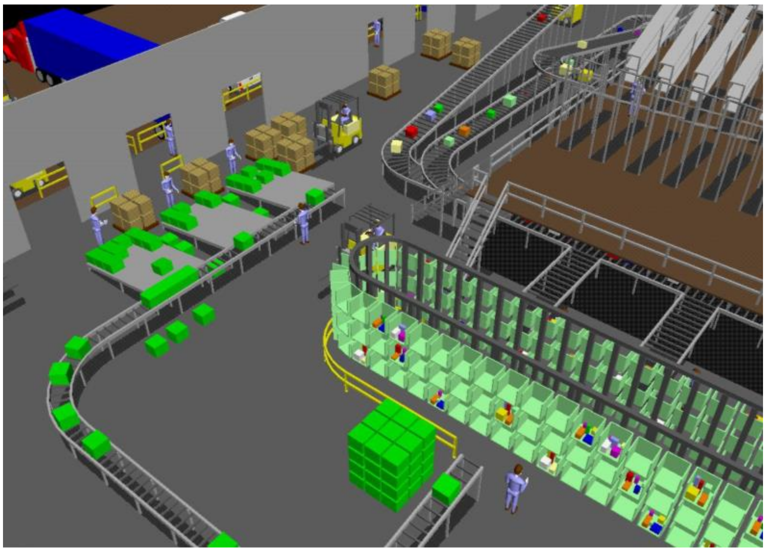


Figure 2-6 Illustration of a DES model with high level of animations (AutoMod, 2013)

Figure 2-7 Illustration of a DES model with low level of animations (Automotive Engineering Services Co., 2013)

It is easy to understand the benefits of having well developed animations built into a simulation model, but it is also vital to understand that animations take time (Sadowski, 2007). The animation part of a simulation model has always room for improvements and it is possible to spend extreme amounts of time on creating good illustrative models. Here is a tradeoff that should be considered, the level of detail in the animations can be very beneficial for the project team up to a certain level. When this level is passed it will cost more than the project team will gain from the model as a communication tool.

2.3.5 Experimenting with DES models

According to Banks methodology, illustrated in Figure 2-8, a simulation modeling project is usually performed in a number of steps (Banks & Carson, 1987). The phase between step 1 and 7 is an iterative process and illustrates the phase where a model of the current state DES model is created.

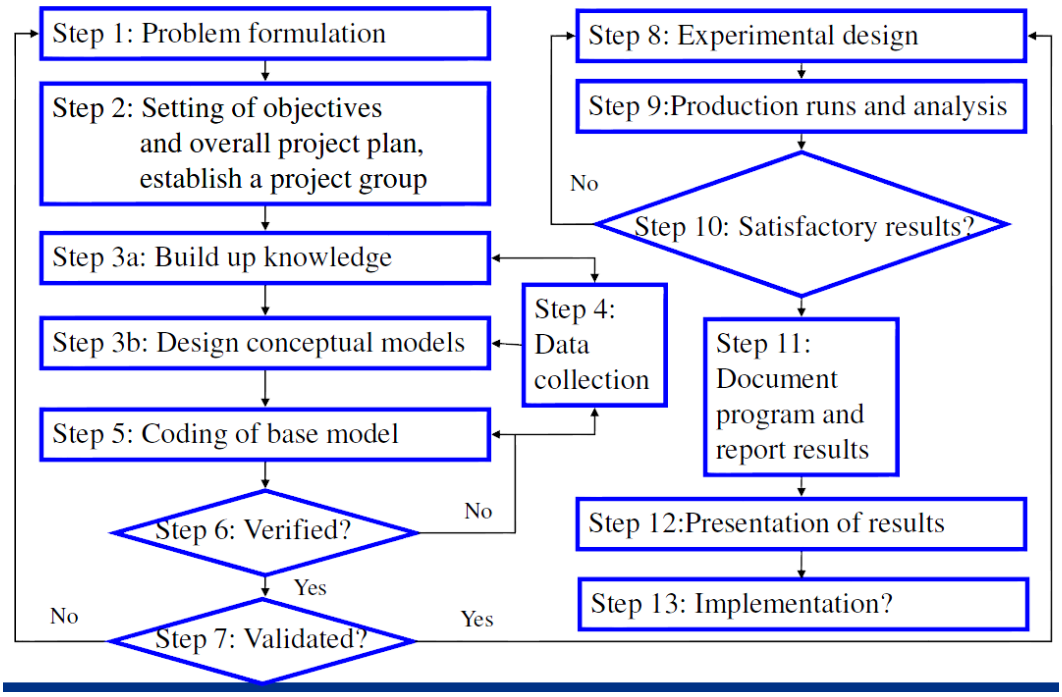


Figure 2-8 The procedure of conducting simulation projects (Banks & Carson, 1987)

When the DES model is constructed, validated and the verification is ready, the model is to be used to run experiments to analyze the production system. At this point the simulation expert will try to find constrains of the system by changing the variables which describes the characteristics of the system. By doing this it is possible to find indications of where efforts and investments should be made in order to improve the system, in terms of increased output in the same or in shorter time. This part of the simulation, according to the procedure presented in Figure 2-8, is often the reason why simulation projects are initiated and the phase where the value of performing the study becomes obvious. It is relatively common that simulation experts have a large focus on the model itself, in these cases the tile left for testing and experimenting may be less than hopes for. Due to the importance of the experimenting phase, it is recommended to schedule at least 25 percent of the total project time for testing (Sadowski, 2007).

2.4 Project model at GKN Aerospace Engine Systems

The project model for production system development, which was developed recently at GKN Aerospace Engine Systems, will be presented in this section. To learn more about the model please see (Därnemyr & Lindell, 2013).

2.4.1 Project organization

In the production development handbook at GKN Aerospace Engine Systems, suggestions are available for how to organize a project from the point of time when an event triggers a discussion, regarding needs for changes in the production function at the company.

When the management discovers a need for change, they should initiate the project by appointing a chairman for the steering board of the project. The chairman and the management are suggested to assembly a steering board, consisting of individuals with high authority within the company. It is also suitable that the representatives in the steering board should be elected, corresponding to their own interest in the result of the suggested development. The size of this group should be between 4 and 6 individuals.

The steering board is assigned to choose and elect a project manager. The appointed project manager will have the responsibility to manage the project during the “measure and analyze” stage. During the remaining steps, the project manager’s role can be passed on if the steering group and the project manager find it suitable for the specific project. If on the other hand the steering group and the project manager find that the first project manager has the qualifications and experience needed to manage the whole project, this can be an alternative as well.

The first assignment for the newly elected project manager is to define the needed competences for the different stages (or phases in some projects) of the entire project, these competences are then requested from the organization. Each of the competences should be considered from a time perspective, a plan should be formed containing information regarding expected time (in terms of number of days) and intensity (percentage of time required during these days).

The project manager is responsible for achieving the assignment in each phase and to hand in the required deliveries associated to each gate, up to the end gate. When the end gate is reached, the steering group is responsible for securing that the activities in the follow-up phase is performed according to plan.

2.4.2 Work methodology

In the project model, illustrated in Figure 2-9, the authors imply that one of the most important development from earlier models is that the project team needs to be flexible in design until the final conceptual model is decided. It is important not to limit the project to one possible solution early in the design phase. Due to the characteristics of productions system development, it can be difficult to maintain an objective view of the design. Objectivity can be achieved by conduction a green-field study in parallel with a study of the factory constraints, which is the suggested work methodology for the “Measure and Analyze” stage.

The green-field study will be performed in order to find the most efficient production unit. In the green-field study, it is important that no consideration is given for the constraints of the available factory area, and thereby the optimal value-flow should be constructed. In the project model the project team is suggested to heavily focus on using simulation- and visualization tools. At the same time as the green-field scenario is constructed, all constrains (or attributes) of the factory area should be documented and evaluated. The optimal situation would be when there are several available areas in the factory, where it is possible to place and build the production system. The area (or areas if there are several available) should be scanned with a 3D-scanner. The point cloud model, that is the output from the scanning activity, will act as base for construction of a virtual production environment. The virtual production environment together with the green-field scenario will form a basis for the concept generation in the pre-study phase.

The part of the project team that were involved in the factory constrains study will be assigned the task to motivate changes from the green-field scenario. In the end of the Concept Design Phase at least two alternative concepts should be formed for further evaluation. In the Design Phase one of the concepts will be elected for further development. When the Design Phase comes to an end, one overall concept has to be elected. The production system concept generated in the Design Phase has to be specified to an extent where it is possible to start the investment process of the items with long lead times for delivery. The benefit of investing in different phases is that there will be room for some changes in the system even after the first items are specified, and the possibilities of having the system installed on time will increase as the parts with long lead time can be ordered at an earlier phase.

2.4.3 GKN Aerospace Engine Systems – Suggested production development model

The main focus of the project model is to support and guide project groups at GKN Aerospace Engine Systems, when new production lines/departments and the associated equipment should be purchased. An illustration of the model is provided in Figure 2-9.

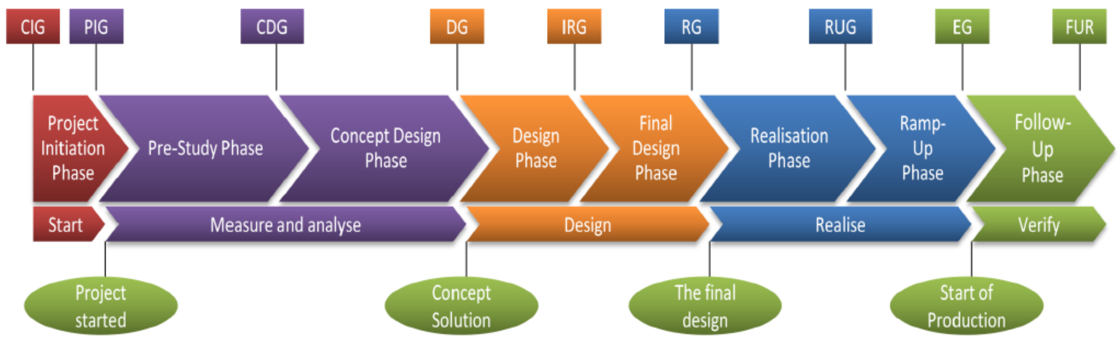


Figure 2-9 Conceptual model of the project model, available in the GKN Aerospace Engine Systems – Production development handbook (Därnemyr & Lindell, 2013)

The project model has five mains stages: Start, Measuring and analyze, Design, realize and Verify. At the bottom of the conceptual model, the green oval circles, represents the milestones for the each project. These are the main outputs from each stage in the project and are necessary to achieve before proceeding to the next stage.

The main stages are divided into different phases; the squares at the top of the pictures are called gates and they represent decision points. Between each phase there are decisions that needs to be taken, the project model suggests areas that need consideration in each of these gates. The purpose of the gates and phases are described in Table 2-2, which is a copy from the GKN – Production development handbook (Därnemyr & Lindell, 2013).

Table 2-2 Informative table of gates and phases in the project model (Därnemyr & Lindell, 2013)(The content of the table is copied from the original table)

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 organization 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. 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 industrialization
Realisation Phase	Investment of tools, machines, equipment, layout changes and the deployment and verification of the final production system
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

2.4.4 The suggested GKN Aerospace Engine Systems production development model and virtual production tools

In the GKN Aerospace Engine Systems production development model there are guidelines for how to work with visual- and simulations tools, throughout the whole project time. The general form for how to work with these tools suggests the use of Discrete Event Simulation (DES), workplace design simulation, 3D-scan, ergonomic simulation, flow simulation, robot performance simulations and CAD-models in different phases of the development process. An overview of the suggested steps of the production development model connected to the use of visualization- and simulation tools is illustrated in Figure 2-10.

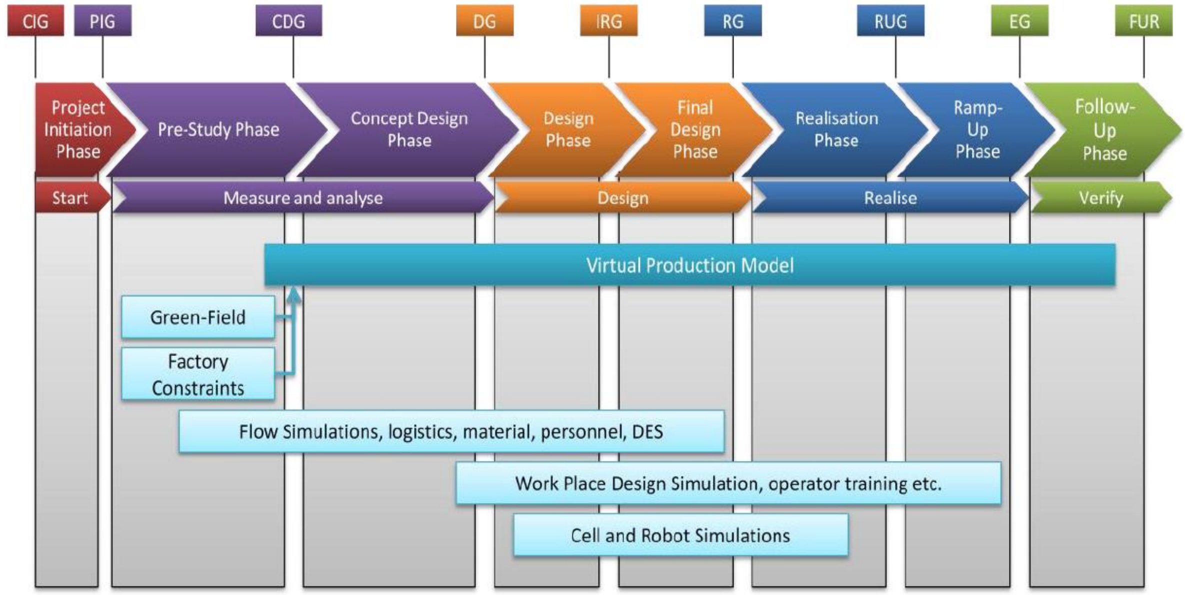


Figure 2-10 GKN Aerospace Engine Systems suggested production development model connected to simulation tools

The reason why the project teams at GKN Aerospace Engine Systems are suggested to use these tools is that they can, according to the project model handbook, reduce the time needed to conduct the new production system and to do so at lower costs.

At an early stage of the development process as mentioned above, the project team should create a green-field scenario model. The starting point of the green-field scenario the team are suggested to perform a value stream study, and create a value-stream map on the basis of this study. The value-stream map will act as an illustration of the optimal production system. At this stage of the development process the first simulation activity is suggested, a DES model should be constructed and used as an analyzing tool of the green-field scenario.

In parallel with the green-field scenario, one part of the project team should focus on describing the attributes of the production facilities in a constraint study. One way of making a realistic model of the facilities is to perform 3D-scans in the areas of interest. In the development model it is suggested that 3D-scing can be an option in this phase. It is also suggested the 3D-scan, or the point cloud generated by performing a 3D-scan, can be used in combination with a 2D value map, with all resources mapped in layout suggestions, to get a clear picture of possible constrains. See Figure 2-11 for an example of a value map from the Project Model- Production System development handbook.

In addition to the 3D-scan activities the project team is suggested to simulate existing material flows through the factory.

The 3D-scan activities, flow simulation and DES model should all be performed in the Pre-study phase.

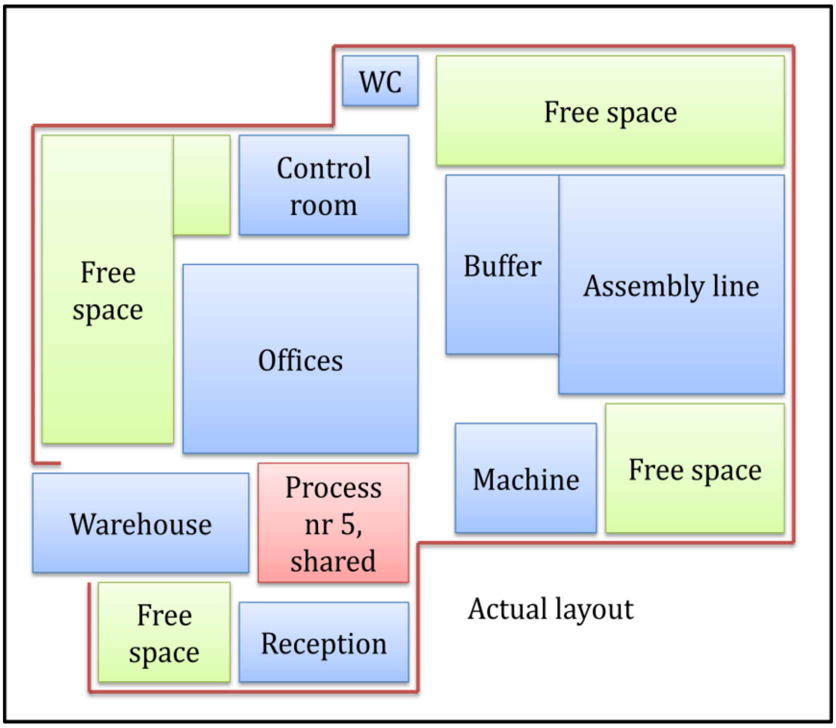


Figure 2-11 Illustrative value map example (Därnemyr & Lindell, 2013)

The final step in the process of creating the first virtual production system is to merge the result from the green-field study and the factory constrains study. In this phase the green-field scenario needs to be fitted into the available factory area in the best possible way. If there are several available areas in the factory, where the new production system could be installed, the one that provides the best opportunities for meeting the green-field scenario should be elected. In the end of the Measure and Analyze step of the production system development model, included in Design Gate (DG) the results from the simulations and 3D-scan should be presented. The virtual production environment that has been created until this stage is the one that will be used and developed during the rest of the project time.

Reaching the Design phase, the virtual model should act as base for further development. The model should be updated as the project progress and if possible, complimented with CAD-models to make the virtual environment as complete and close to the real production system as possible.

During the Final design phase the use of visualization and simulation tools should be focused on creating simulations for robot performance, manual work, and ergonomic situation at the workplace and machine performance.

To sum up the recommended use of visualization and simulation tools suggested in the production system development project model following types should be used during the project time:

- Flow simulation, DES and 3D-scan should be activities included in the Pre-Study Phase. These models should be updated during the project progression.
- During the Concept Design Phase, the 3D-scan, flow simulation and DES model should be merged to create a virtual production model.
- The virtual production model may be complemented with CAD objects in the Design Phase.
- In the end of the Final Design Phase, the virtual production model should be completed. Furthermore, robot performance-, workplace design-, machine performance- and ergonomic simulations should be completed.

2.5 Lean production

The origin of lean is to be found in the Toyota Production System (TPS). Lean production is a concept for how to achieve great results by producing the right amount product at the right time by using small amounts of resources (Bellgran & Säfsten, 2010). In this section the main principles of Toyota productions system, or lean production, will be presented. The text is based on information from chapter 1 in "The Toyota Way Fieldbook" published in 2006 by J. Liker and D. Meier, see (Liker & Meier, 2006) to learn more.

2.5.1 Toyota´s 4P model

As a backbone for Toyota as an organization, the employees and management rely on the 4P´s (philosophy, process, people and partners and problem solving) for guidance on how to run the organization in the best possible way. Under these four 4P´s, there are 14 subcategories called principles, to learn more please see (Liker & Meier, 2006). In this section the 4P´s will be explained.

2.5.2 Philosophy

The company is a "vehicle" that exists to create value for the society, the community, the costumers and its associates. This is how the management and employees at Toyota see their company. The whole idea is that the employees and management, together with the owners and associates have the purpose to contribute the world's welfare, and to build cars is one way towards achieving this goal.

2.5.3 Process

At Toyota the processes are in focus and the general opinion amongst leaders is that the right processes will produce the right results. This does not necessarily mean that the production lines at Toyota are perfect in a productive sense in current version, but by following the principles connected to this P the processes will evolve in a never-ending strive towards perfection.

2.5.4 People and partners

The leaders at Toyota respect their suppliers and employees, they believe in their ability to grow and improve their skills. As a consequence they challenge them and support them in the learning process to provide them with the opportunity to grow as individuals and professionals.

2.5.5 Problem solving

Problems should be handled when they appear and the issue should be investigated careful so that the real root cause to the problem can be solved. In this way it is possible to minimize the risk of having trouble due to the same reasons over and over again.

2.6 Interviews

Interview is a concept including several ways of collecting data. In most common situation when interviews are being performed, the aim is to support qualitative studies by collecting information from the interviewee (Rowley, 2012) . However, the means and procedure varies from structured forms to open discussion, to iterative processes where the interviewer and the interviewee interact over longer periods of time. A common deviation of interview techniques is to divide the concept into three subcategories, structured, semi-structured and unstructured interviews (DiCicco-Bloom & Crabtree, 2006). In this section these subcategories will be presented, advantages and disadvantages with different techniques for different kind of objectives and questions to be answered will be discussed.

Structured interviews are often performed in order to test a specific hypothesis or to gather information from a large number of interviewees (DiCicco-Bloom & Crabtree, 2006). In general these interviews are as an alternative to questioners that are to be filled in; typically questioners consist of a large number of questions that are to be answered. The difference between questioners and structured interviews is that the interviewer handles the documentation instead of the interviewee, as would be the case with questioners. The idea of having an active interviewer instead of questioners is often to raise the response rate.

Semi-structured interviews are generally arranged around a number of pre-determined questions that are meant to act as triggers for structured discussions regarding specific questions or topics (DiCicco-Bloom & Crabtree, 2006). Semi structured interviews can be performed with one or several interviewees. The level of structure that is represented in this subcategory is suitable for focus groups, and the objective can be to handle a topic that is in the area of interest for the interviewees. An example could be a group of experts within the same field, trying to solve problems by a joint effort. Another typical group of interviewees could be a group of peoples with quite different backgrounds, trying to share experiences and point views in order to find answers for complex and specific subjects, which can have consequences for a large number of individuals or the society at a larger scale. The interview session can continue from 30 minutes to several hours. In this kind of interview session, the interviewer should allow an open discussion, without letting the interviewees drift too far from the original questions.

Unstructured interviews can be compared to semi-structured type, with a set of question that guides the conversation between the interviewer and the interviewees. However, when having an unstructured interview strategy the rules for the discussion are vaguer. As the open- ended type of questions is handled, additional questions and topics of discussion emerge as a result of the discussion between the interviewees and the interviewer. In the semi constructed interviews the questions are handled in a predetermined order, whereas in unstructured interview, the interviewer can change the order, and the questions at hand, in order to follow intuition and interesting anecdotes (DiCicco-Bloom & Crabtree, 2006). The interviewees are often encouraged to talk around the questions. This unstructured way of handling the interview demands more from the interviewer, which is required to have a higher level of competence within interview technique in general. Due to the flexibility in the conversation and the evolutionary characteristics of the interviews on this level of structure, the documentation generated by the interviewer from one specific interview is unlikely similar to the documentation from another, which is why answers and other outcomes from this kind of interviews are hard to compare to one and other.

Due to these differences in standardization, interviews on different levels of structure are suitable for different sizes of responding groups. The relation between number of interviewees and suitable form of interview can be illustrated by Figure 2-12.

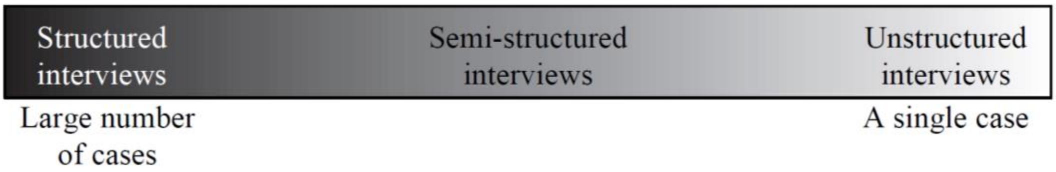


Figure 2-12 The relation between level of structure and suitable number of interviewees (Qu & Dumay, 2011).

3 Implementation

In this chapter all methods and tools used to achieve the result from this project will be presented. In the first section an overall description of the structure is provided to explain the idea behind the procedure. The characteristic of the future state, of which this case study is based, that is presented in this chapter was decided by a production development team at GKN Aerospace Engine Systems. Due to these prerequisites the focus has been to create a visual virtual model of the future state that resembles to the suggested layout alternative.

3.1 Visualization modeling

The visual model of the X-ray cell consists of different systems that have been merged to one model to visualize the physical environment integrated with a conceptual model of the manual work cycle and conceptual modeled objects to visualize the products and associated tools prior to the X-ray manual work cycle. When the case of the current system had been visualized an approach has been made to visualize a possible future state based on indications of a possible expansion. The model of the current system has then been the base for the model of the future state.

Both the current and the possible future state have been modeled to use as a pilot case to investigate the benefits of virtual visual tools in production development in general and to see how these tools can be applied to the production development method used at GKN Aerospace Engine Systems. The software products used in the visualization modeling are listed in Table 3-1 Compilation of software products used for creating the visual model

Table 3-1 Compilation of software products used for creating the visual model

Software	Purpose	Description
FARO Scene 5.0	Handle data from 3D scan	Software connected to the physical equipment used when scanning the factory area
Bentley Pointools V8i	Handle point cloud model	Software used for handling, editing and creating rendering of the point cloud
Visual Component, 3D Automate	Creating simulation model, merging, simulation model, cad models and point cloud models	Used for creating simulation models of manufacturing/production processes. In this case the simulation of the manual work flow was created in 3DAutomate and it was used as a merging software
Autodesk Inventor Pro 2013	Creating CAD models	CAD software used for creating CAD models used as conceptual models in the visual model
CamStudio with Lossless Codec v1.5	Capturing video of visual model	Software for capturing computer screen activity used for creating video of the visual model
Virtual Dub 1.9.11	Merging rendered images from Pointools into video	Used for creating video files from a number of rendered image files. Was used to create video of rendered images of the point cloud model

3.1.1 3D laser scanning

In order to create a realistic virtual model of the X-ray unit and the surrounding area, several 3D-scans were performed and combined into one large virtual model of the factory environment. The procedure was performed in three main steps: preparation, execution and processing of the recorded data. These steps are handled separately below.

3.1.1.1 Preparation

When the area to be scanned is decided there are a few things to consider, first the level of detail for different parts of the area has to be decided. Depending on how focal different parts are they may need extra attention, but it is also important to limit the number of scans since each scan needs planning, takes time and fairly large data space. When the number of scans is decided, the reference objects needs to be taken into consideration. For the scans to able to be properly assembled, at least three specific reference points must be visible in two scans that are to be merged (Lindskog, et al., 2012). In the case included in this project, the execution group decided on performing 13 scans.

3.1.1.2 Execution

During the execution of a scanning session it is important that the area of interest stays motionless. If parts change position during one specific scan, parts may be cut in half in the visualization. If parts change position between two scans, it will be impossible to merge the scans in a realistic way. It is also of interest to avoid capturing objects passing by, such as personnel, on the scans. Therefore the execution needs to take place during a period of time when the scene is cleared from peoples and other moving objects. An alternative solution is to redirect objects passing by and to seal of the scene. During the time of execution, scans should be carried out in order and on position according to the plan determined in the preparation phase.

3.1.1.3 Data handling

After the scanning activities are finished, the information needs to be processed to become useful as point cloud models. By converting the files generated from the scanning device into POD-files in FARO laser scanning software SCENE, it was possible to use the point cloud model in other software products. An example of point cloud environment is shown in figure 3-1.

Figure 3-1 Example of point cloud environment

The next step in the processing phase includes further processing in software where it is possible to make adjustments of the actual point cloud model. In this the case in this case study, Bentley Pointools were used. When performing the scans it is likely that some small disturbances effect the quality of the model, these errors may often include the appearance of non-existing shapes and features in the point cloud. In software products used to manage point clouds it is possible to delete unwanted material from the model. It is also possible to move and multiply scanned equipment. In Figure 3- an example of a multiplied unit is illustrated, the machine equipment at the right hand side, closest to the viewer, is the original one. The machine at the left hand side, which appears in the far back of the image, is a copy of the first one. This can be a helpful in situations when the objective is to create a realistic layout planning etc.

3.1.2 Simulation model

The simulation part of the visual model has been created in 3DAutomate, simulation and visualization software produced by Visual Components, Figure 3-1 shows the modeling environment in 3DAutomate.

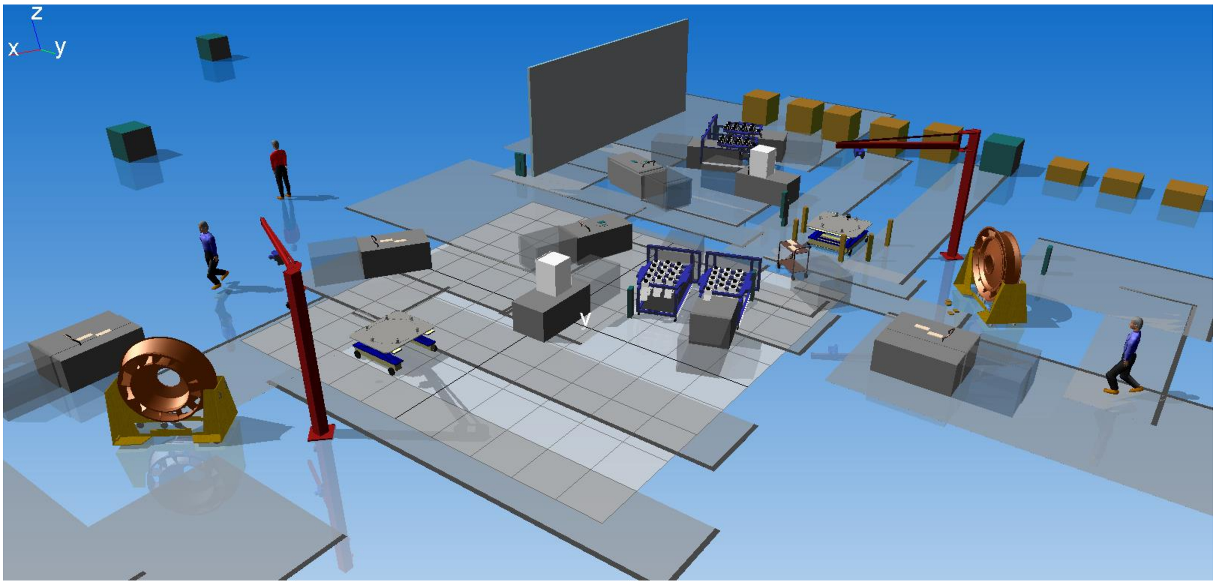


Figure 3-1 Modeling environment in 3DAutomate

The simulation model is showing the different work task that the operator performs during the normal work cycle. Logically the simulation is built up with different stations where the operator is performing the different tasks, in a specified sequence.

The stations are initiated with a component creator that calls for the operator's attention and when a defined number of internal work cycles at a certain stations is performed the next stations is calling for attention in the same way. What the operator is performing at different stations are programmed both regarding to event and which walkway that is to be used. If any of the completed work cycles should start or end with an animation of objects, the component creator will trigger this function as well.

Two similar parallel work flows has been created and simulated to represent the suggested future state and by that it has been possible to program one flow and then by mirror that simulation with modifications to targets between components, the path that the operator should be within to and the placement of the parallel work flow. CAD models and animation objects has been mirrored in the same way.

3.1.3 Animations of objects

3DAutomate has the functionality to enable the user to animate imported customized CAD models in the simulation environment and also to let the user program the behavior of the animations. The object can be animated as a solid object that moves or more in detailed as animated in different joints.

The premise of animating objects in specific joints is that the CAD model is built up as separate parts corresponding to the joints to be used in the simulation software. These parts are then to be assembled in an assembly CAD file and imported to the simulation software. The file format that has been used to import the CAD model to the simulation software in this case study is .3ds. In 3DAutomate the different parts of the CAD assembly that are to be animated as independent joints are separated, given a name and a defined path of allowed motion. Figure 3-2 are showing the interface of defining joints in 3DAutomate. On the top left box it is showing the partial sectioning of the different parts of the CAD file, in this case named X, Y and Z. The box called ServoController: Joints is showing the interface of how to create paths of motion. These paths are then linked to the parts to be animated and by that it has enabled different part of the CAD file to be animated separately and in different joints.

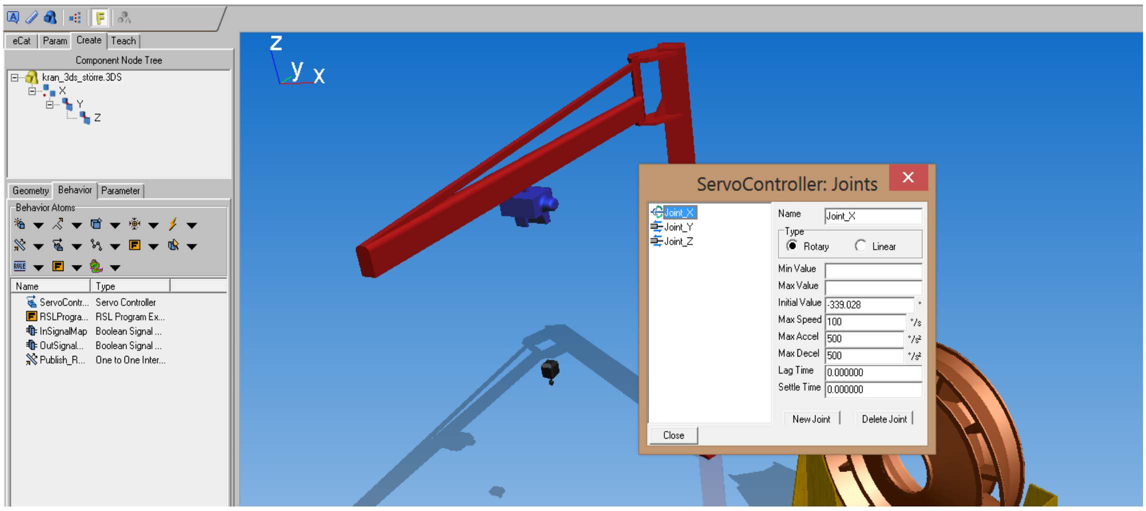


Figure 3-2 Interface in 3DAutomate for creating joints

In the simulation created, different objects have been programmed to interact with each other, in this case the red traverse crane in Figure 3-3 is interacting with the brown product. The interactive animation created in the simulation is created with a parent/child relationships which refers to that one object can call for sequences for the other. By having this arrangement, a sequence schedule is enabled which lets the parent to call for internal motion sequences of the child object and to call for sequences of the parent object. Figure 3-3 shows the interface created in the case simulation which controls the motion sequence of the traverse crane and the product.

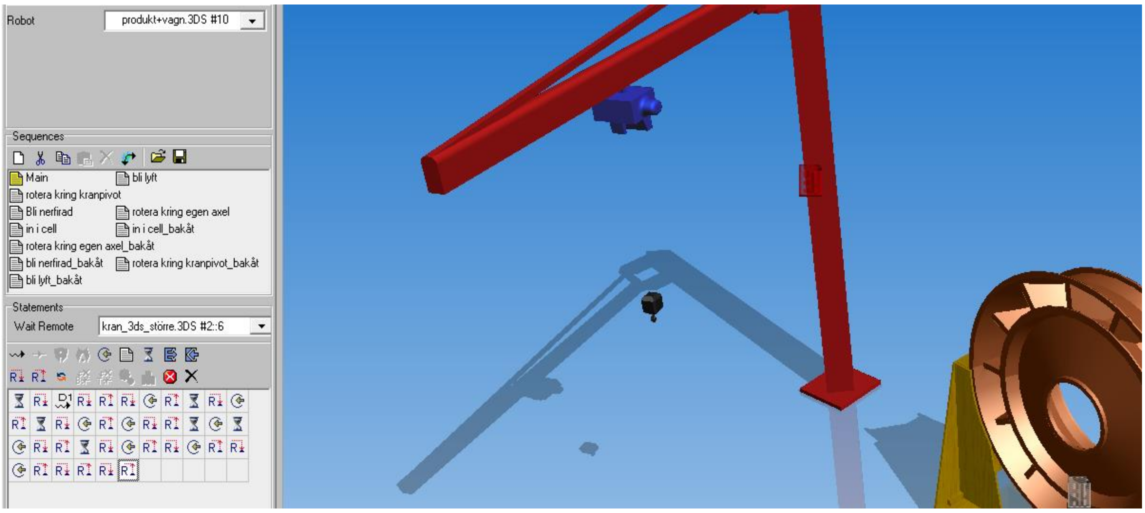


Figure 3-3 Motion sequence of the traverse crane and the product

The internal sequences, for example Main in the Sequences box, are representing one specific movement of one or many joints of an object. These are the sequences called for in the main programmed of the animation.

3.1.4 CAD models of point cloud objects

Since the output of the performed 3D scan is a point cloud (see section 2.1) and that objects that are to be animated in 3DAutomate needs to be solid CAD models a conversion needs to be performed. In this case it has been done through mock-up CAD modeling based on the point cloud models acquired from the 3D scan. Figure 3-4 shows a point cloud object that has served as input for the conceptual solid modeling of the object.

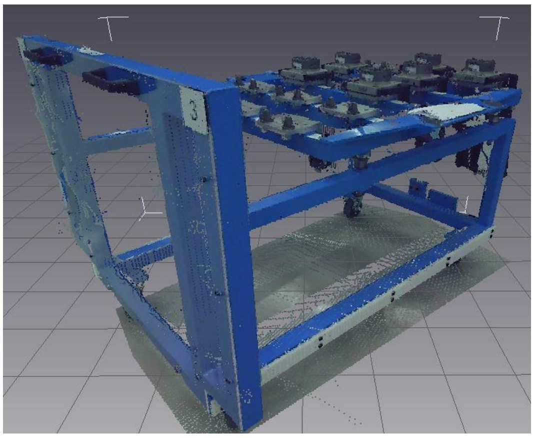


Figure 3-4 Point cloud model of object

The next step has been to measure the object in the point cloud software. Depending of the resolution of the point cloud the measurement of it will fluctuate in tolerance. Measuring an object can be done either by marking two individual points and look how far apart they are or in can be done by choosing several point in one area with the intentions of creating a plane and measure to another constructed plane.

From this measured object a conceptual model is created in a CAD software, in this case Autodesk Inventor. Depending on the purpose of the CAD model it can be constructed in different level of details. For this conceptual visualization model the object has been created with the primary purpose of be illustrative and recognizable with aspect to visual appearance, size and color. The time needed for creating the reconstructing blue cart was around 40min. The CAD model is shown in Figure 3-5.

Figure 3-5 Conceptual CAD model of object measured in Pointools and created in Inventor

During the creation of the simulation model attempts was made to use and animate the real CAD model used as manufacturing document of this particular blue cart but the simulation model became more heavy to work with because of the level of detail of the real CAD models. A visual comparison between the actual CAD model, the created conceptual one and a model taken from the point cloud model was made and is shows in Figure 3-6 where the point cloud model is on the right side, the actual cad model in the middle and the reconstructed one on the left.

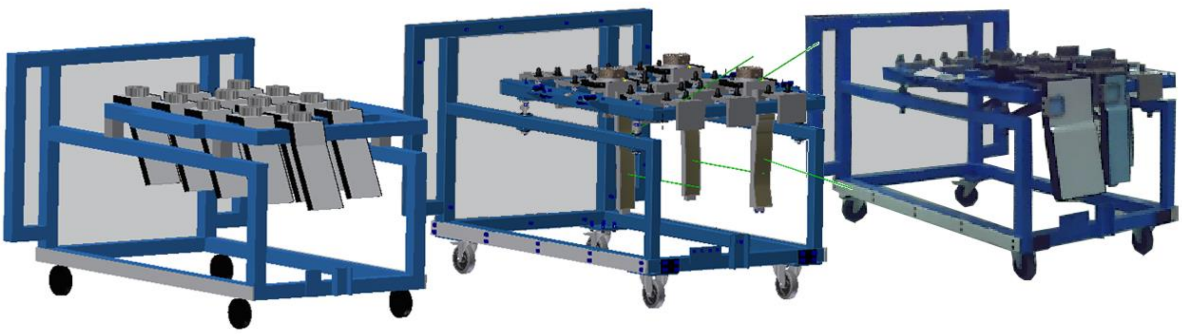


Figure 3-6 Visual comparison between actual CAD model, the reconstructed one and the point cloud model

For a more detailed visual comparison between the actual CAD model and the reconstructed one are shown in *figure 3-7* where the reconstructed is green and the actual is blue.

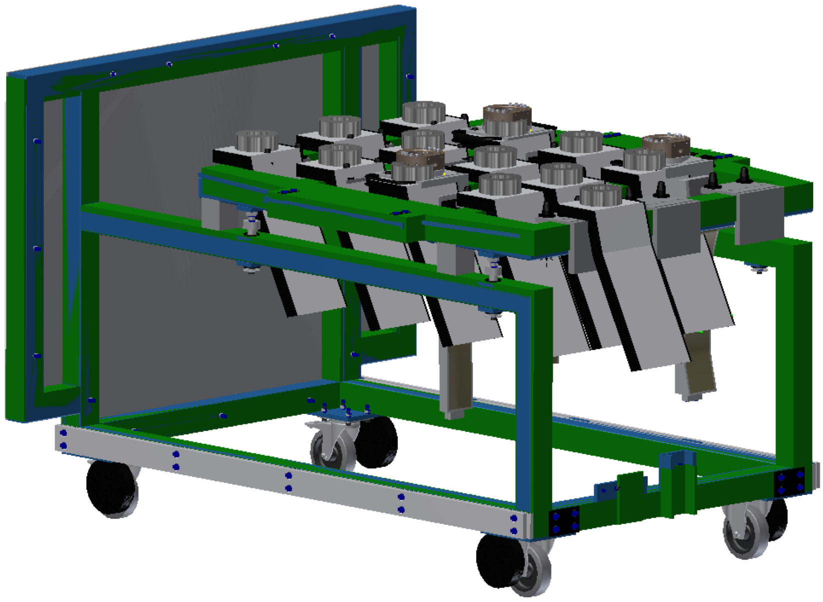


Figure 3-7 Visual comparison between the reconstructed CAD model and the constructed one

3.1.5 Point cloud environment

For the pilot case of constructing a visual model of the X-Ray machine with a supplemented visual suggestion of a possible future state the factory environment has been represented by a point cloud. The cloud was acquired through a 3D scan of the chosen part of factory containing the X-Ray equipment. (See section 2.1).

The point cloud has been cleaned up from unwanted points, for example shadows of objects that accidently moved during the scan, and edited in the software Pointools V8i. For the case of making a visual model of the current state the point cloud has been left intact to a large extent, apart from removing the unwanted shadow points. This was done through selecting the points that where to be removed and the where deleted. Before the point cloud was imported to the software containing the simulation model it was divided into three different parts, one which represented the area close to the X-ray equipment, one that represented the area outside of the X-ray and one that contained the far surrounding of the X-ray machine. This was done to be able to show or hide different part of the total cloud in the simulation software, both to avoid the simulation model being unnecessary computer intense and to get a better overview of the simulation when the point cloud was not the point of interest. Figure 3-8 shows the point cloud model of the current state.

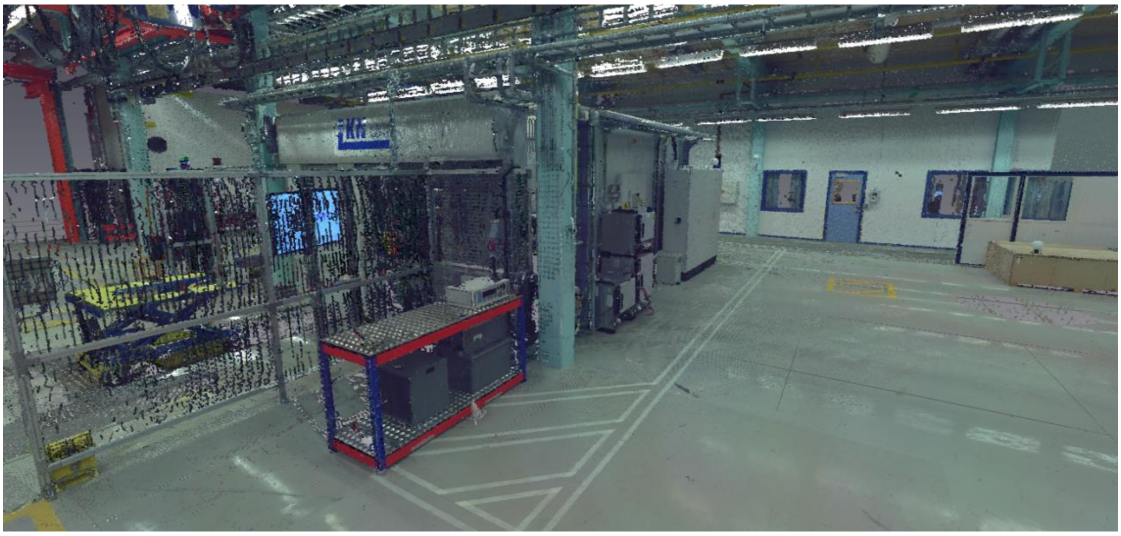


Figure 3-8 Point cloud model of current state

In the case of visualizing the future state, where another X-ray cell was to be installed, modifications to the point cloud where performed. The suggested case that was visualized includes an additional X-ray unit next to the existing one but in an area that in the current state is an office area. To adjust the point cloud to represent the future state, the office area were removed and replaced with an empty factory area that represented the same size as the space containing the offices. The empty factory area was taken from a point cloud model of the factory made one and a half year before the scan of the area around the X-ray equipment was performed. The future state point cloud also included a cloned model of the X-ray cell illustrated in Figure 3-9.

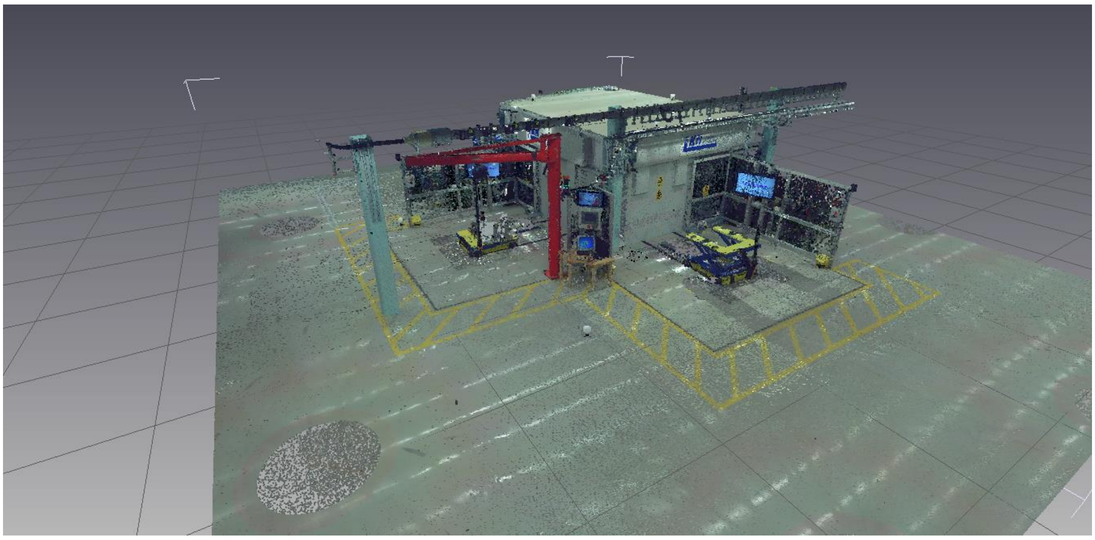


Figure 3-9 Isolated X-ray equipment to use as clone in the future state point cloud

The cloned equipment was placed in the area represented by the empty factory part of the point cloud where the offices are located in the current state model. The point cloud model of the current state was also divided into different parts to be controlled respectively in the simulation model. The point cloud model of the suggested future state is shown in Figure 3-10.

Figure 3-10 Point cloud model of suggested future state

3.1.6 Merging components to visual model

The constructed visual model is consisting of a point cloud to visualize the factory layout, a simulation model to visualize the associated manual work flow around the X-ray equipment and solid and animated CAD models to illustrate the associated objects and tools related to the X-ray process.

Since 3DAutomate is supporting the three different types of virtual representations created it was chosen as the software for assembling the visual model. The simulation of the manual work cycle and the animated solid objects where already created and imported into 3DAutomate while the simulation model was created. To import the point cloud model of the factory environment into 3DAutomate, the model was exported as .pts files from Pointools to enable importing in 3DAutomate. To use and develop the simulation model after importing the point cloud into the simulation model requires large computing power compared to the simulation model without the cloud. Therefore the different parts, in the case of the model of the current state, the area of the X-ray cell, area around the cell and the outer area, of the point cloud model were exported from Pointools with different degrees of resolution depending on the distance from the X-ray equipment. The further away from the X-ray equipment the sparser the exported cloud is. Since the area far away from the studied area is of low visual interest it is not equally important to ensure the visual quality of the point cloud model far away from X-ray cell. Figure 3-11 is showing the division of the point cloud model into different parts where the right part is representing the area around the X-ray cell, the middle part is showing the area of the cell and the two sparse parts to the left is representing the outer area. Note that the parts in the figure are moved apart from each other to illustrate the boundaries between them

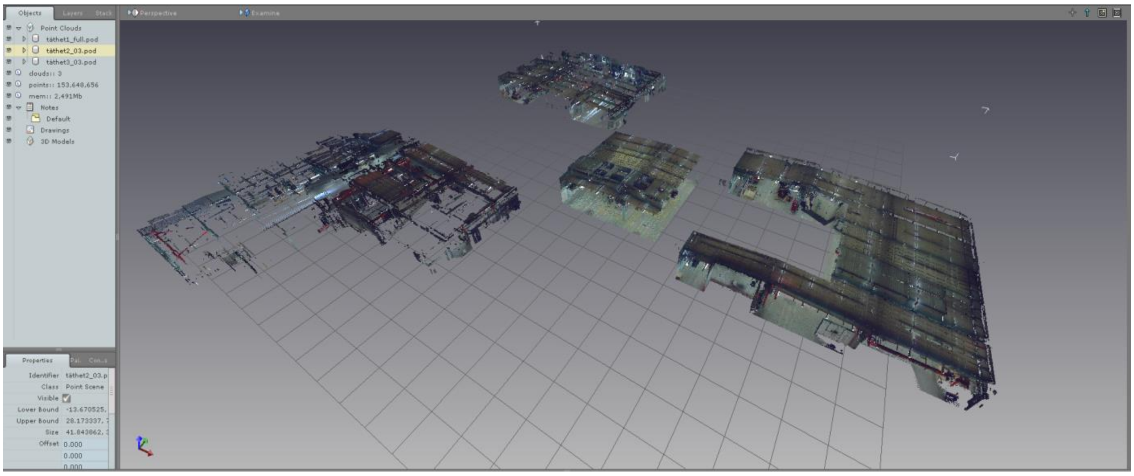


Figure 3-11 Division of point cloud model of current state

In the point cloud model of the future state the cloud was divided into five parts. The three ones from the current state case, one part representing the additional equipment and one part the area surrounding the new equipment. This was done to both be able to adjust the level of detail in the different parts but also to more controlled be handled in the simulation model where they for example can be moved or shown individually.

At this stage in the creation of the visual model the different parts of it were created, saved as individual parts and ready to be merge together in the simulation environment meaning that animations of created CAD models, solid CAD models, point cloud environment and simulation model of the associated manual work cycle were imported to the same virtual environment. Smaller adjustments were made to align the different parts in order to make an accurate fit.

When creating the visual model of the suggested future state, the point cloud environment where updated to represent the future factory layout, duplication of the simulation model and importing of solid CAD models were made to comply with the future state suggestion. The visual model of the future state is shown in Figure 3-12.

Figure 3-12 Visual model of suggested future state

3.2 Visual representation

When the visualization modeling was completed the model was run, recorded and rendered into frames to be able to create a video file of the result. Two different models, the point cloud model and the visualization model of the suggested future state, were recorded. The point cloud model was recorded as the "camera" was flying through the environment and the visual model was recorded while the simulation was running and the "camera" was capturing the simulation from different angles.

To capture video of the visual model CamStudio was used for capturing what happens on the computer screen while the simulation was running. Output from CamStudio was an .avi video file.

The point cloud model was captured using the integrated function in Pointools for capturing movements inside the point cloud. This was done by determine a set of placements and orientations of recording points and let the software sweep through these points and saving picture files continuously during the movement. The output from the recording was individual picture files of the whole sequence which were put together and rendered to an .avi file in the software Virtual Dub 1.9.11. The result of the visualization representation performance was video files of the virtual representation of the suggested future state.

3.3 Literature review

As a part of the implementation in the study, a literature study was conducted to anchor thoughts and suggestion to already conducted studies and literature to ensure the quality and validity of the methods used and as input to the study as whole. When performing the study, the aim was to contribute to the overall goals of the project by trying to handle following issues, the researcher should:

- Learn to understand the "body of knowledge" in order to understand what areas may be of interest for further research.
- Learn from earlier published material.
- Be able to present the information known on the subjects handled in the report.
- Conclude why the research ought to be performed, how can the research project contribute to the scientific area of research?
- Support the purpose, goals and methodology proposed for the study.

These points are suggested by (Levy & Ellis, 2006), as a starting point why to perform a literature study. A summary of the information conducted during the literature study can be found in chapter 0.

3.4 Creation of visual production development concept cases

During the development of the visual models of the current and future state, possible methods of using virtual visual tools in production development were discussed. To investigate how these discussed methods could be applied in a real environment of production development and which benefit they would result in, two cases where constructed as a part of the implementation of this study. The cases were based on the experiences gained from the development of creating the visual models. The purpose of creating the cases was to present the virtual tools being used for people with an active role within production development and put them into a context of how they can be used in production development. The purpose was related to evaluating the virtual visual tools and to identify perceived benefits of using them more than evaluating the exact methodology presented.

The cases were created with the idea of presenting virtual visual tools that would be beneficial in the work of production development. To do so they were attempted to be beneficial to the outcomes of the different steps of the proposed model of production development at GKN Aerospace Engine Systems. The recently developed suggestion of production development model at GKN Aerospace Engine Systems (see chapter 2.4) is a documented step by step method serving as designing guidelines while doing production development processes. Figure 3-13 illustrates the different phases of the recently produced production development model at GKN Aerospace Engine Systems. Based on the virtual visual tools and methods used to create the visual model of the current and suggested future state together with the designing guidelines of the production development model, suggestions of methods to complement the development model by using virtual visual tools was created to be used as future documentation to be used for evaluation at GKN Aerospace Engine Systems.

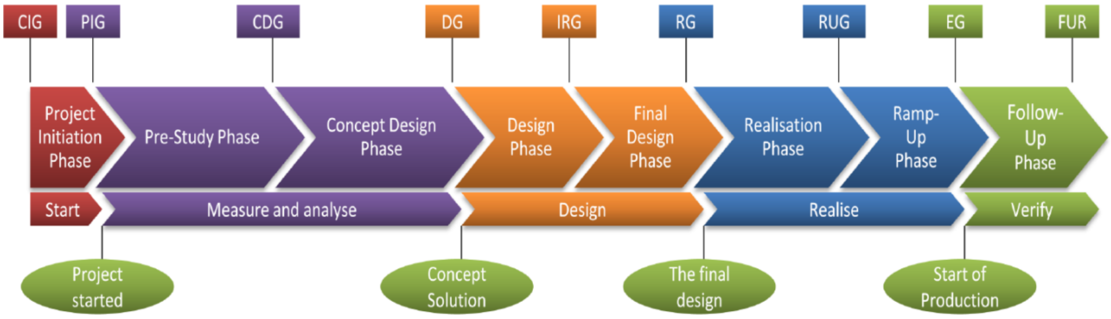


Figure 3-13 The different phases of the production development model at GKN Aerospace Engine Systems

To adapt the tools used to visualize the current and suggested future state and to integrate them into the model of production development at GKN Aerospace Engine Systems, the methodology and output of each development phase has been identified and used for finding virtual visual tools that complies with and being beneficial to the specific development phase. The suggested methods start from the Pre-Study Phase of the development model since the initiation phase is not an operational phase in the production development process.

3.4.1 Pre-Study Phase

The stated output of the pre-study phase is to find one optimal green field scenario and to define factory constraints. This can be investigated and presented in different ways and to identify ways to support and improve the outputs of the pre-study phase potential improvements where listed by thinking in terms of quality, speed, accuracy and cost. When these potential improvements of output were suggested and listed they were mapped to a corresponding method of virtual visualization that has shown to result positively to the identified potential output improvements.

Table 3-2 Potential improvements and suggested methods for pre-study

Outcome(s)	Selection of suggested method(s)	Potential outcome improvement(s)	Identified virtual visualisation method(s)
Find one optimal green field scenario	Value stream mapping	More accurate visual perception of the factory layout >>more accurate factory constraints	3D scan for acquiring point cloud model of factory layout
Find clear defined factory constraints	Material flows	Faster creation of factory constraints	Conceptual Discrete event simulation for calculations
	Estimations of equipment size	More substantiated calculations of necessary machinery	

According to (Lindskog, et al., 2012) and (Sadowski, 2007), visualized environments leads to better understanding of solutions presented. The improvement identified for more accurate perception of the factory layout is suggested to be achieved through a 3D scan of the area discussed.

For the identified potential output improvement of achieving more substantiated calculations of necessary machinery, this could be done using a Discrete event simulation for trying different scenarios according to (Sadowski, 2007) it is not always the best idea to use Discrete event simulation tools when analyzing the capacity or to find improvements for a specific productions system, in many cases the analysis can be performed by the use of less time consuming and advanced methods, such as queuing analysis or spreadsheet calculations (Sadowski, 2007). Therefore the suggestion of using visual tools will exclude the usage of DES models in the pre-study phase and focus on using a point cloud environment for making for accurate factory constraint conclusions.

3.4.2 Concept design phase

In the concept design phase the outcome should according to the development model be one recommended solution among several solutions and plans on the chosen concept solution. Similar methodology as for the pre-study phase has been used for the concept design phase where potential output improvements have been suggested and possible virtual visual method has been mapped for achieving the suggested improvements. Table shows the suggested potential output improvements with associated visual tools for the concept design phase.

Table 3-3 Potential improvements and suggested methods for concept design phase.

Outcome(s)	Selection of suggested method(s)	Potential outcome improvement(s)	Identified virtual visualisation method(s)
One recommended solution among several solutions	Merge green-field scenario with factory constraints	A recommended solution that is more accurately developed	Use the point cloud environment as tool for evaluating different solutions
Plans on the chosen concept solution	Risk analysis for unplanned future changes	The presented solution is more common understood	Complement the point cloud with imported concept designs of solutions for evaluation and comparison.
	Block layout	The plan for the solution is better connected to the actual factory layout	
		Faster evaluation of suggested solutions	
		Better comparison between concepts suggested.	

The suggested method of working with factory constraints included working with point cloud environments and this concept design phase is supposed to merge the factory constraints with the green field scenario. By that the point cloud environment will be a natural visual foundation to continue building and evaluating different suggested concept solutions on. This is what is suggested as the work methodology, to import different concept design into the point cloud for evaluation and comparison. The objects imported can be of various level of detail depending on how much is yet known about the suggested solutions. For example it could be cubic CAD structures representing the future equipment and related items. Another way of using the visual tools is to use the point cloud model as reference and draw different solutions in it, perhaps used when several people are discussing possible solutions.

3.4.3 Design phase and final design phase

The design and final design phase is related as they both serve as phases for further developing the suggested solution designed in the previous phase. These phases involve workplace design, developing necessary documentation for investment request and fine tune the project lead time. Table 3-4 illustrates the suggested potential output improvements with associated visual tools for the design phases.

Table 3-4 Potential improvements and suggested methods for design phases.

Outcome(s)	Selection of suggested method(s)	Potential outcome improvement(s)	Identified virtual visualisation method(s)
Detailed solution to freeze the overall solution	Work place design	More accurately describe the work place design	Simulation model of work cycle
List of long lead time items	Defining long lead time items	Faster evaluating work place design	More detailed CAD and associated models merged in point cloud
Final solution ready for deployment	Design solution on detailed level	On an earlier state discover possible design issues	Discrete event simulation for analysing performance and resources needed.
Training plans for personnel		More accurate training result	

When looking at the outcomes of the design phases it is clear that the importance of these phases is the quality of the future design of the chosen suggestion that is important. The suggestion is that the use of virtual visual tools in this phase will help and improve the speed and the quality of the documentation of the future state. When looking at work place design the identified virtual visual tool is to start making a simulation model of how the work should be performed which tools that are needed, where they are and how the flow of material should be handled. Also as complement to updated and more detailed CAD models merged with the point cloud, the simulation model can be imported as well for evaluation of the suggested work method and design together with the surrounding area and more detailed versions of CAD models representing the equipment to be installed and used. If early CAD models from suppliers are starting to appear they should be included in the point cloud environment as well.

To design solutions more accurate in the planning phase it can be useful of creating discrete event simulations of the suggested work methods (Vallhagen, et al., 2011). The simulation does need to include every exact step of the solution discussed but as extra input of how the actual work method and work flow will work in the real factory. The DES model can either be based on the simulation model of the surrounding work method or the other way around that the simulation model is based on the Discrete event simulation.

3.4.4 Realization phase

The realizing phase is when the physical production system is realized in the factory. The phase is including installation of machines and education of the personal stationed by the equipment. When training personal it is important to have accurate training material and good knowledge about the process being taught. This is promoting virtual visual tool since it beneficial for creating greater understanding of processes (Rovaglio & Scheele, 2011). The potential outcome improvements and possible tools for promoting this improved outcome are presented in Table 3-5.

Table 3-5 Potential improvements and suggested methods for realizing phase.

Outcome(s)	Selection of suggested method(s)	Potential outcome improvement(s)	Identified virtual visualisation method(s)
A physical production system	Installation of equipment	Faster installation	Point cloud model merged with final CAD models of equipment for more accurate planning of installation
Educated personal	Train personnel according to plan	Personal are trained faster	Simulation model of work flow merged with point cloud environment and accurate CAD models to study the work flow
Responsible persons to hand over the production system to	Test of production system	The training are more accurate and covering of the work cycle	The virtual model of the production system is used for planning and testing the future state for smoother ramp up
Plan for ramp up		Ramp up goes faster	

To work with training and also as for involving operators or technicians, the suggested method is to use the simulation model of the work cycle(s) created when designing the work cycle. By using the model to look, run and rotate in, it allows the involved persons to share the same view of the process. The model can be used for creating job descriptions for or together with the persons being the ones of using the equipment daily.

As for installing the physical equipment the suggested complemented tool is to use the point cloud environment and the actual CAD files of the equipment and the surroundings and analyze the installation phase in the virtual environment before the equipment is arriving to the factory, in order to be able to cope with unexpected events.

By having a DES and/or simulation model of the process, point cloud model and the actual CAD models merged in the same environment it can be used for simulating the future ramp up state, for example increase the inflow of products to the virtual environment, predict and analyze possible difficulties or if the system designed seems to function properly.

3.4.5 Ramp up and follow up phase

The outcome of ramp up and follow up phases are to realize the ramp up phase according to the plan created in the realization phase and to in total fully implement the production system. The follow up phase aims to evaluate the developed production system and to verify that the system is fulfilling the requirements. Table 3-6 presents the potential outcome improvements and the identified virtual tools to use as complement.

Table 3-6 Potential improvements and suggested methods for ramp up and follow up phase.

Outcome(s)	Selection of suggested method(s)	Potential outcome improvement(s)	Identified virtual visualisation method(s)
Implemented production system	Execute ramp up plan	More substantiated ramp up plan	Merge the virtual visual model with the real implemented production system (Adjusting them to align)
Take over directive	Implement solution in full scale	Solution is implemented faster	
Follow up report	Plan follow up	The evaluation is more accurate and pointing to improvement areas	
Probability and financial report	Evaluate the production system		

The identified beneficial virtual method in the ramp up and the follow up process is to align the virtual visual model to match how the real production situation it working. This is to make sure that the tasks being performed in the virtual model also reflects what is happening in the actual process. This will serve as a base for future improvements, for visualizing the process in training purpose or when explaining it to persons with little or none existing knowledge about it.

3.5 Creating concept cases of possible work methods

Based on the identified virtual visualisation method(s) for improving the outcomes from the production development phases, the methods have been compiled and put together as a conceptual work method meant to complement the current way of working with production development. This conceptual work method will be serving as an example of work method which will be discussed and evaluated in focus groups containing functions involved in production development projects at GKN Aerospace Engine Systems.

Two cases were created to use for investigation and as subjects for discussion in interviews with employees at GKN Aerospace Engine Systems. The first one illustrating a possible way of using virtual visual tools when planning for installing and implementing new equipment in an existing factory area and the other a possible way of working when planning for installing new equipment similar to already existing ones in a factor area that needs modification.

The result of the constructed cases used for evaluation can be found in Appendix 1.

3.6 Evaluation of suggested work methods in focus groups

After the cases of suggested work methods were constructed, evaluation meetings with functions from GKN Aerospace Engine Systems were held to get inputs and feedback of the presented cases.

The purpose of having interviews with different focus groups was to get information about the present production development process at GKN Aerospace Engine Systems, find out how different functions at the company relating to production development may benefit of virtual visual tools. The interviews are based on the two pilot cases (see section 3.5) constructed to investigate the possible benefits they would bring to the production development phase. The pilot cases presented are illustrating two different scenarios of using visual tools and how they can be used as an integrated tool complementing the present production development model at GKN Aerospace Engine Systems.

Questions were asked, on-going as the discussion of the cases presented, continuously about how the present situation looks like, what virtual and visual tools are being used and how the processes in general regarding production development looks today. This was done to provide a basis for conclusion of general benefits achieved by using virtual visual tools linked to different theories and conclusions found through the creation of the visual models of the current and future state.

In these interviews the semi-structured interview type where used. The reason for the selection of semi-structured interview techniques was the characteristics of the questions and the aim of the interview session. As described in section 2.6, structured interviews are used in order to investigate a pre-determined hypothesis and unstructured interviews have an evolutionary characteristics and the focus of the questions asked may change direction as the interview proceed. Semi-structured interviews consists of a set of questions that acts as backbone for the discussion, the discussion can be open but when if the focus drift from the area of investigation, in this case the use of visual virtual tools, it is the task of the interviewer to lead the discussion back on track. The aim of this interview study was to gain better understanding of the needs, of different functions related to the production development projects at GKN Aerospace Engine Systems, and it was of interest to create an internal discussion in the groups. Due to these reasons, the semi-structured interview type where chosen.

The meetings were divided into four sessions where different groups representing persons with similar functions of production development at GKN Aerospace Engine Systems. The interviews was carried out by presenting the two cases that has been worked out as suggestions on methods of using virtual visual tools and depending on the interviewees and their functions the discussions where held from different point of views. During the presentations of the cases, the interviewees were asked to reflect and to discuss what benefits and possible difficulties the different ways of working may lead to. The reason for this was to access both the immediate reflections of the participants regarding the suggestions and also to hear if the reasoning about it were changed as the discussion moved forward.

The focus of the interviews has been to by using the cases constructed, investigate if the functions related to production development at GKN Aerospace Engine Systems identifies any benefits from their individual point of view of using virtual visual tools. These identified benefits related to the cases presented will then be taken into consideration as an input to the investigation of benefits acquired by using virtual visual tools by studying the benefits located at GKN Aerospace Engine Systems.

The result and compilation of the interviews can be found in Appendix 2.

3.7 Compilation of the method used

The method used for obtaining the result has been divided into different steps which has been performed for acquiring knowledge, creating suggestions and evaluate them. Since the study has been performed at GKN Aerospace Engine Systems and at the X-ray equipment in particular, the suggestions are treating that process. The persons that the cases have been presented to are working at GKN Aerospace Engine Systems and have experience of the development of the current equipment and are involved in the current developing phase of installing a similar second equipment. The methodology that has been used is presented in Figure 3-14 below. The collection of theory information has been on-going throughout the study and is excluded in the flow chart.

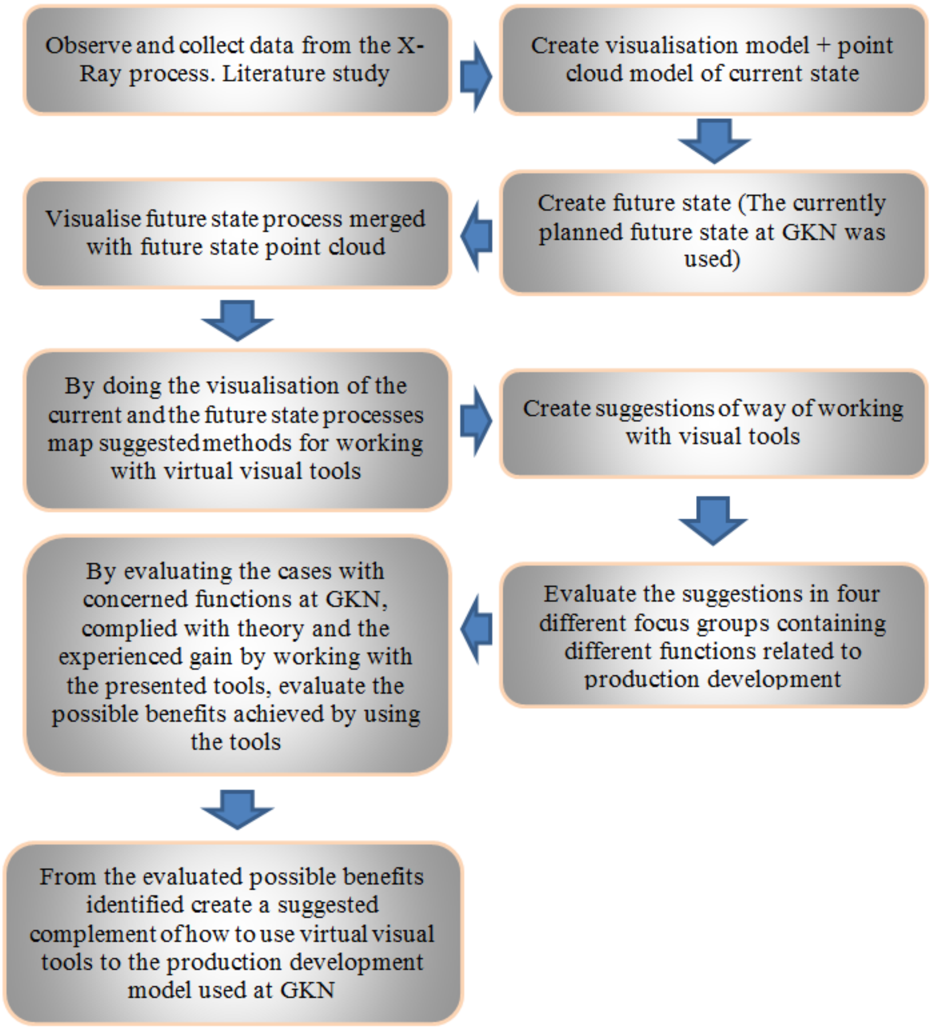


Figure 3-14 Flow chart of the methodology use

The compilation of the result has been based on the identified benefits found at GKN Aerospace Engine Systems and at the X-ray equipment in particular. Since the X-ray process is quite newly planned for and installed and that new equipment just like it is planned for at the moment, the comparison between the working method being used when installing the current equipment and the one that is suggested, and is including the virtual visual tools, becomes easy for the involved functions to relate to.

The interviews being performed in the different focus groups has also included discussions about how the current work methods are and what they are satisfied with and what not. This discussion is then linked to applicable theory and also to the conclusions that has been noted during the work of using the tools while creating the visual models. When finding pieces of the current way of working that would benefit by using the virtual visual tools presented, in combination with the identified benefits expressed by the persons interviewed linked to the presented cases, the resulted benefits are being put together.

4 Result

In this chapter the results from this study are presented. In the first section general benefits of using visual virtual tools in production related development. The second section these benefits will be linked to the production development model at GKN Aerospace Engine Systems (see section 2.4). To learn more about the procedure of which the results are based, please see chapter 0.

4.1 Identified benefits achieved by using virtual visual tools

More accurately planned future states where decided solutions are more thoroughly investigated before they are decided.

During the interviews it came up that more than ones that one general feeling of the planning phases in production development projects is that solutions and the surrounding details, like manual work cycle, associated tools and utilities of those solutions are planned for after the actual equipment is installed. By using virtual visual models to illustrate the future state it becomes easier and more natural to plan, not only for the main equipment and the work around that, but also the surrounding environment, tools and space needed and the interaction with the current material flow.

The benefit was identified during interview one, three and four and (Wiendahl & Harmschristian Fiebig, 2003) (Gausemeier, et al., 2006) states that by using visual tools future states are easier to plan for.

Using virtual visual tools will help decision-makers understand presented solutions better and to make better decisions

Since visualization of suggestions provides a more common picture of them according to (Gausemeier, et al., 2006) it will help to use the presented tools for explaining how a suggested solution will function, look like, interact with nearby processes etc. for functions that are not equally familiar to the solution as the people that has developed them. This was a repeated identified benefit of using the virtual visual tools emerged from the interviews that it is hard to explain and present solutions suggested accurately and making sure that people making decisions if it should be realized or not fully understand it.

This is also the feedback that was given to the presented case of the future state that it was easy to understand how the solution would actually look and functioning in the real factory.

Comparing suggested solutions will be faster, easier and more fair against each other

To place equipment virtually in a point cloud environment and include the simulated work flow, if it is created, to see if it fits and how it looks is easily performed in a virtual visual model. The cases performed in the study have, after the point cloud model and the simulation model of the manual work was created, easily been modified, been replaced and adjusted to investigate different placements and settings.

By working in a visually realistic virtual model of the actual factory and the fact that comparisons between different suggestions are done in the same visual environment compared to each other makes it more likely that they are evaluated on the same conditions and one does not favor another because of an incomparable aspect. This scenario and identified benefit was discussed during the interviews and was expressed as a scenario experienced by functions working close to production development. The fact that comparing scenarios in a virtual visual environment would take shorter time was also perceived by the interviewees with experience of comparing suggestions with current used methods.

Using virtual visual tools will help involved functions to get a similar view of how a suggested solution actually works, looks and interacts with other systems

Identified as a spot on benefit from all of the focus groups and was also experienced while working with the presented tools creating the current and future state cases. When presenting the cases and working methodology for functions working close to production development the general response was that it was easy to understand what the future state actually would look like and compared to the current way of presenting suggestions this was far ahead when it comes to understand the actual appearance of a solution.

It will be easier and take less time to include union and protection agents in discussions regarding work place design already in the planning state of the work place

A result of using the virtual visual tools presented emerged through the discussions in focus groups that it will be much easier and natural to involve both union representatives if needed such as functions like protection agents responsible for the work environment. As it is today, in most of the cases functions like these are involved when the equipment is installed and peripherals are being placed. By visualizing suggestions in the real factory environment it will enable these discussions and evaluations to be done along as the suggestions are being drawn.

It is easier to involve and educate operators/technicians already in the planning phase of the future state

When discussing the performed development process of the X-ray equipment it was identified that the operators of the cell was not involved in the process until a late stage where many attributes of the solution already were decided. The feedback through the focus groups and the experience acquired through the study is that by using the virtual visual environment of a point cloud model to visualize the factory layout and by creating a simulation model of the manual work it is easier and more natural to involve the operators early in the planning process since the visual appearance of the suggestion promotes earlier planning of the manual work cycle and it is easier to explain and understand a suggested solution when it is more realistic visualized and simulated.

Making sure that equipment fits in a specified area of the factory will be done in shorter time

It appeared during the study that in one practical case when installing new equipment at the pilot company, two supplier resources spent two days measuring the ceiling environment of the factory area and made solid models of it to ensure that the suggested design of the equipment would fit. The 3D scan performed in this study, which were quite detailed and comprehensive, took two resources four hours and about one hour of virtual preparation. The current state point cloud was then ready to use for collision detection, visual representation etc. If areas are identified as risk areas of not fitting equipment, then more detailed observations can be done.

By using the virtual visual tools presented the risk of working longer than needed with suggested solutions not able to be realized will decrease.

During the study performed it emerged that in the planning phase of installing the X-ray equipment, many concepts was produced and planned for which after a being investigated quite thoroughly, needed to be changed entirely because when the factory layout for the suggestion was studied, it was realized that objects were already placed there, the ceiling height was too low or the space needed was too narrow in the real factory. These are things that have been able to identify during the creation and evaluation of the visual model of the current and future state.

The impression experienced during this study is that by investigating the factory layout in a point cloud environment and placing the planned equipment in different spaces makes it easy and fast to evaluate if different solutions will fit in the specified factory area and which space it will need for the manual work around it. The study performed where the result has been anchored in focus groups points at the risk of working on concept that aren't able to realize will reduce and thereby save time for the development work as whole.

4.2 Link between identified benefits and targets/KPI´s in production

To identify how the different identified benefits are related to production development and/if they can be reflected on the everyday production process, different links has been attempted to be made between the different processes, production development and production.

To be more specific of the benefits and what need/goal/metrics this complies to, the following model, Developing model, (Vallhagen, et al., 2011), illustrated in **Fel! Hittar inte referenskälla.** has been used as reference for pinpointing the actual benefit in production.

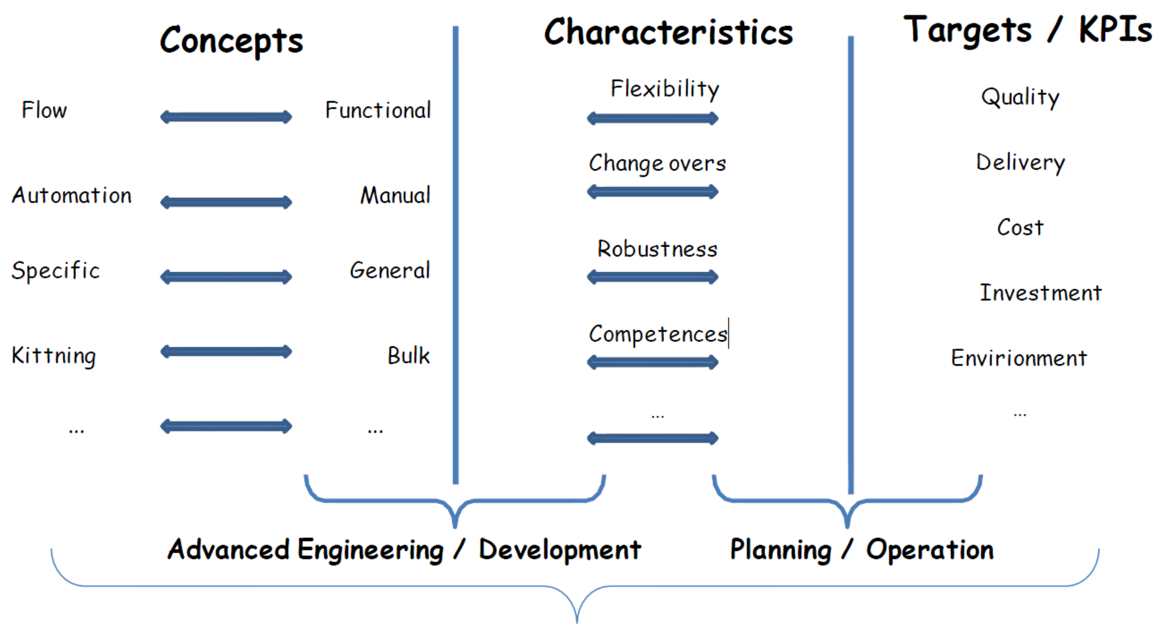


Figure 4-1 Identification of benefits in production, (Vallhagen, et al., 2011).

The result is based on the decision model from (Vallhagen, et al., 2011) and is created based on the experiences gained and estimations made from the performed study. An explanation image is shown in Figure 4-2 below, the example are directly followed by results.

Benefit	The identified benefits are presented
Production development	→ The identified benefit reflected on the production development process
Production	→ Reflected or possible reflection on production

Figure 4-2 Example of result structure

4.2.1 Discovered benefits related to production development and daily production:

More accurately planned future states where decided solutions are more thoroughly investigated before they are decided.

→ Cheaper in total since late changes are avoided and the work environment are easier to design to become more efficient.

→ Possible: Speed, quality, flexibility

Using virtual visual tools will help decision-makers understand presented solutions better and to make better decisions

→ More likely to take the right decision of choosing among suggestions, saves time if the better solution is obvious and decided quickly, avoiding misunderstanding will lead to a smoother implementation phase.

→ Possible: Speed, quality, flexibility

Comparing suggested solutions will be faster, easier and fairer against each other

→ Speed and accuracy in development process

→ Possible: Speed, quality, flexibility

Using virtual visual tools will help involved functions to get a similar view of how a suggested solution actually works, looks and interacts with other systems

- Better quality of design suggestions, faster decision process, avoiding misunderstanding and late individual surprises of solutions
  - Possible: Speed, quality, flexibility

It will be easier and take less time to include union and protection agents in discussions regarding work place design already in the planning state of the work place

- Faster design process, better quality of suggestions
  - Safer production process

It is easier to involve and educate operators/technicians already in the planning phase of the future state

- Better quality of the processes designed, faster implementation, faster education
  - More involved and motivated operators, possible faster and more qualitative work performed

Making sure that equipment fits in a specified area of the factory will be done in shorter time

- Faster design process, more fair comparisons between suggestions
  - Possible factors: Speed, Quality, flexibility

By using the virtual visual tools presented the risk of working longer than needed with suggested solutions not able to be realized will decrease

- More efficient process
  - Possible factors: Speed, Quality, flexibility

4.3 Suggested complement to the proposed production development model

In the proposed production model suggested for GKN Aerospace Engine Systems through (Därnemyr & Lindell, 2013), the outcomes of the different phases are listed and linked to suggested methods to be used for achieving these outcomes. The parts of the methods mentioned that includes virtual tools has been investigated during this study of benefits and methodology by using virtual visual tools and has resulted in a more detailed complement suggested to the proposed production model.

The different inputs gathered in this study, combined with the production development model proposed to GKN Aerospace Engine Systems, has resulted in an additional more detailed description of which virtual tools could be used and in what way with a suggestion of how to use the presented tools in the different phases. The graphical identity, figure 4-3 – 4-8, of the suggested addition to the development model is retrieved from the currently proposed development model and the detailed virtual methodology is a result of this study. The suggestion starts at the pre-study phase since no operative development work is done in the initiation phase.

Pre-Study Phase

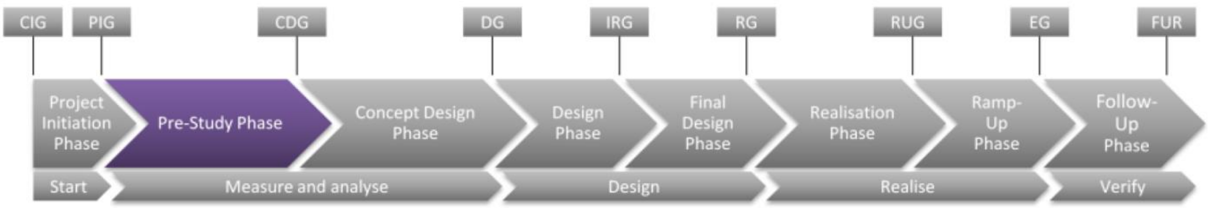


Figure 4-3 Pre-Study phase of suggested production development model

Virtual visual tools:

- Point cloud visualization

Virtual visual methodology:

The outcome of a making a green field scenario is supposed to be created without considering the limitations of the real factory layout. To achieve this, the project team's opinion is that this can be done with and without using DES simulation tools. The question that needs to be answered here is which method that suits the situation best (Sadowski, 2007). In cases where the capacity and downtime of machines are vague, as is the situation for new machine equipment, less time consuming techniques as spreadsheet calculations may be better suited. Therefore the suggestion for the green field scenario is to not use DES modeling as a given tool for analyzing work flow.

For the outcome of evaluating the factory constraints the recommendation is to identify the possible physical factory locations and perform a 3D scan of these areas. The point cloud environments achieved from the scanning are then discussed and evaluated in teams where everyone sees the same environments presented in the same way. Constraints like ceiling heights, factory space available and impact of nearby equipment are to be considered to come up with clear defined factory constraints of the available factory spaces identified.

Concept Design Phase

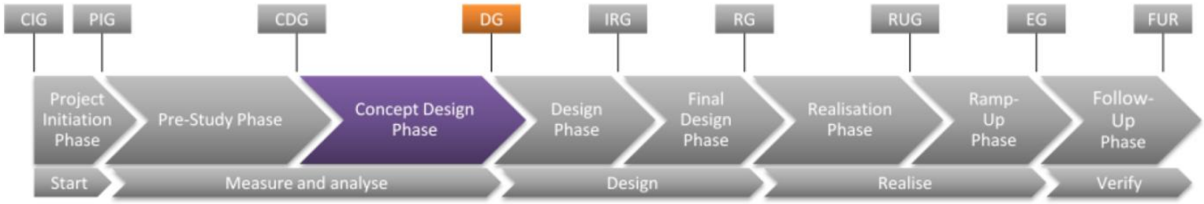


Figure 4-4 Concept design phase of suggested production development model

Virtual visual tools:

- Point cloud visualization combined with conceptual CAD models of the suggested solution
- Simulation model of the conceptual manual work cycle

Virtual visual methodology:

In the concept design phase the outcome is to produce and evaluate conceptual solutions. This is suggested to be done by creating conceptual solid objects representing the equipment to be invested and as far as the concept is developed, including surrounding equipment. These objects are then able to move around to different locations in the point cloud model for evaluating the positioning of the concept solution. Suppliers of equipment may preferably be contacted in this stage to get inputs of possible measurements.

As the location and physical appearance of equipment are moving forward, a conceptual simulation model of the manual work and material handling is performed. This to start thinking in terms outside of the physical equipment and to be used together with the conceptual CAD models integrated in the point cloud environment for more detailed recommended solution including as much attributes of the solution as possible.

Design Phase

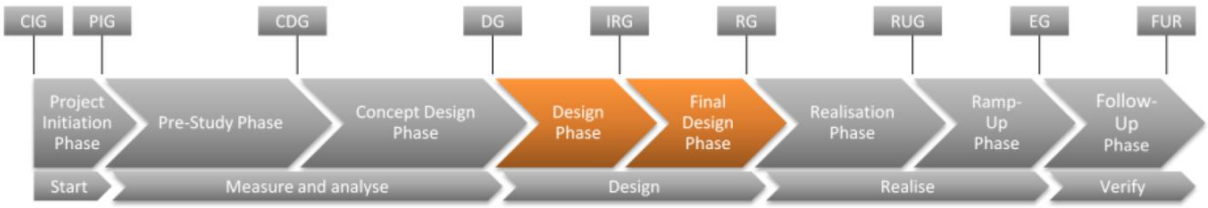


Figure 4-5 Design phase of suggested production development model

The design and final design phases can be methodologically combined to one phase when it comes to using visual tools and methods.

Virtual visual tools:

- Discrete event simulation
- Point cloud model
- More detailed CAD object of main and surrounding equipment
- Simulation model of manual work and material flow

Virtual visual methodology:

The final design phase can be seen as a refinement and final development of the design phase which can be integrated as one phase regarding the use of visual tools. The suggested goal to achieve at the final design is that a DES model is created to analyze buffer sizes, cycle times for investigate possible capacity issues, resources necessary when running full production speed etc. The output from the DES model can be used as input to the final development of the simulation model of the manual work cycle and material handling to analyze how much space is actually needed and how many resources that will be operating in the same area.

The simulation model should be integrated in the point cloud environment continuously to review that the solution are functioning within the physical limits of the factory area. The visual model should also be discussed in production development teams consisting of different functions to cover as many aspects as possible while the project still is in design phase. The discussions shall be held with the visual model of the design suggestion as base to make sure that people involved are having the same picture of the solution discussed.

If suppliers have been involved and presenting some design suggestions that might work, these shall be included in the visual model to keep it as updated and close to the accurate solution as possible.

When the virtual visual model is considered to be complete, has been revised and agreed by involved functions the solution should be virtually represented very close to the actual appearance of the real future production environment.

Realisation Phase

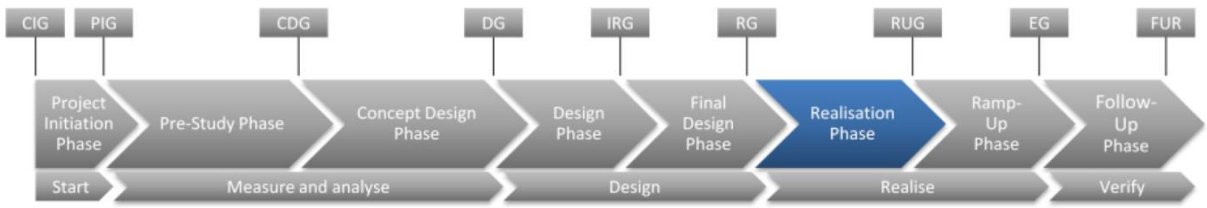


Figure 4-6 Concept design phase of suggested production development model

Virtual visual tools:

- The visual model of the process created in the design phases

Virtual visual methodology:

The realization phase is the part where the equipment is installed, tested and the personal is being educated in the decided process. This phase is more focusing on bringing the decided solutions to reality than evaluation and development and most of the benefits identified have a planning, evaluation and decision-making angle of it though the benefit of having virtual support to the education of the personal is something to take advantage of. Since virtual representation is helping to educate persons, the suggestion is to use the virtual visual environment created in the design phases to use as complement to the real workplace as educating forum.

Ramp-Up Phase

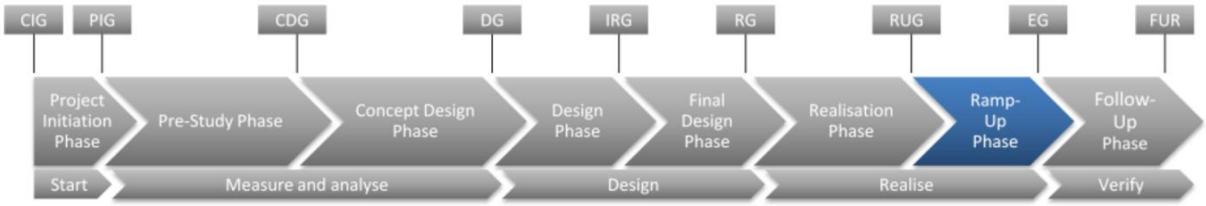


Figure 4-7 Ramp-Up phase of suggested production development model

Virtual visual tools:

- No virtual tools are suggested in this phase

Virtual visual methodology:

While working in the ramp up phase, most of the work with the virtual visual models is already performed and the identified benefits achieved so the suggestion is to ramp up the process only with the guidance found helpful from the virtual visual environment.

Follow-Up Phase

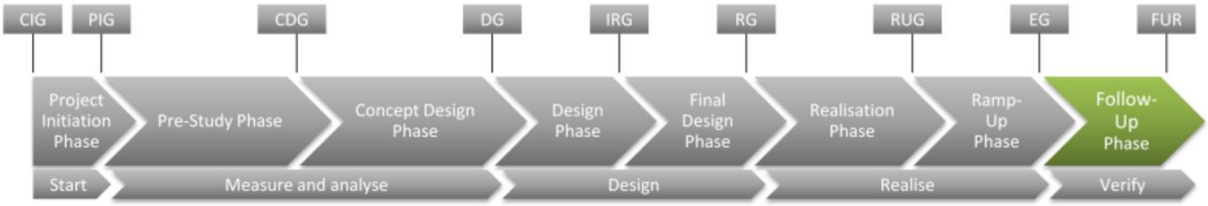


Figure 4-8 Follow-Up phase of suggested production development model

Virtual visual tools:

- Updated 3D scan
- Updated simulation model of manual work and material flow

Virtual visual methodology:

To keep the virtual environment updated to use as base for improvements and if it needs to be visualized in any other way the suggestion is to update the point cloud model by performing a new 3D scan of the now updated current state. When this is performed, the simulated model is updated as well as the CAD models and other virtual accessories this forms a base for the virtual representation of the current state to be used for future projects and follow ups.

5 Discussion

This project has resulted in some recommendations for the production development teams at GKN Aerospace Engine Systems, for how to work with virtual tools for visualizing production systems in the development phase. In addition, general benefits that may be possible to achieve by using virtual tools for visualization has been stated. Eight general benefits have been stated in the result chapter. These general benefits include for example, virtual visual tools:

- facilitates improved possibilities for the project leaders of the production development projects to communicate their ideas to decision makers,
- helps the project teams to detect issues with the production system that are under development earlier,
- helps the project team to have a unified view of the production system,
- makes it possible to include additional functions in the development phase, e.g. operators and protection agents, en an easier way.

The results has been conducted as a merge of three separate studies, one literature study, one construction phase where o production system was built in a virtual world and four interview sections, where different functions related to the production development projects were represented.

In this project we have been using and analyzing technology for visualization that is fairly new. Due to the limited spread this kind of technology the published material on the topic is also limited. Therefore, the results from the literature study might be questionable, since a few conclusions has been dram from the base of literature on similar simulation topics, such as DES project management, and not the actual technology. However, it is the opinion of the team members that it is safe to make connections to related technology in the cases made in the report.

Some of the conclusions and results are based on our experience from working with the software products. Even though the area of visual simulation of this kind is limited to only a few users around the world, and therefore makes the opinions of the users valuable, there is always a risk that personality and subjectivity influences the results.

Another aspect that needs attention is the interviews and the questions asked during the four sessions. As a starting point of the interviews, the interviewees where introduced to the visual virtual tools that was used in by the team of this master´s thesis project when constructing the virtual visual model of the X-ray unit. After this introduction, two cases where suggested and presented, illustrating how the production development teams may be using virtual tools in their profession during development projects. Individuals that are unused to this kind of tools may respond to the presentation in different way depending on their level of appreciation. Individuals that in general are interested in new technology are probably more open to new ideas if the kind presented. Apart from the interest of the participants in the interview session and how impressed they are by the new tools, the performance of the model builders will most likely have an effect on interesting the new technology. A poorly executed model would unlikely convince new users to adopt the tools, and excellent visualizations will likely attract more individuals.

When It comes to questions asked during an interview it is important not to lead the interviewee towards an answer, it is as important as it is hard to stay objective. During the interviews performed in this project this aspect was considered. However, it is a subjective opinion that the questions was objective and therefore it is possible that the questions where leading to some extent.

The aspects that have been discussed regarding the validity of the different parts of the projects might imply that the validity of the whole study is questionable, and if the case was that each of these studies was presented individually, the idea of the study being misleading may have been realistic. But due to the different parts of the study, that together forms the results; the level of objectivity necessary is considered to be achieved.

During the project time the focus has been pending between a focus on supporting the production development projects at GKN Aerospace Engine Systems, to the idea of generating ideas of general benefits of using virtual tools for visualization. In the end the project outcomes contribute to both of these causes. The employees at GKN Aerospace Engine Systems have been provided with information needed to start their work to adapt to the new technology, if the interest has been triggered. The main objective of this master´s thesis has been to support the research project called “Visual Production” at the department of Product and Production Development at Chalmers University of technology. The contribution achieved by this thesis consist different parts, firstly a number general benefits of visualization tools has been stated and proved by a combined study of three parts, secondly the tool used have been presented to relevant individuals in the industrial world, which is of great important for the development of the technology, the third part of the contribution is a spinoff opportunity in the research area. One issue that has been discovered regards how to integrate the software products in organizations, who should be using the software? Who should own it? How can organizations be stimulated to start using new technology similar to the technology used in this project? Is it best to use a bottom-up strategy, where the ideas are introduced to the users who make it possible for the ideas to grow up in the organization? Or the opposite top-down strategy where the management handles the introduction? These are questions that are suggested for further research, and the opinion of the team of this master´s thesis project is that they need to be investigated for the technology to be integrated successfully in large companies like GKN Aerospace Engine Systems.

Regarding the software producers and their capabilities a few areas, where improvements/development, have been discussed during the modeling activities. In most software products available today that handles point cloud models, it is not possible save the information as solids instead of point clouds. If point clouds could be saved as solids, simulations and animations using parts generated from the 3D scanning would be easier. Moreover, in the conducted model a point cloud model, which was edited in one software product, was integrated with a second software product. The possibility for integration was crucial for the model construction in this project but nevertheless, the number of software products available where integration with point cloud models are possible is limited. To sum it up, to be able to convert point cloud into solids and capability with other software products would be helpful for a widespread adoption of this technology.

The recommendation for GKN Aerospace Engine Systems after performing this study is to start introducing the thinking of that the tools and methods presented actually is something that can be implemented and not only seen as a demonstration of possible future work methods. Based on the result of the study and the response from the participants at GKN Aerospace Engine Systems, it would be in there interest to start working towards a more virtual visual methodology in production development. Furthermore, based on the feedback given from the involved participants, it is important to appoint a function or department that is responsible for the tools and models to avoid an unclear structure of who should use what tool when etc. If it becomes uncertain how, who and when to use the tools and methods it becomes harder to implement a natural methodology involving virtual visual tools.

5.1 Sustainability aspects

The result of this study have enlighten achieved benefits of using virtual tools for visualization and suggested a method for GKN Aerospace Engine System to apply these methods to their suggested production development model. The result has shown benefits in the matter of saving time, resources, be more efficient and it is likely to end up with a better final solution if it is more accurately investigated. Here is a clear link for the company to be more economical sustainable since it will lead to a more efficient use of resources.

Another aspect is the result pointing towards getting different functions more involved in the processes which potentially can lead to a more satisfying work place in general. This could be achieved both for operators and technicians to be able to see and have inputs on their future work place as well as people with planning tasks which also will be able to be more involved in the planning process since it becomes easier and faster to show and talk about suggested solutions. The fact that people are getting easier involved in different processes is taken as a sign of the suggested method in the future potentially will lead to a better social sustainable work place.

6 Conclusions

This study has been investigating the benefits linked to the use of virtual visual tools in production development. The result has been based on constructed visual models of an operational process at GKN Aerospace Engine Systems in Trollhättan. The constructed models have been evaluated, both regarding the result of them, how they were constructed and what benefits they would enable, by focus groups at GKN Aerospace Engine Systems consisting of individuals closely linked the production development processes.

The result of the study showed that many different areas of production development would benefit from using the virtual visual tools used and presented in the study. Most of the benefits are linked to speed and accuracy in the process but also work safety environment and collaboration within the project teams working with the development and usage. The result also pointed at the tools and work methods being suggested in the study are new to the company and the impression of the people involved is that it is perceived as the future way of working and is of high interest.

By using the tools for creating and presenting a development process that people at the company could relate to and recognise, has experienced to promote useful discussions about the tools and methodology since it is easy to compare the scenarios of using the presented methodology and the one not using them. Is has also been perceived that it is easier for people working close to the development process to see and identify ways these tools would be beneficial when the pilot case of presenting the tools has been involving a process they easy can relate to and embrace.

As for future development and investigation of taking the methodology of virtual visual tools in production development further, the starting point could preferably cover the usage of the tools for different functions. One suggestion that came up during the study was to use quite simple viewers for functions not interested in editing the visual models but just to look at and discuss them. Also it would have been beneficial as an extension to this study to involve other processes linked to the one studied in this case for evaluating the tools also for covering interactions between processes and to study material flow and material placements virtually for example simulating interactions, material flow and area needed for full production speed.

As pointed out by participants during the study, and also experienced by the project team members when working with the presented methods, to work visually with production development and virtually visually in particular is a future way of working that hopefully will be a completely natural way of working a few years from now.

Bibliography

Alpman, M., 2013. *Automation.*
Available at: http://www.nyteknik.se/nyheter/automation/cad/article3641535.ece
[Accessed 8 5 2013].

AutoMod, 2013. *Simulering.*
Available at: http://automod.se/simulering.html
[Accessed 3 5 2013].

Automotive Engineering Services Co., L., 2013. *Services.* [Online]
Available at: http://www.aesjp.com/service/introduction.php
[Accessed 3 5 2013].

Banks, J. & Carson, J. s., 1987. *Applying the simulation process.* New York, The 1987 winter simulation conferance.

Bellgran, M. & Säfsten, K., 2010. *Production Development.* London: Springer.

DiCicco-Bloom, B. & Crabtree, B. F., 2006. The qualitative research interview. *Medical Education,* 40(4), pp. 314 - 321 .

Därnemyr, C. & Lindell, M., 2013. *Project Model - Production system development Handbook.* Trollhättan: GKN Aerospace Engine Systems.

FARO, 2013. *Faro focus 3D overview.*
Available at: http://www.faro.com/products/3d-surveying/laserscanner-faro-focus-3d/overview
[Accessed 3 5 2013].

Gausemeier, J., Ebbesmeyer, P. & Eckes, R., 2006. Virtual Production – Computer Model-Based Planning and Analyzing of Manufacturing Systems. In: A. I. Dashchenko, ed. *Reconfigurable Manufacturing Systems and Transformable Factories* . Berlin: Springer Berlin Heidelberg, pp. 743 - 759.

Hutchinson, S. A. & Wilson, H. S., 2006. Research Interviews (Qualitative). In: *Encyclopedia of Nursing Research.* New York: Springer , pp. 521-521.

Ingalls, R. G., 2002. *Introduction to simulation.* Stillwater, Winter Simulation Conference.

Johansson, B., 2011. *Methodology for DES projects (Lecture Material).* [Online]
Available at:
https://pingpong.chalmers.se/courseId/1273/courseDocsAndFiles.do?nodeTreeToggleFolder=694652
[Accessed 3 5 2013].

Knoll, J. M. & Heim, J. A., 2000. *Ensuring the successful adoption of discrete event simulation in a manufacturing environment.* Orlando, Winter Simulation Conference.

Kosonen, K. & Buhanist, P., 1995. Customer focused lean production development. *International Journal of Production Economics,* 41(1), pp. 211 - 216.

Kühn, W., 2006. *Digital factory – Simulation anhancing the product.* Wuppertal, Winter Simulation Conference.

Lee, J., Han, S. & Yang, J., 2011. Construction of a computer-simulated mixed reality environment for virtual. *Computers in Industry,* 62(1), pp. 86-98.

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.,* 9(1), pp. 181-212.

Liker, J. K. & Meier, D., 2006. *The toyota way fieldbook.* 1 ed. New York: MvGraw-Hill.

Lindskog, E., Berglund, J., Vallhagen, J., Berlin, R. & Johansson, B., 2012. *Combining point cloud technologies with discrete event simulation.* Berlin, Winter Simulation Conference.

Mortensen, J., 2012. *Mentalwod*. Available at: http://mentalwod.com/the-crazy-myths/
[Accessed 30 5 2013]

Mueller-Wittig, W. Jegathese, R., Song, M., Quick, J., Wang, H. & Zhong, Y., 2002. *Virtual factory - interactive visualisation for manufacturing*. San Diego, Winter Simulation Conference.

Mujber, T., Szecsi, T. & Hashmi, M., 2004. Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Tech,* 155–156(1), pp. 1834 - 1838.

Pröckl, E., 2003. *IT Telekom.*
Available at: http://www.nyteknik.se/nyheter/it_telekom/allmant/article233660.ece
[Accessed 8 5 2013].

Qu, S. Q. & Dumay, J., 2011. The qualitative research interview. *Qualitative Research in Accounting & Management,* 8(3), pp. 238-264.

Rovaglio, M. & Scheele, T., 2011. Virtual reality - improves training in process industries. *InTech,* 58(3), pp. 32-36.

Rowley, J., 2012. Conducting research interviews. *Management Research Review,* 35(3), pp. 260-271.

Sadowski, D. A., 2007. *Tips for successful practice of simulation.* Washington D.C., Winter Simulation Conference.

Schulz, w. & Bischof, C., 2012. *Integrative Production Technology for High-Wage Countries.* Berlin, Springer.

Standridge, C. R. & Marvel, J. H., 2006. *Why lean needs simulation.* Monteray, Winter Simulation Conference.

Vallhagen, J., Stahre, J. & Johansson, B., 2011. *Visual Production – strategic manufacturing system development tools for aerospace industry.* Gothenburg, International Symposium on Air Breathing Engines.

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,* 16(7-8), pp. 535-540.

Appendix 1

The result of the two constructed cases used for further evaluation together with personal working at GKN Aerospace Engine Systems of possible work methods related to virtual visual tools is presented in this appendix.

Case one – Layout and workflow planning of new equipment

The factory layout of the area around the X-Ray machine has been renovated and fitted with new equipment during the last two years. This has made it possible to reproduce the design process of the X-ray part of the production system and make a visual model of how the planning could have been visualized and then make conclusions about if the design phase had been carried out more accurate or efficient with the use of different virtual visual tools. The possible visual work method was constructed and presented to key persons that had been involved in the decisions related to the X-ray machine acquisition, work flow and process planning to get reviews of this simulated visual way of working.

The initiation of planning for a future state production layout should begin with a 3D scan of the production area or areas that are suggested and possible as placement areas of the future state equipment. This is to fit future suggestions into a more realistic visual environment, either by conceptual box CAD models or to use it in any other way as representation of the actual available factory layout. Figure 0-1 below shows a point cloud of the factory area before the installation of the X-Ray machine. The point cload was produced in the late autum of 2011, approximatley one year earlier than the equipment was delivered.

Figure 0-1 Early point cloud produced before the installation of equipment.

When the 3D scan is carried out and the point cloud is enabled the first visual planning state can begin. Before any equipment has been modeled in any CAD software and the only information available is the approximate size of the future equipment it is possible to evaluate the space required and how a possible workflow could work by elaborate with boxes in the point cloud environment.

Figure 0-2 illustrates a scenario where the future equipment is presented by boxes which are easy to create and to handle in the virtual environment. This step is carried out as a rough planning tool and will illustrate possible physical factory constraints related to certain suggested scenarios.

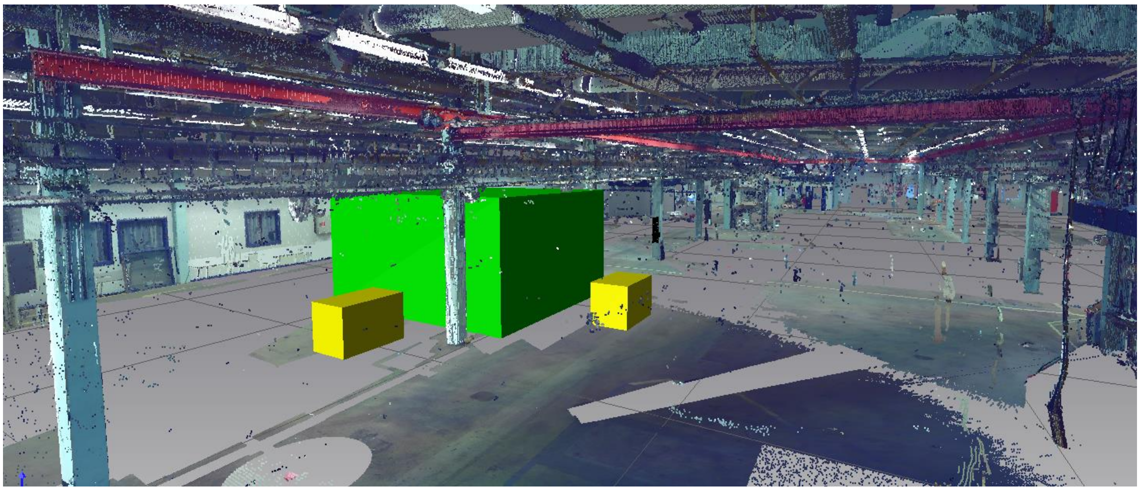


Figure 0-2 Box modeling of an idea of future equipment

When the rough box modeling has been carried out and the layout and design of the future equipment is completed, the accurate CAD models are replacing the boxes in the virtual environment to enhance the visual model as decisions are determined. The CAD files delivered from the supplier of the X-Ray machine together with the early point cloud enables the foundation of a 3D visual model where object easily can be moved, rotated and also changes can be made to both the equipment or the surrounding if necessary. Figure 0-3 and Figure 0-4 below shows the CAD model of the X-Ray machine merged with the point cloud. As other components and solutions are determined, they should be included into the virtual model.

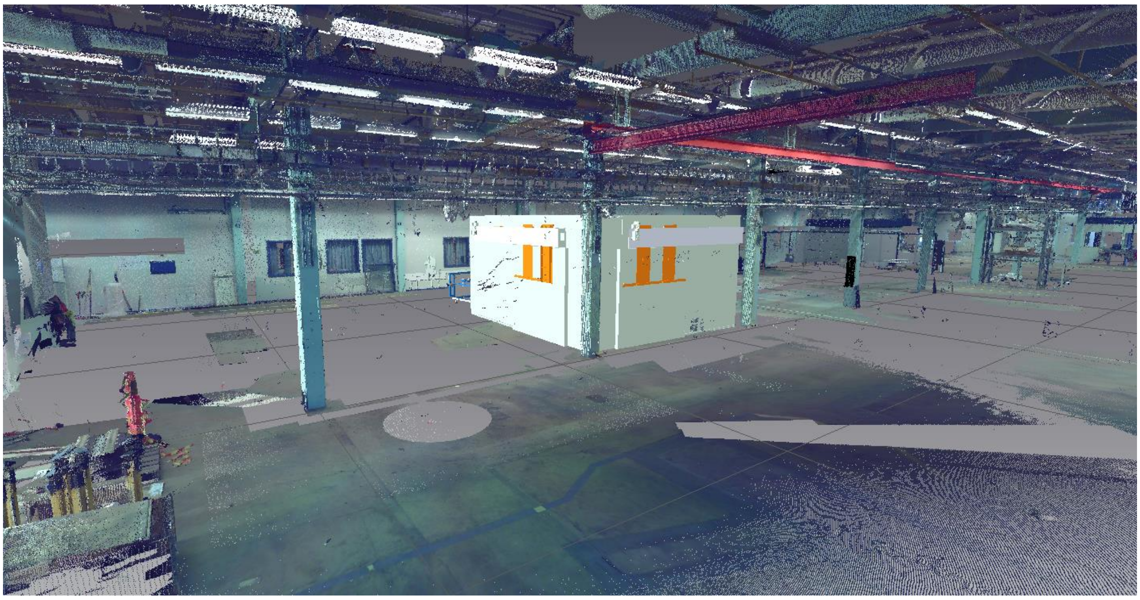


Figure 0-3 CAD model merged with an early point cloud.

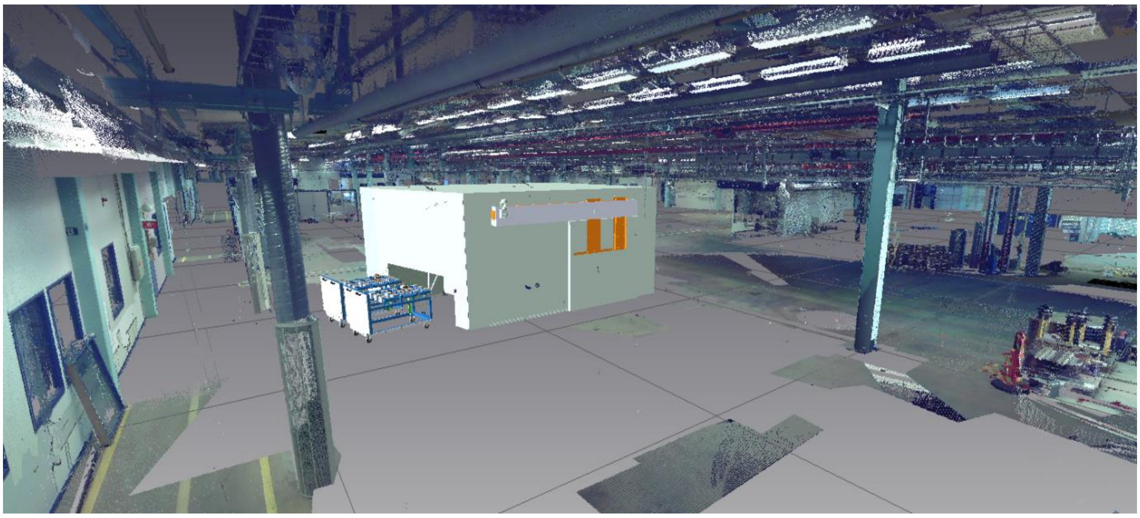


Figure 0-4 Early version of CAD model merged with an early point cloud.

When fitting the equipment into the point cloud it visualizes immediately if it need more space and what the options are of replace the equipment somewhere else. Based on this visual setup, logistic decisions of material routing to and from the machine can be made as well as more detailed interaction between this and other processes. If the space for the equipment and logistic conditions are approved by the project team the visual model proceed.

The next step in this visual suggestion is to involve operators and technicians in the virtual visual model to evaluate the work flow more in detail. This step is done in a visual, dynamic and programmable environment to capture the movements of operators and products to identify narrow working areas, material stockings and physical impact of queues. This step aims to save time in the start-up process since most of the work to be performed needs to be determined in some way to carry out the visualization of work cycles. In Figure 0-5 and Figure 0-6 the CAD model, the early point cloud and a visualization model has been merged into one 3D model to evaluate space required for work cycles, called the dynamic space, material handling routing and the work cycle environment for the operators and maintenance issues.

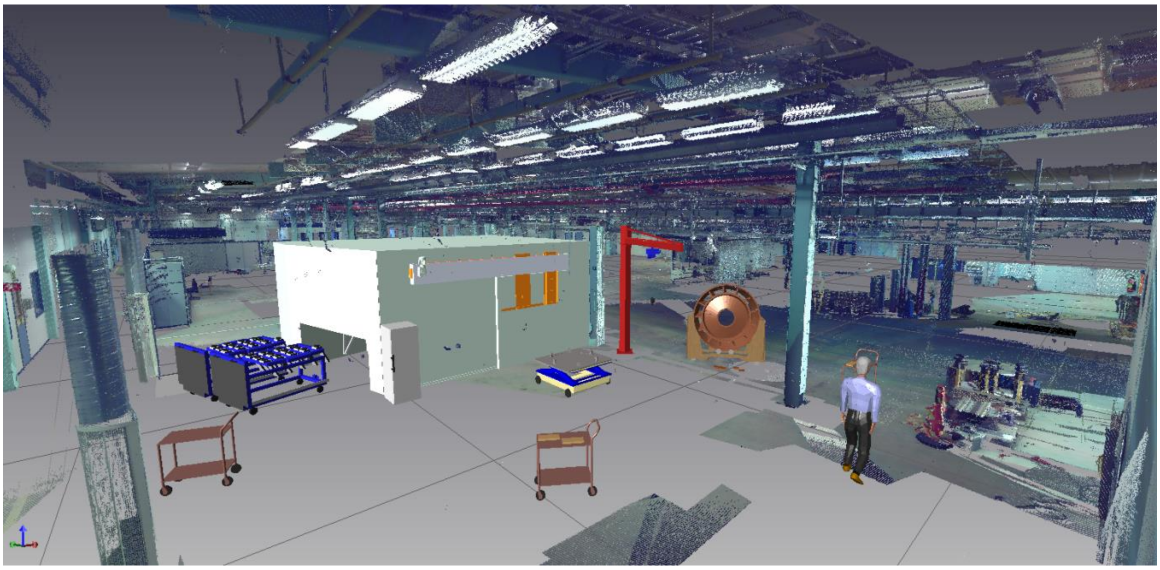


Figure 0-5 CAD model, early point cloud and visual model merged together.

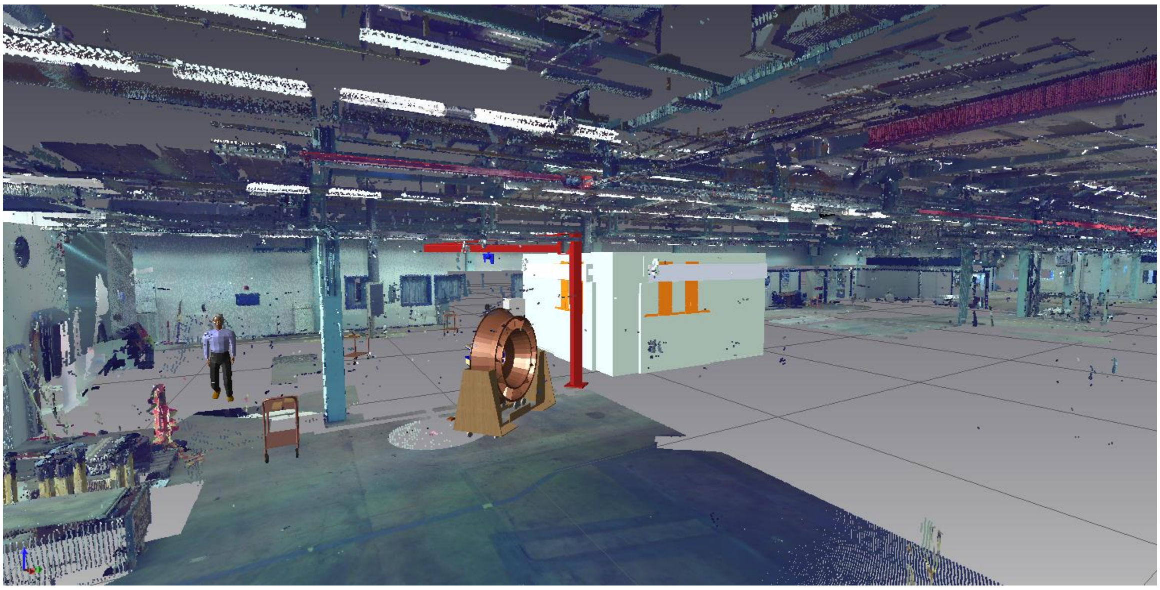


Figure 0-6 CAD model, early point cloud and visual model merged together.

A large number of parameters can be studied in this setup and particularly the machine layout with associated work cycle and material flow is visualized and can in an easily way be presented in a 3D environment to people that have low detail knowledge about the actual process. A project team consisting of roles with different knowledge areas will have the same visual experience to base decisions on which will lead to fewer misunderstandings (Lindskog, et al., 2012). Fewer misunderstandings will most likely lead to the need of fewer changes later in the project; thereby the efficiency and cost aspects of the project will be improved.

According to lean production development one important step is to follow up on performed projects, work with improvements and learn from any methods that could have been performed better and bring that into other projects (Liker & Meier, 2006). To have a common picture of the process, to serve as a base for improvements or if new machine acquisition close to or connected to the existing equipment shall be installed; the suggestion is to perform a new 3D scan to obtain an updated point cloud of the existing setup. Depending on how well the visual simulation reflects the real work in the dynamic space, a new simulation can be carried out or the existing one can be merged in the updated point cloud. By having a common picture of a situation will lead to fewer misunderstandings (Lindskog, et al., 2012) and thereby a more efficient performed task which is the purpose of the work method.

Figure 0-7 and Figure 0-8 shows the updated point cloud with the actual equipment installed merged with a visual model of the manual work connected to the work station.

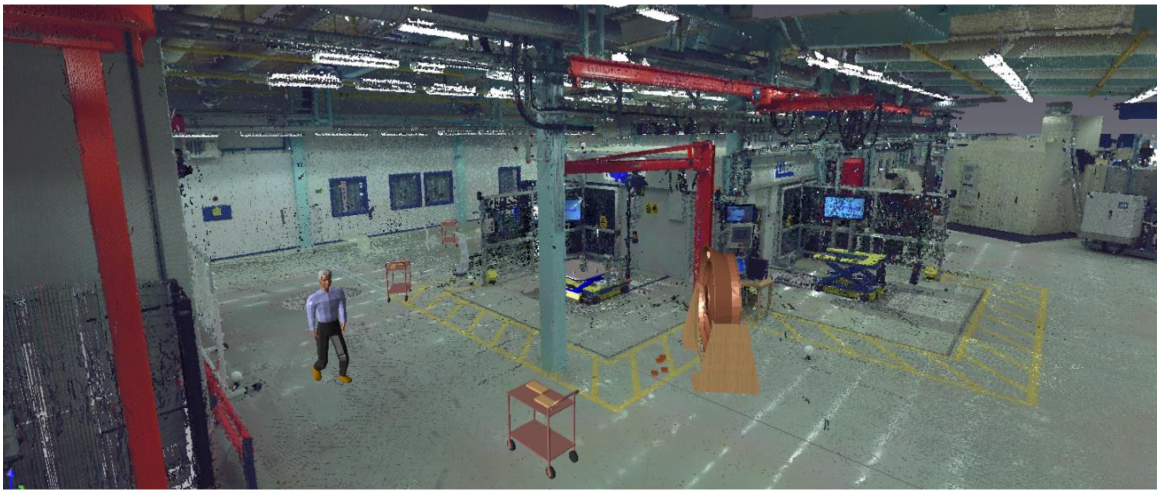


Figure 0-7 Updated point cloud merged with the visual model of manual work.

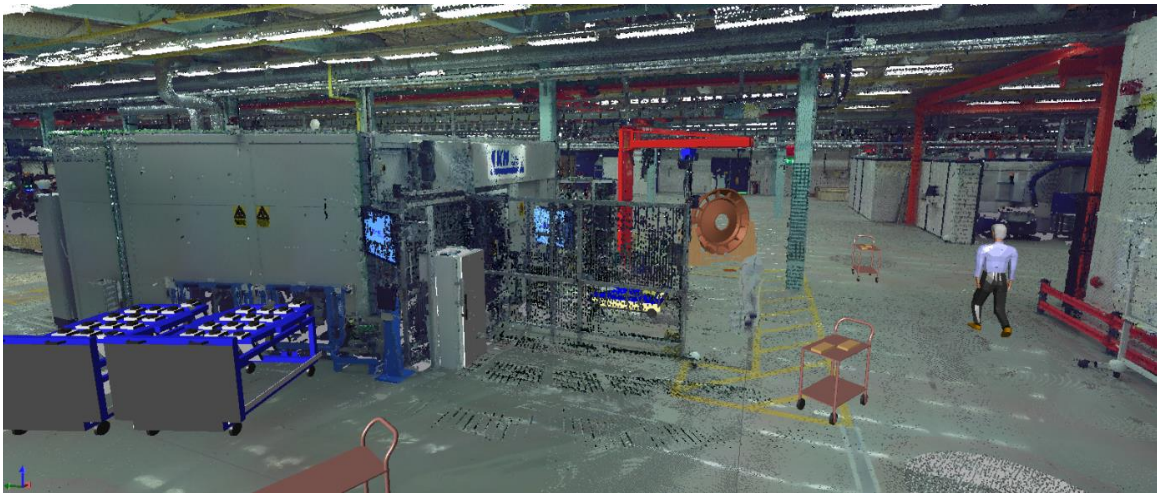


Figure 0-8 Updated point cloud merged with the visual model of manual work.

This state is now seen as the current state and is the virtual representation that can help to narrow the gap between the mental image of the production system and the real system (Lindskog, et al., 2012). In this way individuals with different experiences can use the visual model as a tool for communication. Any changes, improvements or installation of new equipment should be discussed using this virtual model together with the actual production system as reference.

Case two – Planning state of placing additional similar equipment

When changes, improvement or updates are to be made, the suggestion is to make changes in the updated visual model if any changes is made or planned for the factory design and to import new CAD models or point cloud models if available and update the visual model of the dynamic space to evaluate different proposals.

In the case of installing another equipment similar to an existing and evaluate the positioning of this and the integration of workflow the visual planning starts from the current state and the evaluation of suggestions is made with the visual model as base. Since the equipment to be installed is similar to the existing one the point cloud model already processed can be used to visualize the future state.

Figure 0-9 shows the point cloud model of the existing equipment that will be used for the future state model.

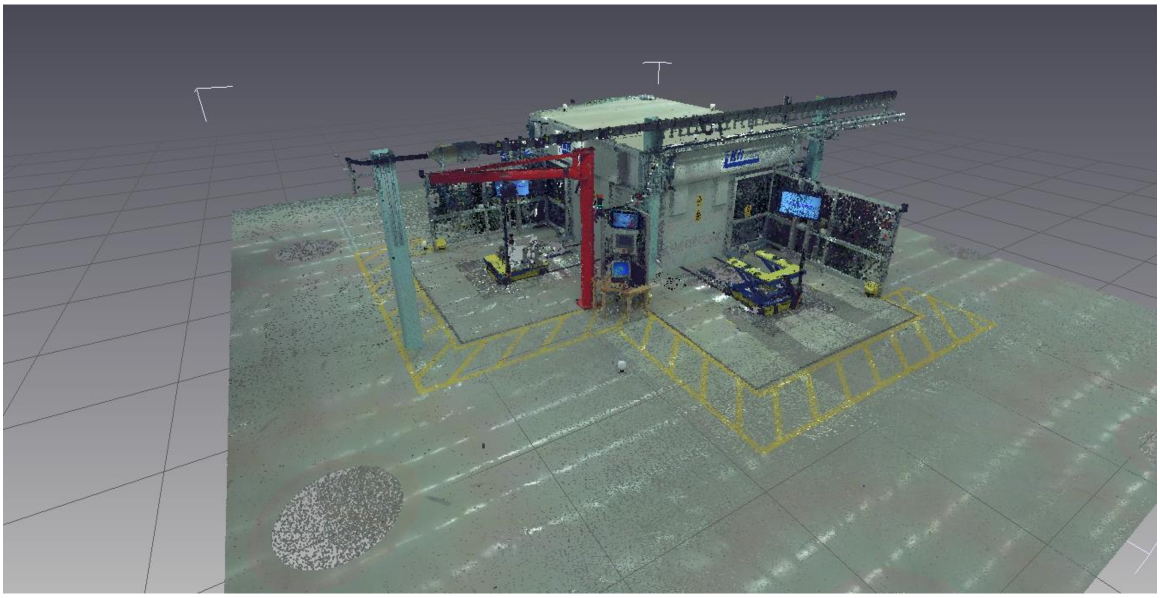


Figure 0-9 Point cloud model of existing equipment

If any future state suggestions include changes to the physical factory it can be simulated in the visual model to see if there are problems with space or other physical constraints. It is preferred that all changes that are made to the point cloud is controlled and followed up by inspection of the real factory to reduce the risk of making changes in the virtual visual model that is difficult or even impossible to carry out in the real factory. Figure 0-10 shows one suggested integration of the new equipment where physical layout changes has been made to the factory.

Figure 0-10 Current and future state point cloud visualized as one suggested layout

As in the case of investing in all new equipment, this stage can also be supplemented with a visual simulation model of the dynamic space that includes both the work cycle for the current equipment and a similar one for the new one. By doing this, space needed for two manual stations next to each other can be observed in the visual model and conclusions can be discussed by a team looking at the same visual model seeing the same obstacles or possibilities.

Figure 0-11 illustrates an example of a future state where another process cell of the same kind as an existing shall be installed with associated manual work. Again aspects like area needed, interaction with connected flows and area for the work cycle is taken into consideration with a common visual experience.

Figure 0-11 Current and future state point cloud merged with current and future state visualization of manual work

Appendix 2

In this appendix information acquired from the interviews in the focus groups, consisting of employees representing different functions related to the production development processes at GKN Aerospace Engine Systems, are presented.

Interview one

Participants of the first interview were a responsible function of machine acquisition, a project leader within production development and two facility engineers. The two cases constructed has both been involving the X-ray machine as example and both the responsible for machine acquisition and the project leader have been involved in the actual project of installing that specific equipment. The starting point of the discussion quite soon developed to a comparison of the methodology that had been used while planning for the setup with the X-ray equipment and how the usage of virtual visual tools would have impacted that process. The discussion also covered how they usually worked in project similar to this one in general and their view on how to use virtual visual tools.

Results from interview one:

Current situations identified as possible to improve by using virtual visual tools:

- The factory layout available in drawings or 3D models is not consistent to the actual layout. For example power cables and other important details
- Large amount of machines and equipment are available as 3D models but not used in planning purposes
- Have frequently happened that the methodology of a planning phase has been more like: plan projects along the way based on how the different steps are being carried out.
- Sometimes CAD engineers are modeling an area where the frequently need to measure the factory area by hand back and forth since there are no comprehensive accurate drawings.
- Can be hard to show the benefits of a certain solution compared to others for the people deciding go or no go for certain solutions.

Identifies benefits of virtual visual tools:

- Involve operators visually at an earlier stage to inform and to get inputs
- Being able to show management teams or other decisions makers the thought out and planned for solution
- Show union and protection agents the visualization of the manual work cycle to discuss possible risks and ways to avoid them already in a planning stage of a process.
- Perfect tool for visualizing non existing work flow
- Showing people not familiar to the factory how machines and equipment looks like, where they are and which tasks will be perform (for example third party maintenance functions)
- Helps to spread a feeling of that suggestions and solutions are worked through.

Possible drawbacks:

- The point cloud outcome of a 3D scan cannot be used for anything else than for visualize and planning compared to a 3D solid model.

- Time consuming creating simulation of work flow for each project.

Non value adding aspects (or similar):

- Hard to see the optimal case, even while doing simulations
- Simulating an existing work flow feels overdone.
- The way of working needs to be perceived as a useful tool for everyone using it, otherwise it will not be used.

Identified desired way of working with virtual visual tools:

- Have a point cloud viewer available for everyone to use and look at. Becomes a useful but light variant of using a potential 3D scanned factory.
- Let the supplier or company 3D scan similar equipment already installed somewhere else to use as visual model.
- Good projects are projects that involve people and letting them know about how the current suggestions looks like and why certain decisions are made. Visualization is a tool for that.

Interview two

The second interview consisted of one operator at the X-ray cell and one technician with good knowledge of the same cell. Like the first interview, the two cases were shown and thoughts, possible experienced benefits and drawbacks were discussed as well as their view on how the work of production development looked today from their point of view. They were also asked about if and in that case how they would like the tools presented to be used to be beneficial from their point of view.

Results from interview two:

Current situations identified as possible to improve by using virtual visual tools:

- They have an idea of how the future process will work and wants to show a suggested alternative but thinks it is hard to make a fair comparison.
- Planning phase of purely physical items can sometimes take long time.
- Feeling of that planning the work flow of goods is hard today.
- Problem when the work cycle differs from time to time, sometime products are delivered in one way sometimes in another.

Identifies benefits of virtual visual tools:

- If workflow is simulated it would be easier to compare suggestions against each other and base decisions on a more thorough documentation.
- Good that people have the same visual image of suggestions or equipment.
- Visualizing the work flow will force planning of details like where different buttons shall be installed and how the material flow will look like.
- When it comes to furnish a factory, virtual visualization tools is the future.

Possible drawbacks:

- Hard to determine the owner and the authorization of editing suggestions.

Non value adding aspects (or similar):

- Not think that it is a perfect tool for teaching a work method, better to do in reality

Identified desired way of working with virtual visual tools:

- Would be good to simulate work flow at max pace to see how the process works, where the bottlenecks are and what maximum output you can expect of a certain process.
- Wants to include big surrounding equipment into the planning phase that feels like it often isn't planned for.
- Wants to put two suggestions right next to each other and compare them in the same visual and simulated environment.
- Wants to know how the manual work cycle will look like in different suggested solutions.

Interview three

Participant of the third interview was a person working with virtual tools today such as building CAD models, making simulations and visualizing material flow which is closely related to the study of how to benefit from using virtual visual tools. The interview covered his roll of production development, which virtual tools that are used today and his view of using the methodology presented in the cases constructed.

Results from interview three:

Current situations identified as possible to improve by using virtual visual tools:

- In the planning phase of the X-ray equipment, many alternatives were drawn on 2D drawings but many of them were also turned down naturally because equipment and physical objects not shown on the 2D drawing were in the way.
- Happens that when new equipment is installed the work associated to it is planned. Feeling of that could have been visually foreseeing
- Finds it sometimes difficult to explain ideas based on the documentation that is produced of suggestions today.
- One scenario where CAD models were produced in the wrong scale and needed to be reproduced.
- Before deciding the placement of the additional X-ray equipment there were many suggestions on placement. Feels that it is hard to include all properties when visualizing them in 2D drawings.
- When installing equipment the supplier of the equipment was there for measuring the area and surrounding for a long time. They had the responsibility but their time equaled cost for the project.
- The surrounding equipment prior to the X-ray cell weren't included at the beginning of the planning phase.

Identifies benefits of virtual visual tools:

- If the suggested solution is looking like reality it is easier to explain how it works, what benefits there are and what drawbacks.
- Good to show material flow in tight areas, hard to visualise/simulate that today.
- Good to be able to kill discussion like will it fit in the current planned space? Will the work flow around the machine be bothered by closely located operations?
- Today there is a risk of that people look at different suggestions and seeing different things, virtual visualisation is a way of reduce that risk.
- Being able to visualize the surroundings more accurate, like pallet rack etc. The supplier of certain equipment is not included in these questions.
- Human ergonomic risk situations would be good to identify and plan for in the beginning of a project. Not to identify afterwards when the budget for the project is reached.
- Making an accurate solid 3D model of the factory environment would be practically impossible if the level of detail should be compared to a point cloud model.

Possible drawbacks:

- Risk of unnecessary work since point clouds and CAD models cannot be imported and exported as easily as solid CAD models between different software products.

Non value adding aspects (or similar):

- Concepts developed do not fail because of lack of simulation models but often it feels that it would be nice to have. You get a feeling for when it should be done and when it won't give that much extra input.
- Simulating a workflow that you already know how it works does not give that much to a production development project for example when installing similar equipment as an existing one.

Identified desired way of working with virtual visual tools:

- Wants to show suggestions in a virtual realistic environment with simulated work flow to sell in ideas, compare suggestions in a fair way. Possible to show that this way works better than the others or to say that this won't work because of different reasons.
- Wants to scan the suggested area for fitting new equipment in and provide it to suppliers that are designing new equipment. They will still have responsibility for fitting of the equipment if that is agreed but it will go faster and be cheaper.
- Would have been nice to have a point cloud model of the factory to look at in viewer's software and be able to import different object just for testing new ideas.
- Would be good to work with point cloud models as complement to solid CAD models depending on what to achieve. Visualize or use as construction documents.

Interview four

Interview four consisted of two persons currently working at the logistics department. They were involved in matters that where simulation of material flow, cycle times and queue configurations. The interview started with an introduction of their functions and of the study being performed with visual tools.

To introduce the presented work methods two videos were shown, one of the future state point cloud and one of the future state visual model. This to get an initial feeling of the result achieved from the different tools. The cases were then presented and during and after that the discussion enlightened how they are working today, what they thought about the presented way of working, which benefits they could identify for different functions in different scenarios. They also got a direct question if they saw any potential drawbacks of the work methods and the tools in general. The interviewees had also been involved in the installation and planning phase of the existing X-ray equipment and were able to compare how the development work with that process had been carried out and what benefits they could see by using these virtual visual tools in that case.

Results from interview four:

Current situations identified as possible to improve by using virtual visual tools:

- They experience that there are risks of different people having different views on how suggested solutions actually behave in real life. Also if something is unclear there is a risk that persons not fully understand or having an accurate view on a certain suggestion not letting anyone know.
- There have been situations where suggestions have been proposed, approved at first sight and have been more and more developed until it is realized that the solution does not fit in the planned area and that the suggestion needs to be redone completely.
- When planning thins in a 2D drawing environment it often happens that you leave associated tools and equipment out of the planning phase for different reasons and that they are being planned for when the equipment is already bought and installed.
- They have a feeling that it is difficult to get an idea of how traffic and material flow and placement are actually functioning by looking and drawing on a 2D layout.
- In some projects there has been a difference in perception between different parts of a planning team when planning for new equipment is made and some departments are just interested of the part of solution that concerns their area and not thinking of the process as a whole.

Identifies benefits of virtual visual tools:

- By using these virtual visual tools it is easier to plan the processes much more in detail and it is more likely to remember, being able to and plan for associated things as well as for the main equipment.
- If you are working in the same environment for different things, for example placement of equipment, work place design and material flow the risk of planning details falling through the cracks reduces if the involved and deciding persons are looking at the same visual model and can contribute with inputs.
- It will probably be easier to merge different groups into getting along regarding benefits and drawbacks about certain solutions and also to percept how a different solution is working for other parts of the planning team.
- Useful for investigating the work environment for the people going to work in the planned environment, for example do we need more light? Is the process able to visually being

looked after if the operator is performing a necessary task away from the core process if that is needed?

- Good tool for informing the union and functions responsible for the safety about how the planned work environment will look like already in the planning stage.
- The probability of planning and making things right before decisions are being made increases by using the tools presented since it is easier to integrate more details in the development plans and that it is easier to imagine how a certain concept will look like in the real factory and by that make more accurate and thoughtfully performed.
- The tools are allowing a more easily merging between different departments working with separately tasks within a production development process.
- The communication between different groups is probably being more efficient when working with visual tools.
- Very good way of presenting a possible future state (Future state point cloud and simulation of manual work)
- Good for visualise how much space the queues of products are taking up. Especially when simulating large queues.
- Good as integration tool for involving the suppliers and show how they want or need the equipment.

Possible drawbacks:

- When introducing a new tool to use in the production planning phase it is a risk overdoing concepts virtually just because you can and you risk to lose the effectiveness of the tool.
- Risk of losing interest and think that is unnecessary when announcing to an organisation that we are now start working with these new virtual tools. Need to really explain the benefits and make sure that it goes through to the persons going to use them. Otherwise it risks not being used.

Non value adding aspects (or similar):

- Scanning an area of the factory which is not going to be changed for a long time can be unnecessary. Focus on areas which are under development.

Identified desired way of working with virtual visual tools:

- To use the same documents in different groups when planning new layouts, for example to have a point cloud model that updates when new things are determined so that different functions are looking at the same kind of visual environment when deciding different solutions and that everyone knows the current decided state in the planning phase.
- Take the spot on identified benefits and start using the tools for achieving them and do the assumable and probable benefits later on when the tools are already being used and accepted as work method later on.

End of report.