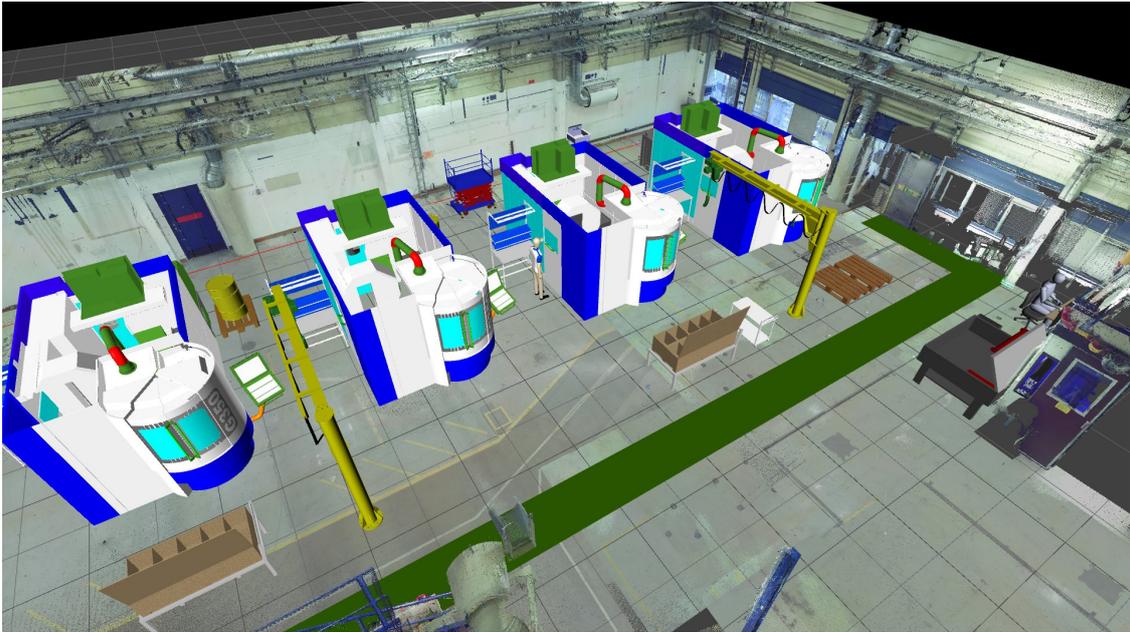# Utilising 3D Laser Scan Data for Redesigning Production Systems

A case study at GKN Aerospace Engine Systems

Master's thesis in Production Engineering

Anders Olofsson
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Utilising 3D Laser Scan Data for Redesigning Production Systems

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CHALMERS
UNIVERSITY OF TECHNOLOGY

Abstract

The competition in industry is increasing each day and it gets more and more important to have cutting edge technology. A way to prosper in this competition is to have efficient production production systems. GKN Aerospace Engine Systems is a company that produces world class products and is seeking to increase the efficiency of their production. GKN decided to investigate the use of 3D laser scanning and visualisation when developing a new production system. The technique uses laser measurements and imaging to create a photo-realistic image of the environment, called point cloud. The point cloud can be combined with CAD objects to create a visual model of the production system. A realistic visual model were created by collecting inputs from stakeholders through collaboration, workshops and interviews. The use of a visual model is beneficial for multiple stakeholders within the project. Results show that working with a visual model can improve communication, risk elimination and develop a shared view of the project. The visual model is shared between stakeholders using the network drive solution for viewing. The use of a visual model in developing production systems is recommended for GKN to improve their production development performance.

Keywords: 3D Laser Scanning, Visual Model, Production System, Point Cloud, CAD, Risk Analysis, Layout Planning

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Anders Olofsson & Martin Sandgren

Göteborg, Sweden, 2015

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Introduction

This chapter is an introduction to the master thesis. The hosting company GKN Aerospace Engine Systems will be presented together with the background, aim and scope of the project. The thesis is a collaboration between GKN and Chalmers and is a part of a larger research project called Visual Production.

1.1 Background

In this section a brief background to the company will be presented as well as a more in depth introduction to 3D visualisation and layout planning.

1.1.1 GKN Aerospace Engine Systems

GKN Aerospace Engine Systems (GKN) is a first tier supplier of engine components for the aircraft industry. The company were founded in 1930 in the name Nydqvist & Holm (NOHAB) in Trollhättan and renamed Volvo Aero in the 1990s. In 2012 GKN acquired Volvo Aero and the company is now part of the GKN PlC.

GKN Aerospace is a world leading global first tier supplier of airframe and engine structures, components, assemblies and transparencies to a wide range of aircraft and engine prime contractors and other first tier suppliers. It operates in three main product areas: aero structures, engine components/sub-systems and special products. The factory in Trollhättan, GKN Engine Products Sweden, focus mainly on engine components along with parts for the space industry.

As the market change and the demand for high end products grows, the need for GKN to be able to supply the industry with their products increases. Therefore GKN decided to invest in a new production area. The project started in 2013 when the board committee decided to grant resources for a new production system. The project is driven as two parallel projects. One that focuses on the product and one that works with manufacturing/production. This thesis will focus on the production project and work in close collaboration with the company representatives.

1.1.2 3D visualisation and layout planning

"Factory layout involves the selection and arrangement of machines and material handling path, material handling devices, resulting in reduction in cost and time involved in man-

ufacturing" [1]. The choice of layout is of course dependent on what type of production that is at hand. A functional layout, batch flow or a line-based flow will look different but chosen to serve the type of production that is conducted [2]. There are of course many other factors to consider when planning a factory such as capacity needs, material and production flows, demands on quality, available space, etc. These different factors will all play a part of the final outcome of a production layout.

The production system development phase is in the beginning fairly abstract. But when the pre-study is done, the specifications and requirements of the production system are set, the production system can be visualised through a layout plan [2]. However it is important to remember that a thorough pre-study is important otherwise there is a risk of creating layout alternatives that do not fulfil the requirements specified [2].

In the production development process the layout is a way to create a visual and concrete representation of a production system. With the visual representation the development team can determine how the requirements and specifications will be realised with space available for production. The visualised layout also creates advantages to be able to discuss and communicate different solutions throughout a company [3]. An investment decision often require a layout plan for the production system. A complete plan of the layout is often needed to properly convey the message to management that will ultimately make the decision regarding the investments [2].

There are many different ways to visualise a production system. Before computers simple pen and paper was used to draw two dimensional layout plans when planning a production layout. Other methods like cutting models from cardboard or paper to create layout alternatives has also been used throughout the years. A big step forward was of course the introduction of 2D Computer Aided Design (CAD) that made it easier to make detailed layout alternatives quickly. An even bigger step forward was the introduction of 3D CAD design where a layout could be presented in three dimensions, thus making the layout plan reflect reality even better.

However these three methods for visualising all have one thing in common. They all rely on measurements and observations that later have to be transferred to the layout manually. It can be measurements regarding heights, lengths, positions of objects, ventilation ducts etc. Typical tools are plain measuring tapes and various kinds of laser measures [4]. Obviously manual measurements increases the risk of getting faulty and inexact measures when there is room for human error. Potential errors in the measurement can then be transferred to the model of the production system, hence there will be a risk of basing decisions on incorrect information [4]. Transferring the manual measurements into a digital model of the factory is also time consuming and expensive [4]. The level of detail and accuracy are far from the real world system [3].

The latest big step in layout planning is the use of 3D laser scanning. The scanner can create a model of a factory area in a matter of hours [4]. Instead of manually measuring everything necessary and then manually modelling the factory, the 3D scanner will produce a high quality and accurate model of the scanned environment. The whole step of measuring is removed and with that the risk of getting measurements wrong that results in a faulty model.

Combining point cloud data with CAD-models (e.g. machines, tables, lifts, tables etc.), gives the possibility to create a detailed virtual representation of the real world. This type of visual representation enables the possibility to move around the visualised environment

in 3D and analyse the data in detail [5].

3D visualisation provides a powerful tool for designing and verifying production systems. It allows for the development team and supportive parts of a company to examine the production system in detail [6]. When properly utilising visualisation tools a wider range of designs may be explored while cutting costs, design time and avoiding errors in the production system design [6]. If the manufacturing system is designed with help of 3D visualisation and with a structured way of working potential design errors can be foreseen and avoided early in the design process [6].

1.2   Aims & goals

The aim of the project is to investigate how GKN can use 3D laser scanning when re-designing production systems. The presented work should be able to support engineers to improve their decision making in the development process. A goal of this project is also to find out whether there are possibilities to save resources by using 3D laser scanning compared to conventional methods. Another goal is to find out whether there are other possible benefits and who within the company can benefit from the 3D scan data during the design or redesign process.

1.3   Research questions

- How can the use of 3D scan data save resources during production system redesign?

- How can the use of 3D scan data facilitate the production system development?

- Who within the company can benefit from the 3D scan data during the development process?

- What prerequisites needs to be fulfilled to be able to use 3D laser scanning and a visual model?

- How well can GKN's current software and hardware support editing, viewing and use of 3D scan data?

1.4   Delimitations

The model will be used mainly as a visual aid for the developing team and not be used for discrete event simulation of the production system during this project. The main focus is to create a virtual layout of the production system to support the developing team in their risk analysis, decision making and problem solving. Focus is also on how the virtual model can be used during the development process and what benefits that could arise.

Due to the time frame of the project there is a need for limitations when working with the 3D scan data. First, there is a limitation in how much time can be spent in editing data. This limitation is set to ensure that the perfection of the 3D scan data does consume too much time in the beginning. The created virtual production system should give the

user a good view of the future state but does not need to be accurate down to bits and pieces.

2

Theory

The chapter aims to help the reader create an understanding for 3D laser scanning and the supporting software as well as theory about visualisation, project work, LAMDA and 7 flows.

2.1 3D laser scanning and modelling

Gathering large quantities of environmental data is an area of growth. It becomes more and more relevant to have high precision information about the surroundings. 3D laser scanning are an easy method of collecting large amount of data with high precision. There are several different techniques of 3D laser scanning. The most commonly used technique when scanning environmental areas is phase shift scanning [7]. The scanner sends out a wave of infrared light which is reflected back when it hits an object. The distance between the scanner and the object is measured by the phase shift in the infrared light wave [8]. A mirror determines the angle of the wave from the scanner. The scanner has the ability to see in 360° x 305° field of view with the help of the built in motors, see figure 2.1 [8, 3].
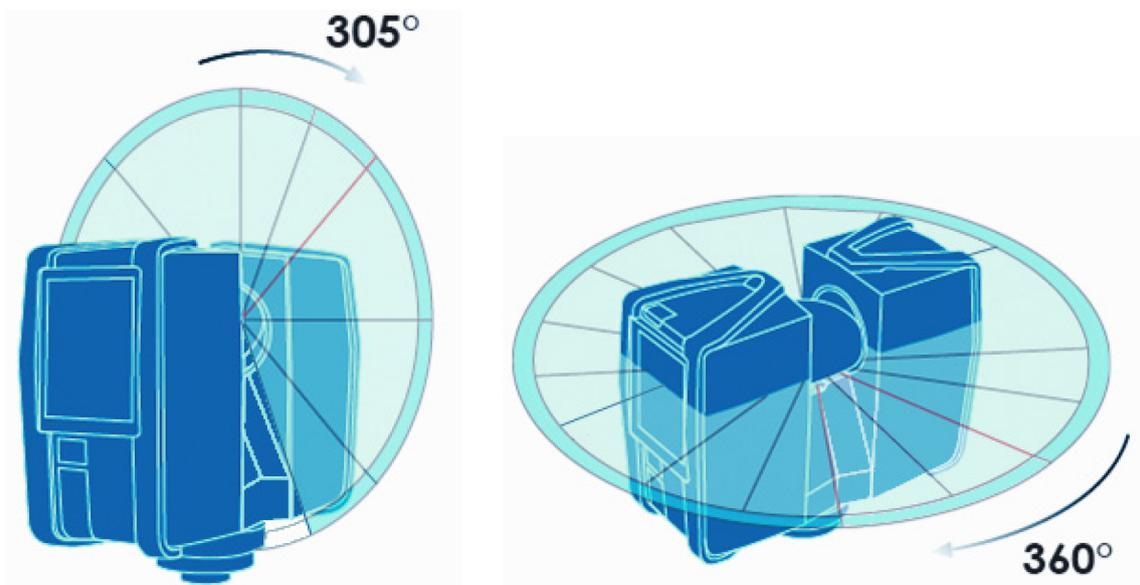

Figure 2.1: Vertical and horizontal view of the scanner [8].

Each wave of infrared light reflection is calculated into x, y and z coordinate and repre-

sents a Cartesian coordinate point. By combining large amounts of points into one single dataset, a point cloud is processed by the scanner. A point cloud is a three dimensional model of the scanner's surrounding environment. A normal scan with medium resolution settings consist of several million points [3, 8].

The 3D laser scanner are able to determine the reflectivity of the objects and assign each point a corresponding grey scale. This feature is combined with an integrated digital camera which captures a photo realistic image of the environment [8]. The photos are applied as a layer on the point cloud that gives every unique point a colour corresponding to the photograph.

Inside the scanner is a dual axis compensator that levels the scan data. Each scan has its individual inclination and is electronically stored. The data is used in the registration process to level the point cloud. The scanner also uses the built in altimeter to determine the altitude of the scanner using air pressure. These features are used in the registration process of the point cloud [8].

In order to combine multiple scans into a single point cloud, the scanner needs reference objects. There are possibilities to use natural targets, such as walls, ventilation piping and corners as reference objects but this might give less accurate results and make registration more complex [8]. To improve the results it is possible to use artificial targets such as spheres and checkerboards. The registration process will find these artificial targets and achieve a more precise registration. The ideal state is that there are three or more reference objects within each scan, known as triangulation in mathematics [9]. Reference objects should be in clear sight of scanner and the line of sight should not be interfered by any objects. The targets should be visible from more than one scan for registration possibilities [8].

2.1.1 Computer-aided design

Since the beginning of mankind there have been a need for the ability to shape and modify material. The introduction of computers opened up a new world for these needs and revolutionised the industry. Computer aided design (CAD) has since then helped engineers to describe and transfer knowledge to others [10].

The use of CAD in visualisation of production systems have limited potential. The process of creating and documenting productions systems with CAD models is time consuming and requires extensive measuring [3]. Every measurement must have high precision, otherwise it leads to inaccurate models of the environment.

Another use of CAD is models of objects. Almost every product that is produced are created in CAD and represented as a 3D model. There are multiple suppliers of software for creating CAD models and they normally support each other's file formats. For standard objects there are online libraries that supply large databases of CAD objects [11].

2.1.2 Storing point clouds

Previous research have showed that one of the largest issues when switching between different software is the compatibility of file formats [7]. Every developer use their own file format and force the user to stay within the walls of their brand. This becomes an issue

since there are pros and cons of every software. The transfer of data between different software suppliers is most of the times possible, but not without problems and occasionally with loss of information as a result. This lead to the development of a standardised file format that is compatible with most software. The result were the E57 File Format for 3D Imaging Data Exchange (E57). According to Huber [12], E57 does not aim to be the best performer in every area. The purpose is to be a general and open standard for storing 3D files.

2.1.3 Registration of scans

For registration of the scans, each manufacturer have their own software. SCENE is FARO Technologies software for registration and editing of scan data. Registration is the process where the different scans are merged into one. The input to the software is the raw scans from the 3D laser scanner. The artificial spheres and checkerboards are used to correlate the scans to make one file out of the scans [13]. With the raw scans imported and registered the user can begin to process the raw scan data, removing disturbing or inaccurate scan points, see figure 2.2. Scan points can be removed manually as well as automatically. Manual deletion of points is necessary in order narrow down the number of points since the raw scan data will have many points that are irrelevant. An example of this can be seen in figure 2.2. Unnecessary points should be avoided to create the best visual result as well as keeping file size to a minimum. After the cleaning, filtering and registration of the scans the scan data is saved to one file that is called a point cloud. The point cloud contains the edited and merged scans, but views it as one united point cloud. The point cloud can be saved in various different file formats, depending on what software that will be used for further usage of the point cloud data [13].
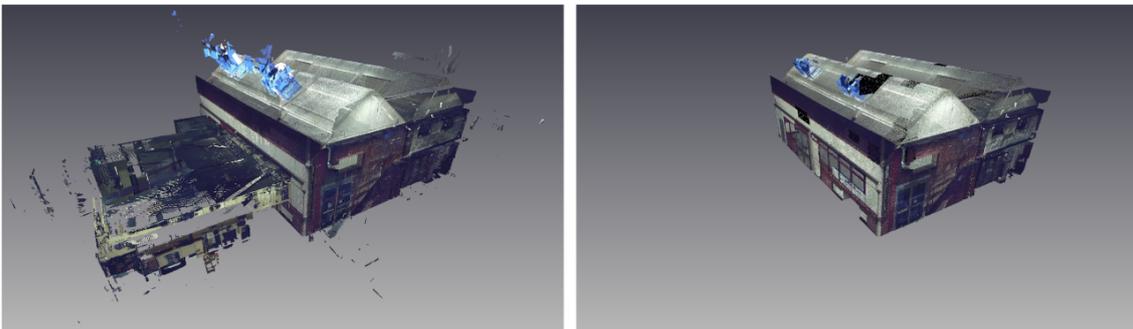
Figure 2.2: Unnecessary scan points removed manually [7].

2.1.4 Point cloud and modelling

In point cloud modelling there are different requirements that a software need to fulfil. As stated in previous section 2.1.2, the software need to be able to import and export E57. Another requirement that need to be fulfilled is the need to combine point clouds and CAD models. A software developer that are cutting edge in this area is Autodesk. They specialise in 3D design software and have a broad portfolio of tools that are applicable within the area.

Autodesk Recap (Recap) is a software for converting point clouds of various file formats, such as E57, to Autodesk point cloud format .rcs, see table 2.1. This conversion compress the file and makes it run smooth on Autodesk software. File format .rcs is preferred since it is designed for other Autodesk software. In Recap there are also possibilities to register scans and edit point clouds. This software has similar possibilities as FARO SCENE, see section 2.1.3.

The conversion of point clouds to .rcs file format enables the use of Autodesk Navisworks Manage (ANM). This software is mainly for architecture, engineering, and construction professionals to view a 3D model. ANM is a tool for combining point clouds and CAD models as can be seen below in figure 2.3.
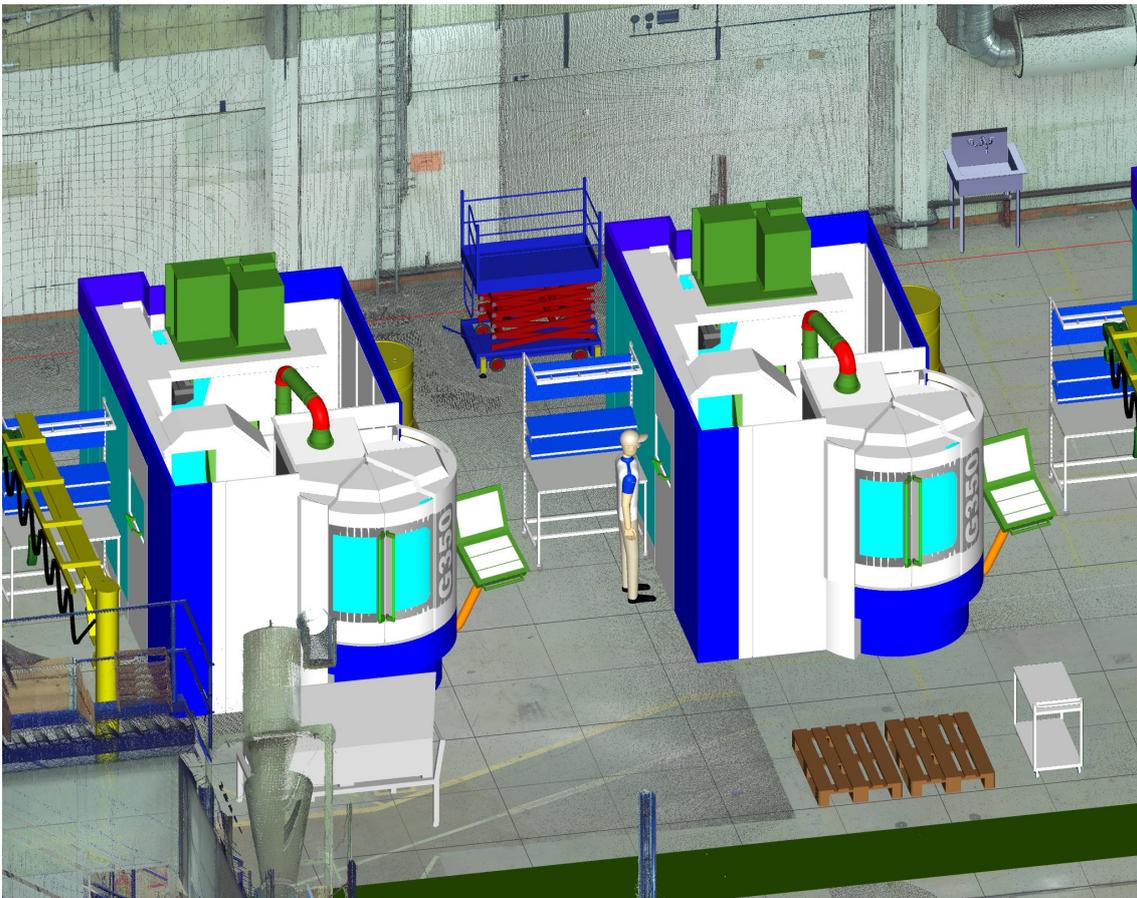
Figure 2.3: Combination of point cloud and CAD models.

Within ANM there are numerous possibilities and features and some of them are mentioned below:

- *Navigation.* Easily navigate in the visual model.

- *Move objects.* CAD objects can be moved around freely within the model. A coordinate system gives the possibilities to accurately move objects to the designated spot.

- *Measurements.* Using the measurement tool, precise measurements in both point cloud and CAD objects are available. Options for measurements are to lock it in x, y, z axis.

- *Comments and arrows.* Easily use comments and arrows to highlight interesting sections of the model.

- *Viewpoints.* Saved viewpoints can be used to quickly identify areas of interest.

- *Third person view.* By using the third person view in ANM the user can walk around the environment to see what it looks like from the human perspective.

One of the drawbacks of ANM is the computer requirements [14]. In order to handle both point clouds and CAD objects system requirements are quite high. For example the need for random-access memory (RAM) increases when the amount of points in the point cloud increases. A lack of RAM leads to less points loaded in the model and decrease in navigation smoothness.

The import and export file formats of ANM are shown in table 2.1. The combination of point clouds and CAD objects are possible and can be exported as a single file. There are two different ways of exporting in ANM. Either export as a file where the information is loaded from the origin or as a complete file where with all information included. This means that the size of saved files can differ. The latter of the two options allows the complete model to be sent to other stakeholders. This feature is called publish and creates a .nwd file format, see table 2.1.

By publishing the file as a .nwd file it allows for other stakeholders to view it. Autodesk Naviswork Freedom (ANF) is a freeware that supports viewing of point clouds and 3D models in .nwd file format. ANF has the possibility to open locally stored files as well as published on a web server. Most of the previously mentioned features are still functioning except editing of the model. ANF gives stakeholders that are part of the project the ability to easily view the model and accommodate updates frequently.

Table 2.1: Table of software and compatibility of file formats.

Software	Import	Export
FARO Scene 5.3.3	xyz, xyb, ptx, ptz, E57, IGES, VRML, csv	E57, VRML, DXF, XYZ text, XYZ binary, IGES, PTS, PTX and POD
Autodesk Recap	ASC, CL3, CLR, E57, FLS, FWS, ISPROJ, LAS, PCG, PTG, PTS, PTX, RDS (3D only), TXT, XYB, XYZ, ZFS, ZFPRJ	RCS, RCP, PCG, PTS, E57
Autodesk Navisworks Manage	.nwd, .nwf, .nwc, .dwg, .dxf, .dgn, .prp, .prw, .3ds, .pri, .sat, .sab, .model, .session, .exp, .dlv3, .CATPart, .CATProduct, .cgr, .stp, .dwf, .dwfx, .fbx, .ifc, .igs, .iges, .prt, .asm, .g, .neu, .ipt, .iam, .ipj, .man, .cv7, .jt, .dri, .x_b, .rvm, .rvt, .skp, .prt, .sldprt, .asm, .sldasm, .stp, .step, .stl, .wrl, .wrz	.nwd, .nwf, .kml, .fbx, .dwf, .dwfx

2.2 Visualisation

Communicating information throughout a company can be done in various ways. There are more or less suitable ways to communicate certain information, and the choice of communication can impact how well information is understood. Sometimes a visual representation can communicate things which words cannot [15]. Throughout history visual representations have been used to convey information effectively and use the enormous bandwidth of the human visual system [16]. Visual representations can convey complex ideas, with clarity, precision and efficiency [17]. The human visual system can be an effective parallel processor that supports the maximum communication channel into the human cognitive centers [16].

A part of the lean concept is Gemba, which means "going to the place to see the actual situation for understanding". In short the first step of any problem-solving or developing problem is to grasp the actual situation which requires Gemba [18]. So by being at an actual place you can get a deeper understanding, critically evaluate and analyse a situation [18]. The method of Gemba from lean production seemingly also tries to benefit from using the human visual system to get a deeper understanding of a situation.

A visual model of a production layout opens up for another version of Gemba. The future Gemba [3]. Where you can visit a model of the actual production layout and apply the same way of thinking as in Gemba. Bringing a concept like this into an early development phase has potential to facilitate the production development and make it easier to have a shared understanding of the production development between cross-functional teams [3].

2.3 Project work

There are different definitions on the term project. A project are usually a unique set of activities with a defined beginning and end that are executed by people within a company to meet a certain set of goals. And while meeting these goals also meet the demands for cost, schedule and quality [19]. According to Pinto [19] all projects have a series of activities that:

- have a specific objective to be completed within certain specifications.

- have defined start and end dates.

- have funding limits.

- consume human and nonhuman resources.

- are multifunctional.

In a previous master thesis conducted at GKN, the model for production system development was investigated. The model used was not specified for production development, and contain information and decision points that are not relevant or applicable for production system development. As a result of this investigation they presented a new production development model more suited for GKN's production development. A project flow model can be seen in Figure 2.4. The development model consists of five stages of development; Start, Measure and analyse, Design, Realise and Verify. During these stages 9 gates (decision points) are to be passed. When using this model the most important part is to
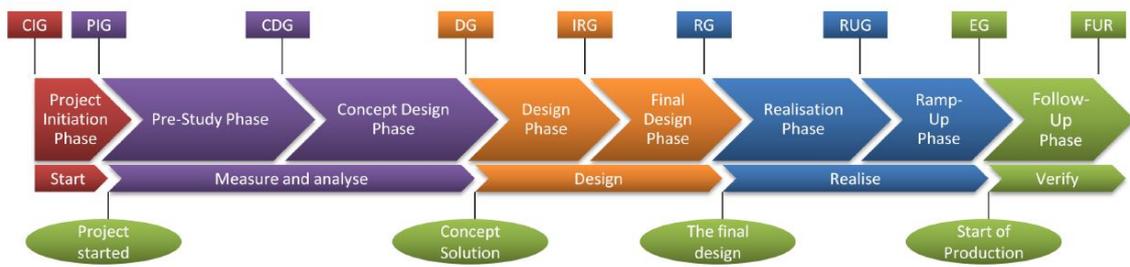
Figure 2.4: The project model flow

understand the development process in the Measure and Analyse phase to reach a concept solution. In that phase it's suggested to create a green-field scenario study and conduct an independent factory constraint study in parallel. Then the green-field scenario and the factory constraint study is merged to create concept solutions. In this merge changes from the green-field design should be properly motivated by the factory constraint study and explain why a deviation from the "perfect" layout is needed. At the end of the Analyse and Measure phase two concept solutions should be presented and one of them should be developed further in the design phase [20].

The thesis from 2013 also point to the benefits of using laser scanning for modelling the factory. Both for gathering information about the factory constraints but also in the creation a virtual factory. The visual model can be beneficial in all stages after the initial pre-study is made. A visual model of the production system will provide a unified understating of the system during the design phase [20].

Using a visual model also potentially minimise misunderstanding and mistakes in communication between different technical areas. Major problems can also be detected and dealt with early in the development process thus give financial benefits [20].

2.4 Risk analysis

When designing a production system there are many factors to consider. Every decision regarding the production system comes with a certain risk. It is important to be able to identify the risks connected to a decision to establish a risk picture [21]. A risk picture is needed in order to compare different solutions and alternatives in terms of risk. One of the main reasons for a risk analysis in a project is to support decision making. A risk analysis can help in finding the right balance between different factors like for example cost and safety [21].

A risk analysis is however meaningless if all relevant risks regarding the production system is not identified. A realistic visualisation of the production system can create a common understanding and support problem solving and decision-making. If a structured way of working is used, the visual model can aid in pro-actively identifying possible risks and problems when creating or redesigning a production system [22]. A realistic visual model of reality can provide better support for identifying risks and thus making it easier to make the right decisions.

2.5 LAMDA

In the development of a production system it is impossible to avoid problems and disturbances. A lot of decisions made in development phases are based on inaccurate facts and assumptions. Even though it is impossible to avoid problems there should always be a struggle to limit the occurrences of such.

Within the LEAN concept there is a tool called the PDCA cycle, Plan-Do-Check-Act. This tool can be used at any levels in a company to surface problems and ensure that the countermeasure is doing its job [18]. The PDCA-cycle is one of the important tools of continuous improvement. Using the PDCA cycle is an iterative process that is continuously progressing in the development of a production system.

In 2002, Allen Ward developed the PDCA cycle to be more similar to the Japanese actual way of working. He found that the PDCA cycle did not reach the same results as the Japanese when it is taught in the west [23]. The improved version was named LAMDA and is supposed to fill the gaps of PDCA. The steps of LAMDA is as follows [22]:

- Look – go and see for yourself,

- Ask – get to the root cause,

- Model – using engineering analysis, simulation, or prototypes,

- Discuss – with peer reviewers, mentors, and developers of interfacing subsystems, and

- Act – test your understating experimentally.

This iterative process can be described as a cycle with the above described steps, see figure 2.5.
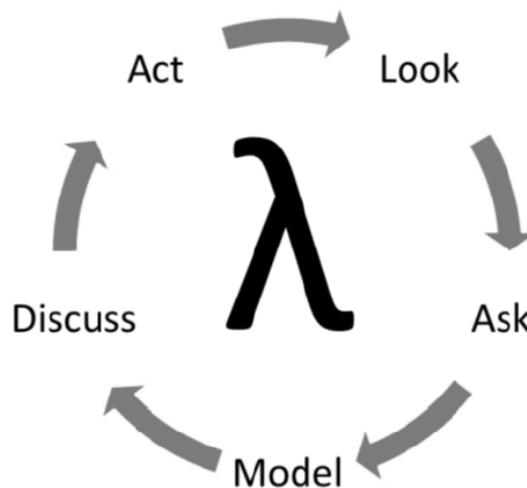

Figure 2.5: LAMDA cycle [22].

2.6 7 Flows

In the process of creating a new production system it is important to know your process. An understanding of the flow of material lets the developers base the decisions on facts and create the appropriate solutions. Value stream mapping (VSM) is a recognised tool of understanding the flow and what parts of the process that creates value. The purpose is to provide a picture of the flow of material and information along the products path in a production system. VSM is primarily used on existing production systems as an evaluation of the value creating activities [2].

An issue of VSM is that it is quite difficult to get a deeper understanding and to define the different parts of the flow, especially in the process of designing a new production system. In VSM it is common to focus on the factory/product perspective and summarise the processes on a higher level. A tool that has a deeper level of process understanding is the 7 flows of manufacturing (7 flows). The idea is that each one of the following flows is observed to get a full understanding of the system [24]:

- The flow of raw material
- The flow of work-in-process
- The flow of finished goods
- The flow of operators
- The flow of machines
- The flow of information
- The flow of engineering

A complete picture is created by analysing each of the processes in the production system and step by step fill in the 7 flows information. The data from 7 flows could then be used for the layout planning as a basis for accurate decisions. Working according to the 7 flows standardise the development phase and assure that the inputs from multiple stakeholders are assured.

3

Methods

The methods used in this thesis will be presented in the next coming sections. Before moving into the details, an overview of the process are presented. Figure 3.1 describes the different steps that were used as a basis for the findings in the thesis. 3D laser scanning were the first step and considered to be fundamental for the project. This is followed by processing the scan data and creating the visual model. A lot of interesting stakeholder inputs were collected through workshops and interviews.
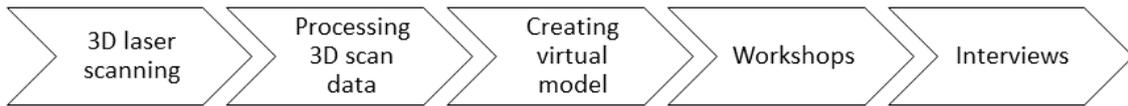

Figure 3.1: Overview of the method used in the master thesis.

3.1   3D laser scanning

The 3D laser scanning were performed at GKN Aerospace Engine Systems in Trollhättan and were a part of the development of a new production area. The area that were scanned was a limited part of the factory. At the time of scanning the area were almost empty except for some cables and a few other objects that interfered. This was due to the fact that electricians were working there and some of the objects that were supposed to be removed still remained on site. The decision was made that the scanning were to be carried out anyway although this would mean more editing.

The area of interest were about 700 m^2. It consist of a larger area, a storage area and a welding room, see figure 3.2

Inside the welding room there were a recently installed robot cell for welding of products together with other equipment. The storage area contained about 15 pallets waiting for inspection. These pallets were not removed prior to the scanning but edited afterwards. Regarding the inspection area there were no modifications due to daily working routines.

Below follows a walkthrough of the steps conducted at the 3D laser scanning of the production area. This walkthrough is not to be regarded as a standardised framework for 3D laser scanning in general. For a thorough general walkthrough, see the 3D laser scanner supplier's manual.

1. **Prestudy.** Prior to the scanning, a thorough inspection of the area were conducted.
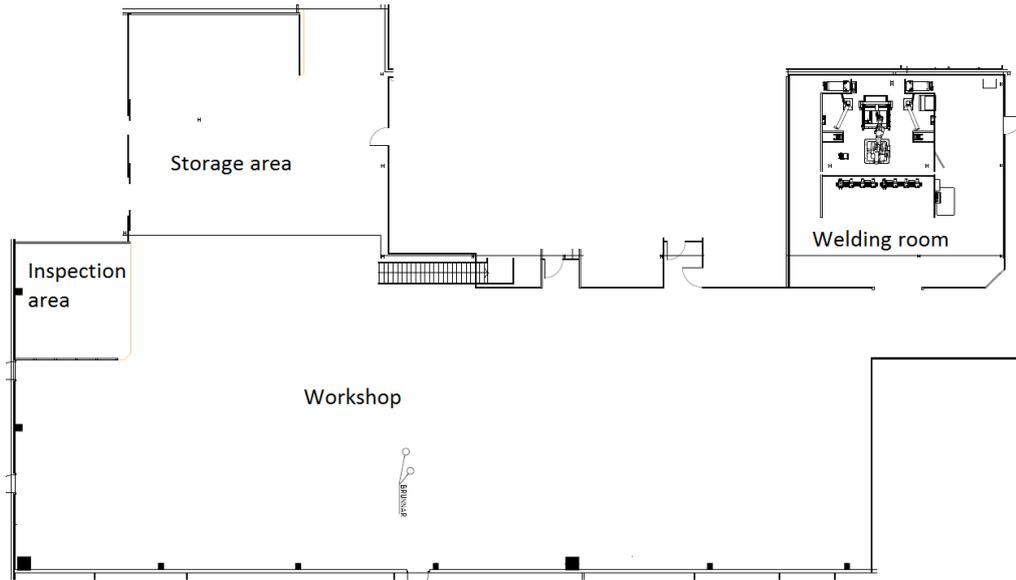
Figure 3.2: Layout drawing over the scanned area.

During this inspection, the operators in the proximity were notified about the up-coming event.

2. **Reference spheres.** During the previous step, a plan for placement of reference objects were discussed. A strategic decision of placement were taken with regards to the recommendations in section 2.1. Six of the reference spheres were mounted with magnetic bricks on the wall which gave the opportunity to perform more scans in the future. The mounting of the magnets were done in cooperation with the electricians on site.

3. **Scanning.** The 3D laser scanning were performed on the 29th of January in 2015. Participating in this step were supervisor Erik Lindskog together with the authors of this thesis. Lindskog's role were as an operator of the 3D laser scanner as well as an expert in the field of 3D laser scanning. The optimal placement of scanning positions were discussed together with Lindskog. A total of 10 3D laser scans were performed to cover the entire area of interest, see figure 3.3. Due to interference from the surroundings, one of the scans were cancelled, erased and not used. Total time for the scanning were around 3 hours.

4. **Restoring.** After the scanning the area was restored to its previous state.

3.2 Processing 3D laser scans

The output from the scanner consist of raw scan data files in .fls format. As described in section 2.1.3, the scans were combined into one single point cloud, also known as the registration process. This was done using the software SCENE from FARO, see the manual [13].

Due to the planning of the reference spheres positions, the registration process were fairly simple. The second step of processing the 3D laser scans were to remove unnecessary points in the point cloud. There is a difference between faulty and unnecessary points.
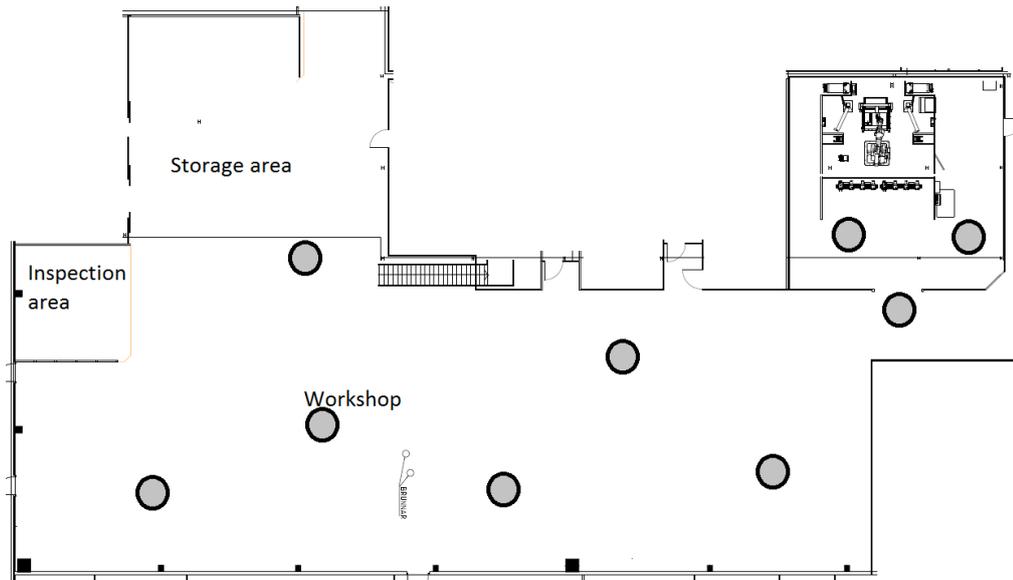
Figure 3.3: 3D laser scanning positions marked as black ring with grey colouring.

The faulty points are caused by reflections off objects and do not represent points from actual objects in the scanned area. Removing all these points were hard since it is very time consuming. There were no need to create a perfectly clean point cloud for the intended usage. Therefore the processing of these points were limited to removing obvious points.

Unnecessary points are points and objects that do not contribute to the point cloud. Examples of things that were removed was cable ladders and ventilation ducts since they were to be removed in the near future and would not impact the new production layout. The ceiling of the was also removed since it did not contribute to the model.

The edited and registered model can be viewed in section 4.1. The point cloud were exported as an E57 file format, see section 2.1.2. This allowed for an easy transaction to Autodesk Recap, see section 2.1.4. Recap were used both to convert files to .rcs and for further editing of the point cloud. The reason why Recap was chosen for further editing was to eliminate the conversion process from E57 to .rcs. The size of the .rcs file is smaller than the E57 file and better optimized for the modelling software ANM.

3.3 Creating the model

The process of creating the visual model were extensive and have gone through multiple iterative steps. An initial version of the production area was made after a meeting with the production layout team. There have been several remakes of the layout with different plans. The iterative cycle is described by the following figure 3.4.

In step 1, one of the stakeholders of the project have an input of something that should be added or moved in the visual model. The information were obtained from the stakeholder by for example email or verbally in step 2. The information given differed a lot from time to time, e.g. number of machines or positioning of jib crane. The model was then altered/created to the specifications of the stakeholder. The visual model were presented
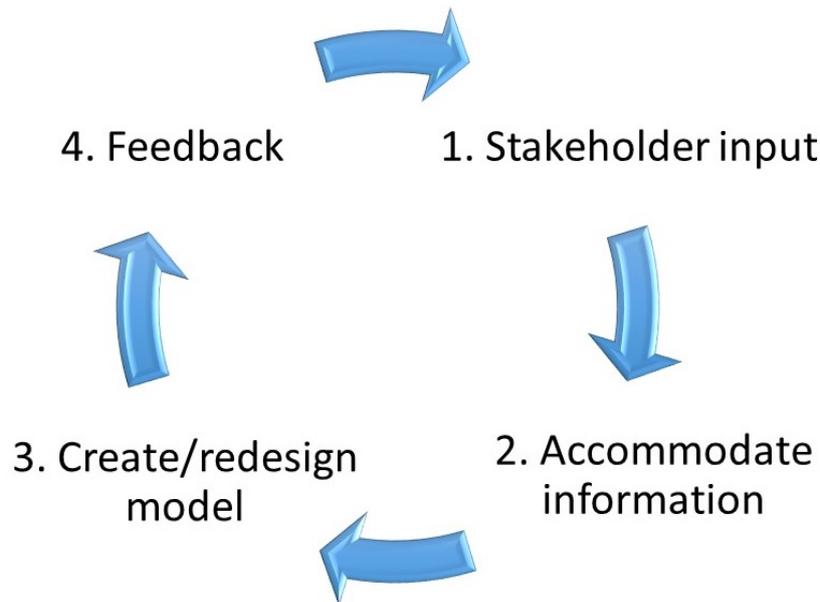
Figure 3.4: Creating the visual model iterative cycle.

to the stakeholder to ensure that the communicated information were correctly understood and visualised in step 4.

This iterative process were active during the entire project and lead to several updates of the layout. The software used for creating the visual model were Autodesk Naviswork Manage, see section 2.1.4. The method used for learning the software were trial and error combined with the Autodesk instruction videos [25].

The creation of the visual model was a big part of the project. The basis for the model is the point cloud which were created in prior section 3.1. To be able to create a real life visual model of the production area, it was combined with CAD objects, see section 2.1.1. Several of the CAD objects included in the visual model are standard objects, e.g. pallets, jib crane, tool benches etc. Many standard objects were found online and downloaded. Primarily, the site GrabCad.com [11] were used to find these standard objects. Other standard objects were found in the Autodesk library. If there were CAD objects that did not exist neither online nor the Autodesk library, they were drawed in 3DS Catia V5 using prior knowledge.

During the creation of the visual model there was a large change in the layout which meant removing walls. Since they still were physically there during the modelling of the layout, the current point cloud had to be edited to fulfil the new requirements. Aside from some walls being removed the inspection area was moved to another part of the production area. The area were moved to another location due to new requests regarding the layout. The original inspection area were removed from the point cloud using Autodesk Recap, since that inspection area consisted of scanned points. That lead to a large gap in the visual model but were replaced with a substitute floor. The substitute floor was a copy of the point cloud from another part of the factory floor. The same method was used to compliment the floor under the pallets that later had to be removed.

3.4 Workshops

In order to obtain a larger scope of inputs from different stakeholders, it was decided to organise workshops. The idea were to sit down in smaller groups of less than 10 people at a time and go through the process using the visual model as a base. The inputs from the stakeholders during the workshops helped to expand the visual model. And the visual model helped the stakeholders to come with inputs.

To ensure that every process of the production system were covered, the 7 flows methodology were used, see section 2.6. In this particular production system there were multiple processes that interfered with each other. The Manufacturing lead engineer were responsible for walking through the different processes using 7 flows. To be able to fully explain the different processes, the Manufacturing lead used the visual model for communication. The discussions that evolved during the workshops were diverse and gave several important inputs for the participants.

The workshops were organised in different stages according to the figure 3.5. The participants at the different stages were according to the area of interest, i.e. that product engineers participated in stage one and so forth.
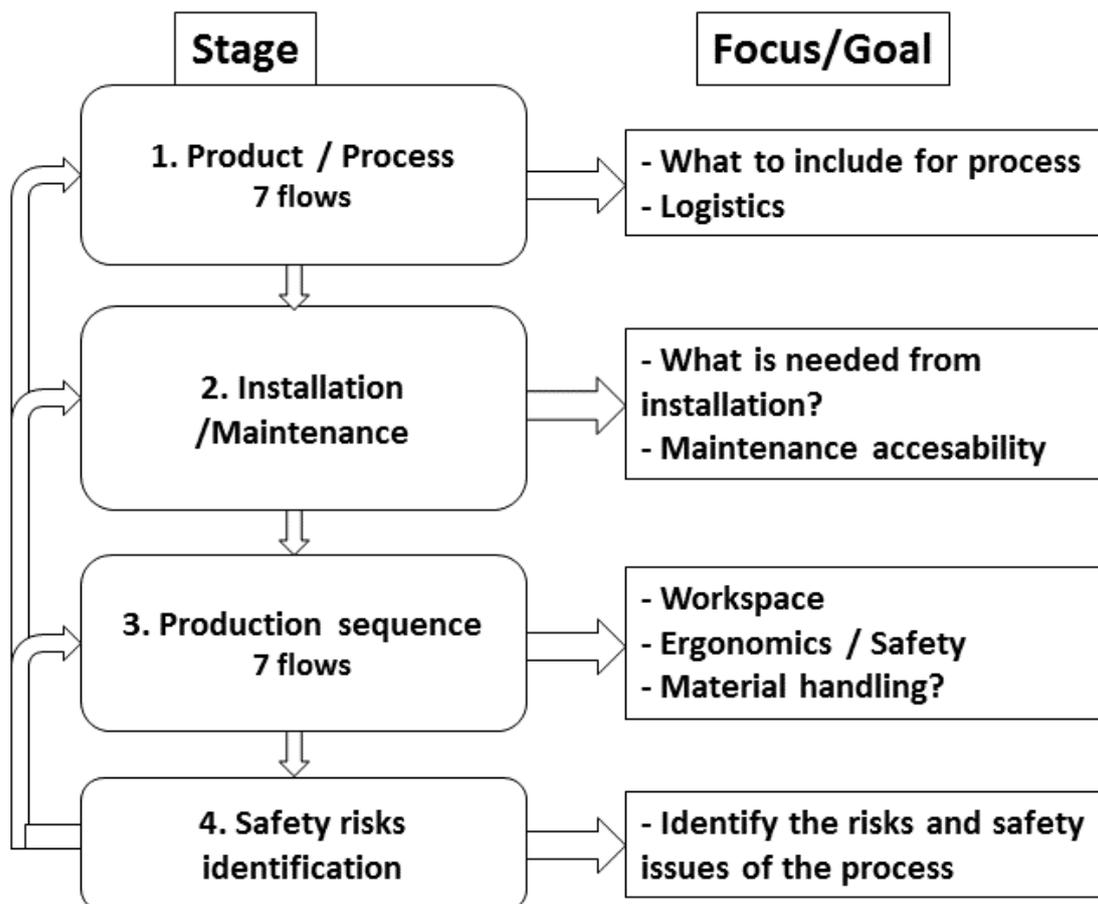

Figure 3.5: The plan of workshops that were conducted.

The initial idea were to go through these steps in an iterative way to create a complete

visual model and cover all aspects of the production area. Unfortunately this did not happen due to time frame of the thesis. The virtual safety inspection stage were not executed due to time frame and lack of interest from stakeholders.

3.5 Interviews

One of the most effective tools for collecting qualitative data for research are interviews. This is also one of the most widespread methods even though it is time consuming. One of the factors of interviews is that it gives the researcher more data to work with then for example a survey. During an interview, the interviewer are able to deviate from the guide to ask follow up questions. Qualitative interviews tends to generate answers that are closer to the interviewees' own perspective [26].

Within the area of qualitative research interviews there are three different types, structured and semi structured and unstructured. The unstructured interview is quite similar to a conversation where no question guide is used and the respondent are able to respond freely [26]. Contrary to unstructured is structured interview. This technique uses an interview guide strictly and do not have any follow up questions.

This thesis used the third interview technique which is called semi structured interview. During each interview a guide is used with pre-documented questions, see appendix A.1. In a semi structured interview the interviewers are free to ask follow up questions to get a deeper understanding of the areas of interest. Each interviewee should be asked more or less the same questions using the same wording to ensure standardisation [26].

The interviews started off with an introduction to the topic and the reason for the interview. Each interviewee are informed that they are to be kept anonymous. The interviews were recorded and notes were written during the interview.

The interview guide were divided into three parts. First part were questions of title and position in the company. Second part dealt with projects in general to see how they normally work. Last part focused on the workshops, see section 3.4. Every interviewee did participate in at least one of the workshops.

Depending on the interviewees' involvement in the project, the interviews were about 30-90 minutes. The interview were conducted in Swedish. Six employees were interviewed and had the following positions:

- Project manager

- Shift manager

- Project leader machine investments

- Manufacturing lead

- Detail responsible production technician

- Chief manufacturing engineer

3.6   Hardware and Software support

To investigate GKN's ability to handle point clouds, a system developer at GKN's IT department was contacted. A meeting was set up in order to determine the current support for point cloud data. That meeting revealed that the software currently at disposal at GKN does not support the necessary file formats for point clouds.

In collaboration with the system developer a test system for handling point clouds on office computers were set up. Two alternative setups were tested.

The first test involved using the free software ANF combined with the internal project software at GKN called TeamSite from Hewlett-Packard. The plan was to use TeamSite for storing the point cloud in a project folder and then run ANF remotely connected to a standard office computer. To try the setup a test file was uploaded to the TeamSite project folder. The uploaded file were then downloaded to an office computer. ANF was started in remote connection and the point cloud file was opened to evaluate the performance with the current setup.

In the second test ANF were installed locally on an office computer as opposed to being remotely run. Instead of using TeamSite to upload files, a network hard drive were used for storing the point cloud data. A test .nwd file were uploaded to the network hard drive at GKN's intranet. From the network hard drive the file were opened, not downloaded, with the software ANF to evaluate the performance.

4

Results

The results of the research conducted in this thesis will be presented in this chapter. First section will present the results from the visual model and the workshops in chronological order. The interview section presents the results from the interviews with different stakeholders which is summarised in a list at the end of the section. At the end of the chapter the hardware and software support results is presented.

4.1 Visual model and workshops

This section will present the different stages of creating the visual model. The thesis did not start at the same time as the project. Therefore there were already plans for the layout presented and four alternative propositions were evaluated to find the most suitable layout plan. Out of these propositions, one were further evaluated and created as a visual model.

1. The first example of the visual model contained four machines lined up from the window wall with 2562 cm between each machine. At the window wall there was a central cutting fluid system in the corner, see figure 4.1. Since the cutting fluid system did not have any CAD drawings it was manually created CAD after the measurements from the documentation. It also contained a new area of 80 m^2 designated for inspection of products, named *insp. 2*.

   The four machines from the drawings were accommodated as CAD objects. They were added to the visual model and measured to be positioned at approximately the correct position according to the drawings. Instead of using CAD of the entire machine, only the outer shell were used.

2. In the visual model, there were a need for other inventory than just the machines, such as chairs, tables, pallets and cabinets. Those parts were mainly gathered from the Autodesk library. Some of the objects were also found online.

   Insp. 2 were created using the inventory of CAD objects, see figure 4.2. The layout for insp. 2 were not confirmed but were seen as an example of how to plan it.

3. Next step was a revised model where the central cutting fluid system was removed. Instead the focus lay on the demand from stakeholders to potentially be able to have seven machines if the demand would increase. This means that the layout had to be configured to be able to squeeze in another three machines. With this new layout the central cutting fluid had to be removed from the current position and instead be replaced by machine dedicated barrels with cutting fluid. These were not included
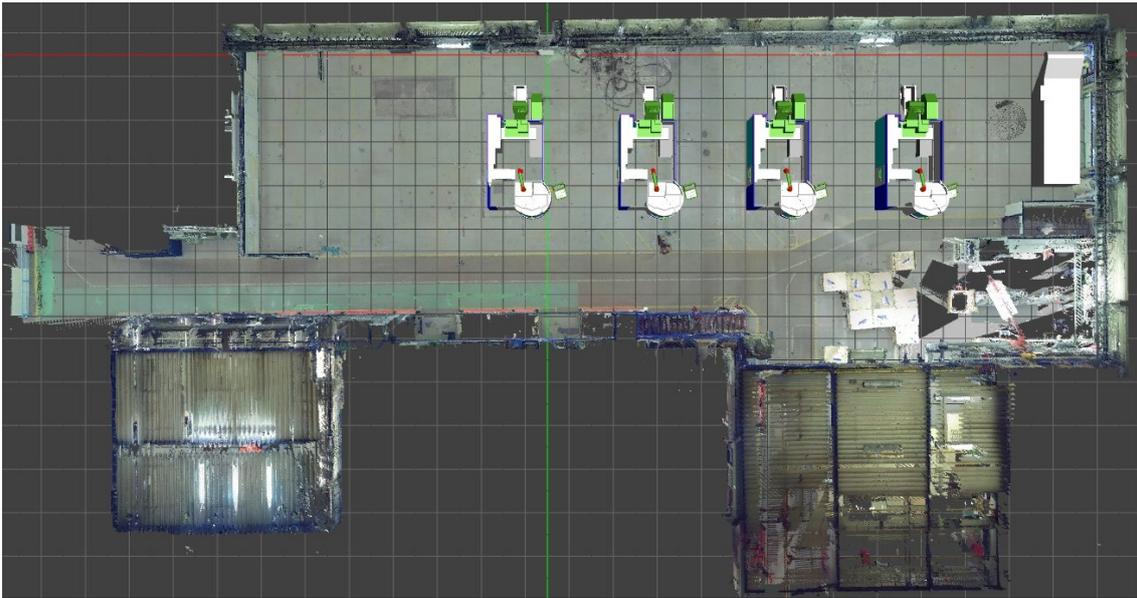
Figure 4.1: First visual model with four machines and central cutting fluid system.
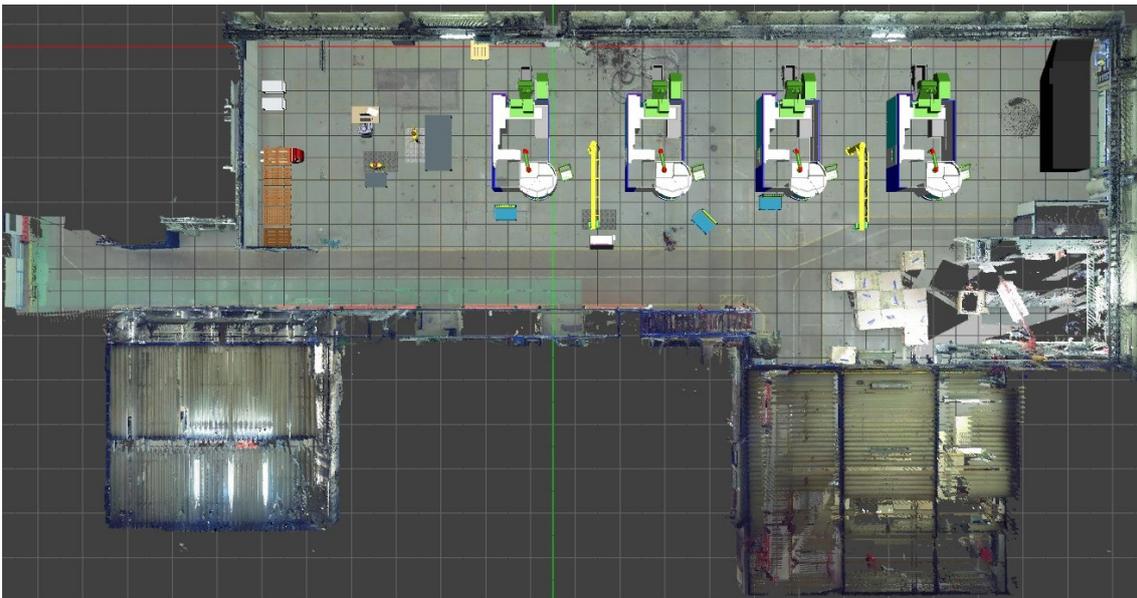
Figure 4.2: The production area including insp. 2.

in the drawings. Due to uncertainty where to position machine number seven it is not included in the visual model, see figure 4.3.

The seven machines were also moved further out from the wall at the back of the machine. The main reason for this was the potential to have room for a high raise lift table to move freely at the back of the machines. A secondary reason was that the chip container had to be able to be moved around the machines to be emptied. There were some confusion between the different stakeholders of the project whether the box that were marked behind machine number one in the drawings was supposed to symbol a chip container or something else. By moving the machines further out from the wall, this lead to the entrance tunnel from the outer door were to be removed

from the point cloud.
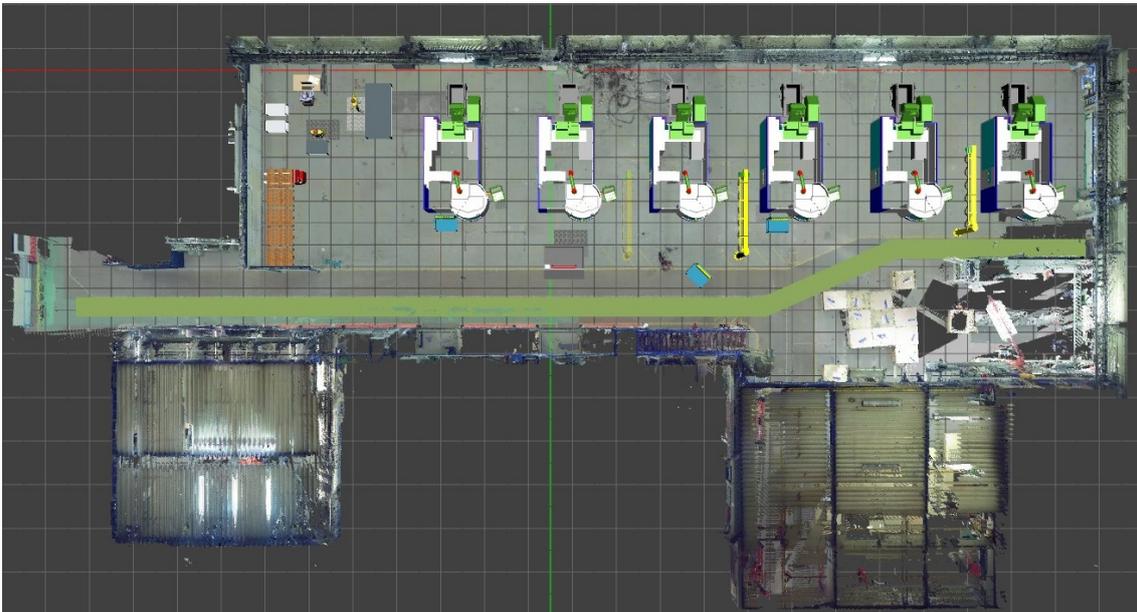
Figure 4.3: The production area including insp. 2 and six machines with number seven not positioned.

4. On the backside of the machines there needed to be chip container for waste disposal. A similar container were found online and modified according to the measurements on GKN standard chip containers. When added to the visual model, it showed that they were too high to fit in under the disposal pipe. The stakeholders were informed about this risk and noted this for further discussion with machine supplier.
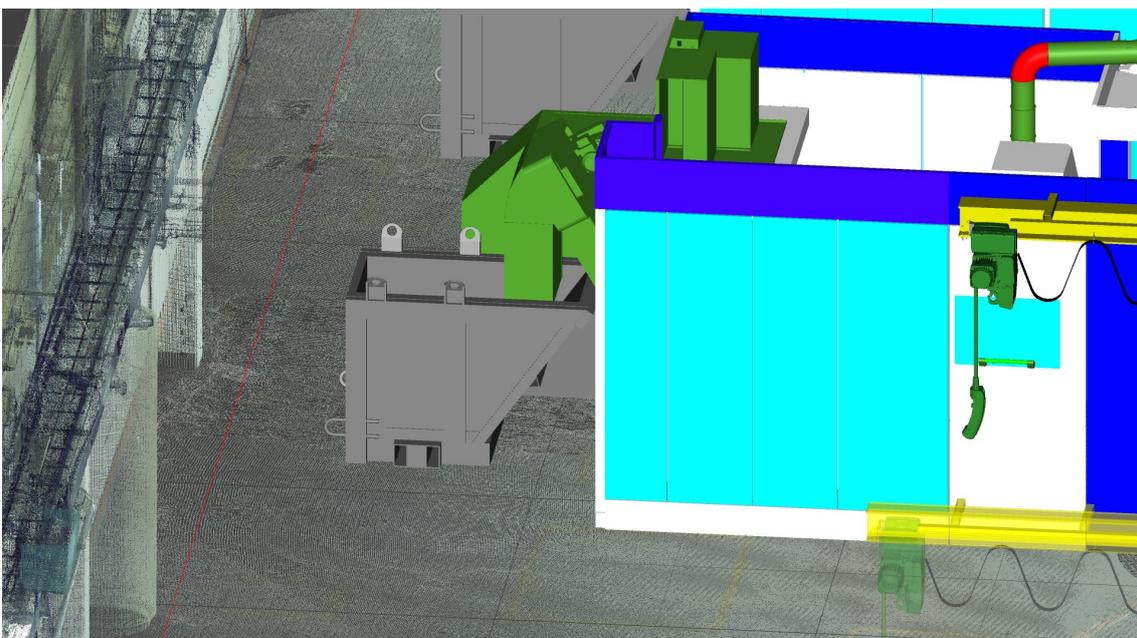
Figure 4.4: This figure shows the chip container for waste disposal.

5. After moving the machines further out from the back wall, it was concluded that the "old" inspection area, *insp. 1*, were to be removed. The section were removed from the point cloud using Autodesk Recap and replaced with a substitute floor, see figure 4.5. The visual model were up to this point based on measurements from a
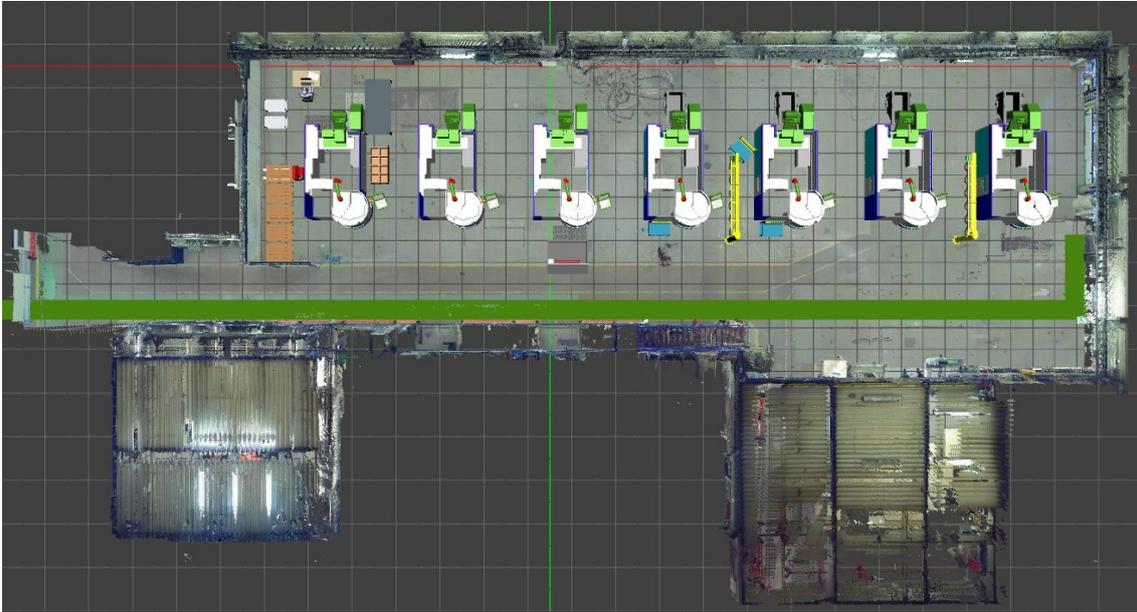
Figure 4.5: The figure shows the insp. 2 removed and substituted with a floor.

drawing on a .pdf where only single measurements were stated. After contacts with the facility department, the AutoCad drawing in .dwg file format were provided. The drawings were combined with the point cloud and CAD objects in ANM and the measurements were assured. The drawing from facility department were accurate with the included objects. Unfortunately there were several objects missing in the drawing that were obvious in the visual model.

6. The point cloud were updated with roof removed on both storage area and welding room, see figure 4.6. This made it easier to navigate and see the details in these areas. It also allowed for CAD objects to be positioned within these areas.

7. To get a more structured way of working in the project it was decided to launch a set of workshops with the stakeholders. A pilot was carried out on the third of March together with Manufacturing lead, two machine operators and one technician. The visual model was presented and used to exemplify what kind of equipment they needed in the daily routines. A few things were added, primarily a work bench for swapping tools. It was also decided that the best spot for cutting fluid was at the upper right corner of each machine, see figure 4.7. The model shows only four of the machines with the other three hidden. The reason were that only four of the machines were planned for the near future, but there should be room for the other three as well. Unfortunately, a lot of the discussions were primarily about operating the machine which was not relevant for the visual model.

8. After discussions with supervisors of the thesis it was decided that a standardised way of working must be established. A model were developed in cooperation with the supervisors on how to work in the project to ensure that the project will progress. This model is described in the section 3.4.
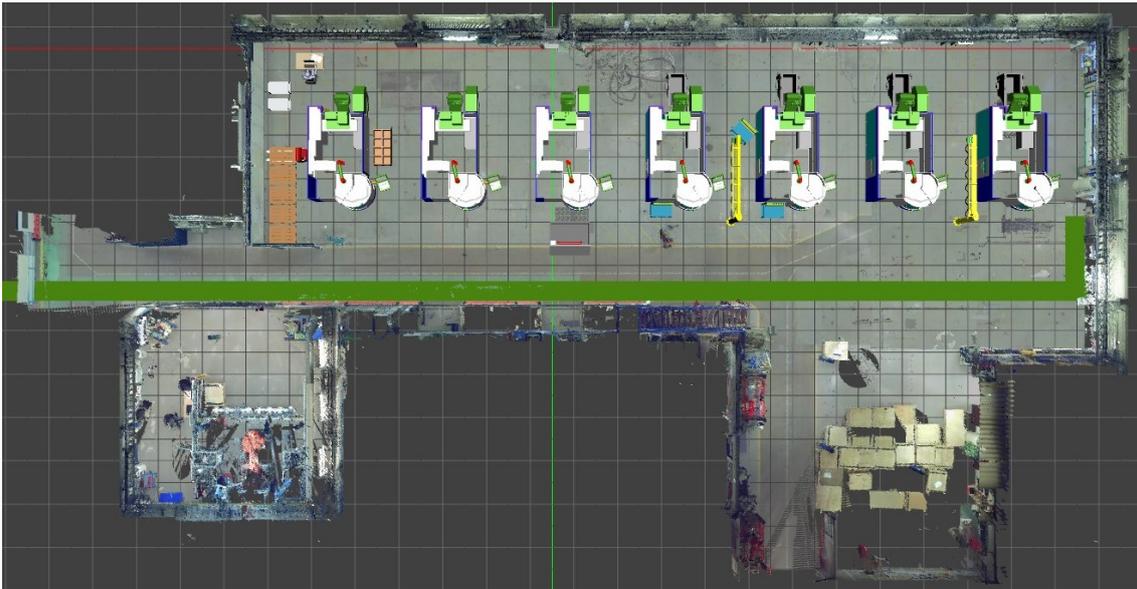
Figure 4.6: Roof of the storage and welding room are removed.
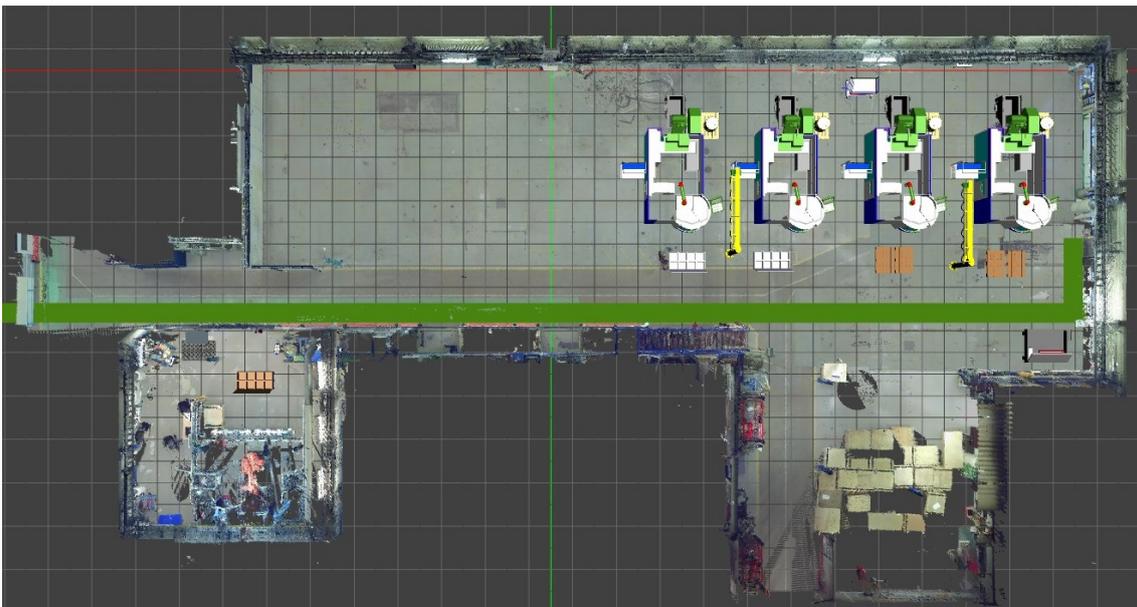
Figure 4.7: Production area after workshop pilot study.

9. *Workshop 1.* During the first workshop on the 6th of March, there were eight participants. In the conference room, two projectors were used, one which showed the visual model and the other showing the document "7 flows" operated by Manufacturing lead. The aim of the workshop was presented by the Production researcher at GKN.

During this session there were a lot of discussions. The visual model were used to show how the current layout were constructed. Using the 7 flows model the different tasks and operations were investigated and discussed. When there were a need for another object in the model or something were missing, it was simply added to the model. By using the model it was easy for the participants to explain what they

meant and a few times they even walked up to point at the screen to explain what they meant.

10. To increase understanding of the processes at GKN, there were an opportunity to participate in a normal procedure meeting. This meeting was about the welding operations and were held in the workshop. The Manufacturing lead were responsible and the participants were mainly welding operators.

    During the meeting, the Manufacturing lead went through the entire operation process and discussed with the operators. A problem that came up were that we needed to know how big a pallet casket were. To do this they needed to find a similar pallet casket which in this case were just outside the door.

    A lot of questions came up and it was concluded that they needed a table for inspection. This would preferably be mobile until they knew a good position for it. A table with 50*50 cm were created in the visual model after the meeting.

    They also realised that the turn tables for welding operations were way to big and unhandy and went on a walk through the factory to find better solutions.

11. *Workshop 2.* Workshop number 2 were held on the 12th of march at GKN Trollhättan. This stage focused on maintenance and installation of the machine. The purpose were to ensure that objects that were needed for the daily routines were included in the model. The workshop raised several questions from the participants and these are summarised below.

    - There were confusion about the doors of the machines. What doors could be opened, how often are they and is it possible to have equipment on the outside? The participants had different information regarding the layout of the machines and it was concluded that the drawing were not realistic.

    - The visual model showed that each machine had its own barrel with cutting fluid. This started the discussions about why not a central cutting fluid system? This were new information to some of the participants and questions were asked about the safety and work routines.

    - When the tunnel from the outside door is removed there is a risk that the chill factor from outside climate will affect the products manufactured. High precision and unsteady climate leads to risk, according to the one of the participants. Solutions are discussed but nothing were decided.

    - The jib cranes for supporting the operators are not positioned optimal. Consider the purpose of the jib crane and the functionality when deciding the position.

    These were the main discussions and talking points of this workshop.

12. *Workshop 3.* Workshop 3 were also held on the 12th of March during the afternoon. The invitation to this workshop were sent to shift managers, operators and safety representatives. In this workshop the participants were also able to walk around the visual model in a third person view. Main topics that were discussed were:

    - During this workshop, once again the discussion about jib crane is brought up. This time from the safety representatives point of view. They wonder about

the weight of the actual product, worst case scenario. Is it possible to lift it without a crane and is it likely that the operators will use it?

- Tool exchange for the machine is discussed. A tool bench is needed close to the tool exchange hatch. In the visual model it seems like the hatch is a little high for most people. Is it supposed to be a ramp of some sort? For explanatory picture, see figure 4.8.
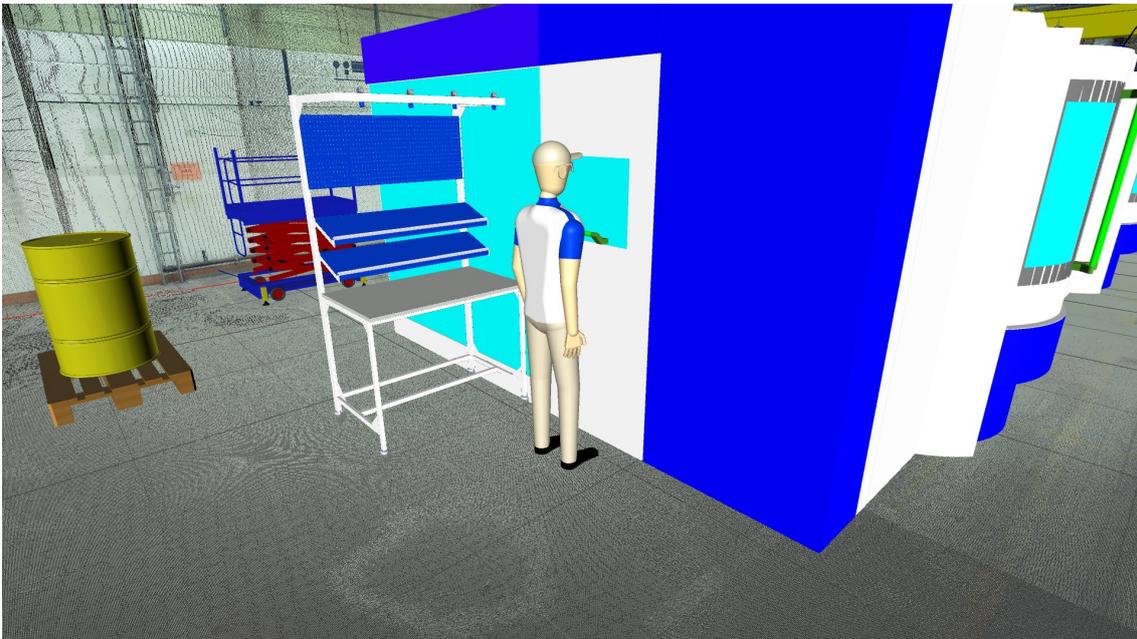
Figure 4.8: Illustration of the work height for a 180 cm tall person.

- Question were raised about equipment for daily routines. For example there need to be compressed air for some tools. This needs to be included in the plan so it is not forgotten.

- The safety representative question whether there is a plan for emergency evacuation? There should not be pallets and such blocking the evacuation paths.

- Included in the daily routines for the operator is documenting the work. For this task a computer station is required. A workstation were added to the model where insp. 2 were previously.

- Another topic of interest were the position of the parts washer. Interesting suggestions were discussed to suit everyone. No permanent position were decided.

13. *Workshop 4.* The last workshop held was the fourth. According to section 3.4, this workshop were a safety risks identification.

   This were the workshop that included most participants. The main topics that were discussed are presented below:

   - It has been decided to use an old parts washer and not buy in a new one. It still an uncertainty where to position it.

   - The process inside the welding room raises a lot of questions. Is it reasonable to handle the weights and is it a fail-safe system? The safety representative

concludes that he is not going to accept the current levels of safety inside the robot cell. To explain what he means, he uses the visual model.

- Once again the discussion about the jib crane is picked up. This time it is mentioned that normal jib cranes will not be used in the daily routines. They are to slow and heavy for the operators to use. The jib crane will not be able to reach two machines as well as the parts washer. Other solutions are discussed and taken into account.

- The pallets in front of the machines are placed on the ground. Preferably they would be placed higher so the operator do not have to bend down to get the parts. It is discussed if the best solution is a table that the pallet is placed on, or if height adjustable pallet lifter are preferred.

14. This version of the visual model shows a modified point cloud where the pallets in the storage area were erased and substituted with a concrete floor. In the corner of the storage area, there will be an inspection area that replaces both insp. 1 and insp. 2, named inspection area 3 (insp. 3). These can be seen in the models lower right corner, see figure 4.9.

Figure 4.9: The pallets in the storage area are removed and a new inspection area is added.

4.2 Interviews

The interviews presented in this section are summarised versions of what was said by the interviewee. At the end of the section the shared opinions regarding the current way of working presented along with the positive opinions and concerns regarding visualisation and workshops.

4.2.1 Project manager

The project manager is very positive to both the workshops and the use of 3D scan data to create a visual model of the factory floor. The interviewee thinks it is a great way to gather all the right people for making certain decisions. The possibility to review an accurate visual model with for example managers and safety representative is a great feature.

The interviewee thinks that the use of a visual model in combination with workshops can save a lot of time in projects. The main reason for this according to the interviewee, is that many small but time consuming problems that would be eliminated with the use of a visual model in 3D. An example was of such a problem was given by the interviewee: For one of the initial layouts the machine placements were planned with the use of 2D drawings of the factory floor. Plans were also made for the supporting functions around the machines. When the layout was visualised in 3D and reviewed at one of the workshops it was clear that the machine placement had to be changed. With the current positions the machine was blocking access for lifts to access the cable ladders on the walls behind the machines. The layout had to be revised.

"There is no doubt that is would be easier to convey a message to management with the 3D model".

With the use of a visual model and workshops the project can be more streamlined and many of those small but time consuming problems would be eliminated. The interviewee also think better end results could potentially be achieved. With the model and the workshops more people can contribute with inputs earlier in the process. For example operators that are the ones actually working in the environment.

The technique with 3D visualisation does not only help with the actual layout planning but is also a good tool for communication. "The communication aspect is probably strongest side of the visualisation". Not only to those that work in the project but also to convey a message to higher management. This type of technology could make that process easier. It is hard to fully understand a layout plan just through a PowerPoint with 2D drawings.

The lead time in a project like this would probably be reduced, because so many unnecessary discussions would be avoided. There are many unnecessary steps in the current way of planning the layout which the 3D visualisation could eliminate.

The interviewee point out the importance of the technology to be easily available and user friendly to be used within the company. There might be a barrier to get past in implementing a technology like this. The people attending the various workshops must know what they are good for so the workshops can be as constructive as possible. There is also a risk if the workshops have too many attendants, that there will not be enough detailed discussions. But the exact composition of the workshops has to be further evaluated to get a good balance.

4.2.2 Shift manager

The shift manager were also very positive to the use of 3D visualisation and workshops. The model of the factory gave much more insight on how it would actually look like and that made it easier to come up with inputs regarding the production area. The possibility to see the heights and size of equipment in the production environment is fantastic. It is

better when a model like this is used so decisions can be made earlier before everything is already in place. The visual model combined with the workshops acts as a virtual Gemba before everything is in place. The shift manager is completely convinced that time can be saved as well as unnecessary mistakes in the design process.

"It very good because everyone can see and understand the same picture"

This way of working can help with eliminating risk and avoid costly mistakes when planning the production area. The workshops opens up the possibility to use the knowledge that the operators have and use that knowledge better when building new production areas. The visual model is a great tool to get their inputs about the production.

The shift manager is also surprised that this kind of technology is not adopted by the company already. It would also be great if actual production simulations could be run with a model like this to get even more out of it.

"It should be a no brainier to use technology that is this helpful"

The shift manager however wonders how hard it us to implement the technology. How much resources would be needed and how much would it cost?

4.2.3 Project leader machine investments

The interviewee is very positive to the use of 3D visualisation and workshops. It is a very good tool to avoid making mistakes in the design process. Decisions could be taken earlier based on an accurate model of the factory floor instead of pushing decision making forward.

"I cannot understand why we are not already using technology like this"

There can be a lot of unnecessary work if one does now visualise this way. Example: Something is decided regarding the layout and is anchored within management. Plans for a way of working in the factory is made with these plans as a basis. The way of working is even approved by management. Then someone realises that a ventilation duct or a beam is hindering that layout and everything has to be redesigned. Those are things that are really wasteful and could be prevented.

Another problem is that decisions are taken too late which leads to delays. Sometimes the delay leads to unconsidered solutions because of decisions that are taken too late in the design process.

"It is really important to be able to have a model like this as a base for discussions"

It is easier for everyone involved to understand the factory layout and everything around it with the visual model. Therefore it also makes it easier for people involved to come with inputs regarding the factory area.

However there might be questions about how this system would work internally and how to handle it properly. It might also be a struggle to convert to this way of working and getting everybody on board. Even though it feel like a great tool for developing factory areas it is hard to motivate the investment with hard facts.

4.2.4   Manufacturing lead

The interviewee were very positive to the use of 3D visual models within the company. The workshops with the visual model gave good inputs from stakeholders that were attending. It was a great opportunity to gather people that were relevant for the project and be able to see the workshop in a detailed way.

"Us that have been involved in the project for a long time thinks many things are obvious regarding the project. But the things we think are obvious can be hard to convey to other people within the company. The model would in many cases make it easier"

Working with the visual model definitely makes it easier to avoid mistakes in the design. It is so much easier to convey and discuss how the layout is going to be. It is easier to explain how the work is going to be carried out using the visual model and also to get a good perception how much space is available around machines etc.

"It is easier to convey a message and discuss when you have a 3D model as a base"

It is also great to be able to have a standard library of CAD objects to quickly modify the production layout. Being able to move objects and turn them around an axis is a great feature. Using a visual model like this would make work easier and because of that save time.

However it is hard to see how much this would cost to implement and use within the company. Should this technology be used for new factories, redesign of factories or both? Who would be responsible for the competence needed? Except for costs the interviewee can not name any downside to the use of 3D scanning.

4.2.5   Detail responsible production technician

The visualisation and the workshop seems like a good thing. It is great to be able to see the whole factory floor modelled. The possibility to move stuff around in real time is good to test ideas straight away. The model is great to have as a base for discussion and have something to talk around.

"I think it can make the discussions easier and more clearer, definitely"

The possibility to see the available space when all objects are in place is great for getting a perception about the remaining space on the factory floor. This kind of visual model can be a help in making sure one is taking the right decisions. Some people involved in the project know what the factory looks like, but for many other people involved the model is a good thing.

But what does it cost to use the system? What is the actual cost-benefit of using a system like this?

4.2.6   Chief manufacturing engineer

The interviewee was impressed by the visualisation of the factory. However in this factory layout 2D would have been enough suit the needs of the project. In designing a new area in the factory there is no point in using 3D. As an aid for working it is not very

revolutionising. There were a lot bigger problems in this process that will not be fixed by using this kind of technology.

The interviewee thinks that in upcoming projects when redesigning a part of the factory the technology could be very helpful. When there are tight spots with machines and hard to visualise and estimate whether solutions can be implemented. In that case the visualisation would be much more beneficial for a developing team. When investments are really cost intense the laser scanning technology can be very beneficial.

"I think some mines could be avoided in redesign projects with using the laser scanning technology"

The workshop in combination with a visual model is a great tool for better communication. Especially in projects that have many people involved. That is the biggest strength with the model.

4.2.7 Shared interviewee opinions

The list below shows the shared positive opinions of the interviewees.

- Positive towards implementing 3D scanning and workshops.
- The technology can help to avoid mistakes and eliminate risks.
- Good to be able to see the same visual model and use that as a base for discussions.
- The visual model and the workshops is a good tool for communicating.
- Easier for everyone involved to understand the solution and see the same picture.

The list below shows the concerns regarding 3D visualisation.

- Is it hard to use?
- What does it cost to implement?
- How can investing in the technology be motivated?
- Who would be responsible for the model?
- How much training is needed to use the software?

4.2.8 Shared opinions about the current project

The list below shows the opinions regarding the current project.

- The communication between the two projects has not been satisfactory.
- Miss-communication between departments causes delays and extra work.
- Scopes and goals between the projects are not aligned.
- Changes within the project are not properly cleared with all stakeholders and creates ripple effects.
- It is hard to retain information if meetings are missed. No protocols are written during meetings.

4.3 Hardware and Software support

The first setup to test the performance did not give satisfying results. Running ANF remotely was considered to be unusable with long load times and running slow. Also, the extra step to download the point cloud file from TeamSite and wait for that download to complete before being able to open it in ANF was very time consuming.

The second setup gave satisfying results. Running ANF locally gave much better performance when viewing the point cloud. Since the point cloud file was stored on a network hark drive it could be opened up straight from ANF without having to download it locally first. A representation of the setup can be seen in Figure 4.10.

Figure 4.10: Illustration of the second setup.
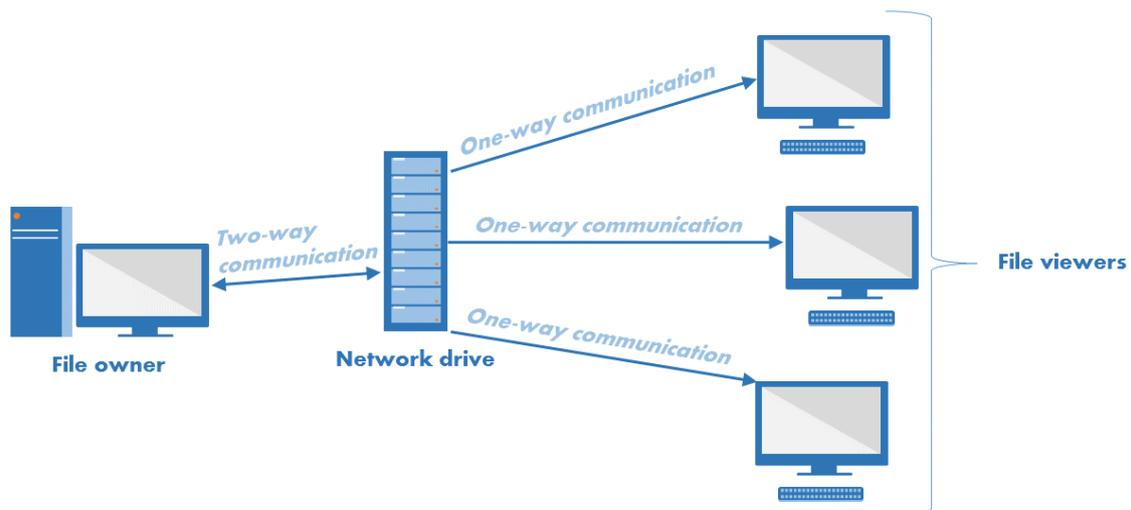
The owner of the visual model saves the file on the designated network drive. Modification of the visual model can only be made by the file owner. Once the file is saved on the network drive office computers within the company are able to open the visual model with their local installation of ANF. Hence, view the current state of the visual model right at their office desk.

5

Discussion

The chapter addresses different topics regarding the thesis work.

5.1 Scanning the factory

One of the factors why this scanning were a success were that the production area were almost free of objects like machines etc. We could therefore cover the entire area with fewer scans. If there would have been objects in the way, we would have to do more scans to be able to see what is behind the objects. This is in theory not more complicated but can be more time consuming.

The results from the laser scanning were satisfying. A recommendation for future scans of factories is to remove as much objects as possible from the area. In our case we did not move electric cables that the electrician were dismantling from previous installations which lead to an area of 8 m^2 with cables. They were removed from the point cloud but still left some visual interference. Removing as many movable objects as possible will result in a better looking point cloud.

5.2 Visual model

During the project the model changed several times, since new decisions were made regarding the layout. The quality of the final version is acceptable, but could resemble reality even further. Some walls along with inspection area 2 and storage containers were removed from the point cloud. Due to that parts of the floor had to be replaced by copying other parts of the floor to fill the gaps. The visual quality of the replaced parts of the floor is acceptable, but could look even better by for example scanning the factory without the storage containers.

Finding CAD objects for creating the visual model was fairly easy and not very time consuming. Autodesk has its own library of standard objects that can be modified to fit the desired measurements. Objects that cannot be found in Autodesk's library can easily be found for free on the Internet as a complement. For GKN, setting up a standard library of common objects to use for visualisation should be fairly quick. This standard library of CAD objects could then be used in all further models made of the factory. With a standard library like that layout alternatives can be created very quickly. That could open up for a quicker and more flexible way in which the layout development is conducted, where results from changes can be seen almost instantly.

It is important to only use verified CAD models. The models for the new machines in the factory were not verified. That meaning that the production development team initially did not know if the machines delivered would look exactly like the CAD model. This is of course an important factor when making a detailed layout plan, to make sure solutions around the machine works in reality.

5.3   Risk Analysis

Risk analysis of a production system is important in finding the right solution. It is hard however to understand all risk and get them written down on paper. The goal with the visual model is of course to resemble reality and it should be easier to identify risks that would otherwise be missed. The point cloud in combination with the CAD objects can be that extra help needed in finding crucial risks that could impact the development negatively. Just during our own participation in the development project problems and risks have been identified through visualising the intended layout. The fact that the visual model is a good tool for identifying risk and avoiding mistakes was also confirmed by the interviewees. One of the interviewees was convinced that the visual model is not very useful when creating a new production system, but rather when redesigning current production areas.

The visual model can reveal smaller problems in the layout. An example of that is again about the chip containers. The created model showed that the standard chip container at GKN wont fit under the machines chip conveyor. So either the machine has to modified or the chip container to fit under the machine. This seems like a small problem but of course it is good to be able to detect problems as early as possible in a development process. Problems regarding the physical layout of the production system becomes clearer with a visual representation of the factory.

5.4   Workshops

Unfortunately the workshops were used to brief the stakeholders about the current situation instead of developing the visual model and adding objects. When reflecting on what really happened during these workshops, one of the conclusions were that almost no decisions were taken. The focus more or less were to describe the process and show what had been accomplished in the model. A lot of questions were raised in the workshop and the answer to most of these were that it is to be decided later on. Not once did we actually decide where to position anything in the model during the workshop, instead we moved around some of the objects to see where they fitted the best.

The intent were that these workshops would be used as opportunities to make decisions based on the visual model. A reason for no decisions being made could be that decisions have a tendency to be pushed forward and that problems regarding the production area will be resolved at a later time. For example the last minute decision on where to position the machines were taken just before the foundation of the machine needed to be started. The workshops could support earlier decisions if they were standardised as a part of the process of developing the production system.

When the model to use workshops were launched it were supposed to be an iterative process that would generate a complete visual model. Due to the lack of time the workshops could not be repeated as a part of an iterative process. We unfortunately did not have time to carry out the last step in the planned model of workshops. The idea were to have a full virtual safety inspection that could identify the risks of the production system. After discussion with safety inspectors about what they were most interested in they named that ergonomics were the main concern. Since this thesis do not focus on simulation of the production system we found it hard to execute this step. This is a very interesting opportunity for future research. However the model could be very useful in identifying the critical areas for ergonomic evaluation, but the actual evaluation would be done separately.

Using the workshops at an early stage gives the possibility to get inputs from stakeholders early in the project. One of the interviewees mentioned that the people that are actually going to carry out the work are the last ones to see the production area. Another interviewee mention the benefits of using the production operators inputs early in the development process since they have so much experience. That could help in making the right decisions early and not have to change the solution in late stages.

5.5 Misses in communication and goals

As seen by the interview results there is a shared view that the two projects have not been able to collaborate in a satisfying way. The main problem seems to be communication and goals for the two project groups. There seems to be somewhat of a missing link between the departments when communicating.

When something about the layout is decided by the project group, for example positioning of machines, the measurements are sent to the facility department to be drafted into the drawings. In this particular example the chip container behind the machine were placed too far back in the layout drawings. This probably happened because the 2D drawings of the machine were hard to interpret. The machine drawing showed the maintenance position of the chip conveyor and was mistaken for the chip conveyor in its normal position. This misunderstanding led to the placement of the machines to be far out from the wall and wasting space in the production area. It could probably been avoided easily if facility would have had the possibility to view the visual model to understand the layout. Even better would of course have been to participate in a workshop to fully understand the layout plan.

Another issue regarding the layout was for maintenance to be able to access the cable trays along the wall above the machines. The initial layout solution did not include enough space behind the machines for the maintenance lift to access the cable trays. Again the layout had to be revised because of late changes in the project. Some of the revisions of the layout have been small but some revisions have been larger which has led to the entire layout being changed.

The example with the access to the cable tray could have been avoided by seeing three dimensions instead of two and involving the maintenance department through a workshop. And the position of the chip containers in relation to the machine would also been easier to understand for the facility department if they could see a visual model.

A major change in the layout was because of misaligned goals between the two project groups. The goal in the layout group was to plan for four machines and in the product group the goal was to be able to have seven machines. This resulted in a four machine layout alternative that was completely scrapped. In other words, many hours of planning a four machine layout were completely scrapped because of misaligned goals between the two projects. And this was fairly late in the project.

To avoid unnecessary mistakes in the layout design process the communication between stakeholders should be improved. In this particular project many unnecessary hours have been wasted because of poor communication between stakeholders, and misunderstandings. Detailed layout plans have been completely scrapped in late stages of the project. To avoid these mistakes workshops in combination with a visual model could help. The workshops would involve the necessary stakeholders in the decision making and the visual model would help in everybody seeing the same picture and understanding the layout. The visual model could also minimize the risk of making decisions that are not applicable in reality, since a model of the actual production can be visualised.

Working in a more structured way would in this case also resulted in more detailed plans regarding the layout in an earlier stage. Since the layout plan changed in such late stages of the project detailed plans regarding the production area was non-existing. Even though 7 flows were used in order to cover all important aspects of the production area it will not help if the scope constantly changes. And if the scope changes it is hard to make decisions in time and make detailed plans for the production area. The layout plan has changed many times since the first visual model was created. However we are confident that the wasted time on all those layout alternatives could have been avoided with the use of the workshops and the visual model at an earlier stage in this project. The fact that one of the project groups were planning a layout for seven machines and the other for four machines would have been caught much earlier.

5.6   If the model and workshops were used earlier

Since the layout have changed so much since we joined the project much focus has been on the rough layout plan. If more decisions regarding the layout had been made before we joined the project the visual model and the workshops could have been used to create more detailed planning regarding the production area. But due to all the late changes we could not explore how well the workshops and the model could support more detailed decisions regarding the production area.

But as mentioned earlier, if the model in combination with the workshops had been used at an earlier point in the project there would most likely been more focus on detailed planning at the later stages of the project.

The late changes in the project might undermine the final solution, since the lack of time may lead to the solutions not being evaluated properly. Decisions cannot be pushed forward to the point where a solution is chosen just to not break the deadline for the realisation of the production system. The late decisions however seems to stem from the two projects working towards different goals and misses in communication between cross-functional teams.

5.7 Hardware and Software support

GKN have good enough hardware in the office computers to view visual models. By having a network drive designated for the visual model it can theoretically be opened and viewed from any computer within the company. The only thing needed is a local installation of ANF. So the model could potentially be viewed by anyone right at their own desk. That could be useful for quickly being able to understand and give feedback on layout solutions.

Creating and modifying the model cannot be done with the average office computer, so for that purpose more powerful hardware would be needed. The powerful computer should preferably be with the production development team where one person is responsible for the visual model. With every update a new version can be saved on the network drive, so everybody always sees the same version of the model. That could be very beneficial in terms of everybody always seeing the same picture of the production system. The updates of the model could also have a change log to describe the changes made between each version. That would make it even easier to understand the model and what reason there were for every change made. That could help people to retain information that they miss in meetings, since no protocols are taken at the moment.

Aside from the computers, a license for ANM is needed to create the actual model of the factory. The actual scanning could be made by an external consult that can deliver a complete point cloud. In other words, to try the technology GKN do not have to buy their own scanner. So there are no big hills for GKN to overcome, to implement the technology in their production development.

6

Conclusions

This thesis aims to answer the research questions that were formulated in the introduction chapter. These questions are answered below where the questions are stated in italic followed by an answer.

- *How can the use of 3D scan data save resources during production system redesign?*

  The use of 3D scanning in the pre-study phase of production development can shorten the lead time by quickly gathering a complete and detailed picture of the area of interest. The point cloud can be viewed by stakeholders right at the office desk and used as base for the development. Stakeholders don't have to physically visit the area.

  During the concept design and the final design phase changes to the production layout can be made instantly, instead of forwarding the changes to another department. This can shorten the lead time by not having to wait for the changes to be made and minimize the risk for misunderstanding between the departments.

  When all departments are involved in the development in a structured way, decisions can be taken with more confidence instead of being pushed forward. Instead of being uncertain about a decision and pushing it forward, decisions can be taken with confidence.

  By viewing an accurate model of the production area and involving relevant stakeholders early in the development process the risk of making mistakes is minimised. Inputs are taken in to account early in the development and lowers the risk of making non-applicable solutions. When using workshops in combination with a visual model, less time can be spent on developing solutions.

- *How can the use of 3D scan data facilitate the production system development?*

  There are also possibilities to use the visual model as a means of communication. Anyone can quickly understand the production area and see the same picture. That can eliminate unnecessary discussions and misunderstandings regarding the production area.

  The key is to work with workshops involving the stakeholders and being able to have a shared view of the production area. The stakeholders can through the visual model and workshops come with constructive inputs, that may not come up otherwise. A visual model can also help project leaders to convey information about the production area to upper management that ultimately make decisions.

  By visualising the production area and create a shared understanding, risks that

may be hard to realise through specifications and 2D drawings can be identified. The visualisation can help finding risks that otherwise would not be thought of.

Information regarding the production area can be found in in the visual model and accessed from any computer.

- *Who within the company can benefit from the visual model during the production system development process?*

There are several important stakeholders that can benefit from the visual model. At the beginning of the development process the facility management can use the 3D laser scan data to verify the 2D drawings. Interviews shows that almost every stakeholder within the project consider the visual model to be an important tool that increases the understanding. The Manufacturing lead explained it as "The things that we think are obvious can be hard to convey for other people in the company". Examples of other stakeholders are; Maintenance, product development, production development, logistic planner, first-line manager, facility management and project leaders. Each stakeholder benefit are stated in appendix B.

- *What prerequisites needs to be fulfilled to be able to use 3D laser scanning and a visual model?*

First off, GKN need to decide whether this technology is something that would be interesting to invest in. If so GKN can choose between purchasing a scanner, use an external consultant firm or rent a scanner. To try the technique within the company and to build competence around laser scanning a rental option could be beneficial as a start.

The visual model can be created in the software Autodesk Navisworks Manage. A standalone license needs to be purchased. Competence for operating this software need be acquired through training and education. Working in the software, combining point cloud and CAD objects requires a high performance computer.

- *How well can GKN's current software and hardware support editing, viewing and use of 3D scan data?*

The current software does not support editing of 3D scan data or creating a visual model with point clouds. For the purpose of editing, separate software must be purchased. For the purpose of editing a powerful computer is needed.

To view a visual model there are free software from Autodesk. The average office computer at GKN is powerful enough to view a visual model and use the basic features in the software.

7

Recommendations

Before GKN considers using laser scanning in the production development the current way of working should be addressed. The two separate projects (product development and production development), should have the same management or be closer linked together during the development process. In the current project composition decisions are taken separately in the two projects which can create negative impacts for the overall goal. In the future it must be made sure that the goals and scope of the project are the same for all parties.

If laser scanning is used at GKN for production development and redesign we suggest that the production development team should consider using the production development model [20]. In that production development process laser scanning data can be used from the Analyse and Measure phase. A designated employee should be responsible for the visual model and continuously update it towards the network drive, so a current model is always available to view. Together with the updates we suggest that a change log is used, to quickly see what has been changed regarding the production area and the reason for the change.

To cover all necessary parts of the production the 7 flows concept in combination with workshops should be used. 7 flows can help in making sure no aspects of the production is forgotten, and the workshops are necessary to take stakeholder inputs into consideration early in the development process. By involving stakeholders early in the development the right decisions can be taken with confidence. The development will follow the iterative LAMDA-cycle to continuously develop the visual model. The visual model will be the base for discussions, communication and analysis of the production area.

The make sure that gates in the production development can be passed in time and with confidence workshops involving necessary stakeholders should be a part of passing gates. Before a gate is passed every stakeholder can understand the solution and come with inputs regarding the current solution.

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A

Appendix 1

A.1 Interview guide

Denna intervju görs som ett undersökande verktyg för examensarbetet i *Utilising 3D Laser Scan Data for Redesigning Production Systems at GKN Aerospace Engine Systems.* Intervjun är inte ämnad att spridas till allmänheten utan endast som material i projektet. Om intervjuobjektet önskar vara anonym tillgodoses denna önskan.

Undersökningen är kvalitativ då vi endast ämnar att intervjua få personer. Strukturen för intervjun är semistrukturerad för att intervjuobjektet skall ha möjlighet att utveckla svaren och ej känna sig begränsad.

1. Vad är din titel och vilken position har du på företaget?

2. Vad har du för roll i i utvecklingsarbetet för den nya produktionsytan i X-fabriken?

3. Hur länge har du varit involverad i projektet?

   _____

4. Vilket arbetssätt använder ni när ni designar ett produktionssystem?

5. Vilka problem är det vanligt att ni stöter på under liknande projekt?

6. Hur kommunicerar ni information mellan projektets intressenter?

7. Upplever du kommunikationen mellan olika parterna i projektet fungerar tillfredsställande?

   (a) Vilken kommunikation är det som inte fungerar?

8. Hur arbetar ni med att kalkylera risker i projektet?

   (a) Tycker du att det finns några risker i projektet för tillfället?

9. Hur och när tas beslut?

   (a) Vissa beslut i projektet har tagits relativt sent. Vad kan vara orsakerna till detta?

   _____

10. Vad är ditt intryck från den workshop som du deltagit i?

11. Hur upplever du att tid kan sparas genom att arbeta med visualisering?

12. På vilket sätt tror du att projektet kan undvika ökade kostnader genom att arbeta med workshops?

13. På vilket sätt tror du att användningen av 3D-visualiering kan påverka ett projekt som detta?

14. Ser du några direkta fördelar/nackdelar med att använda sig av 3D-visualisering?

B

Appendix 2

Table B.1: Stakeholder benefits of using 3D scan data and visual model.

Stakeholder	Benefits
Production development	- Quick layout changes. - Verify solutions. - Gather other departments around the same picture and get inputs throughout the production development process.
Facility management	- Verify drawings. - Detailed visual model of the area of interest.
Product development	- Better inputs regarding the production from the product development point of view.
Logistics	- Visual model helps the planning of material and material flows.
First-line managers	- Be able to involve the operators competance early in the development process. - Use the first-line managers experiance in the production layout. - Knowledge for production planning.
Projects leaders	- Easier to convey messages to upper management. - Easier for everybody to understand the same picture. - Good for project overview.
Maintenance	- Better inputs regarding production from maintenance point of view.