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In Context Manufacturing Development using 3D Laser Scanning at Volvo Car Corporation

Master's Thesis in the Master's Program Production Engineering

ERIK SIMONSSON
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Cover:
The cover is a point cloud illustrating a small part a Volvo Car Corporation factory.

Göteborg, Sweden, 2015

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Erik Simonsson & Jens Johansson

Abstract

Manufacturing companies of the 21th century are today facing new challenges on a more unpredictable market, driven by a growing global competition. This requires shorter development cycles and ramp up periods which decrease the room for error and increase the need to verify both the product and the process before start of production. By integrating virtual tools in the development process it is possible to early visualize, analyse and forecast the impact a change in design has on a production system.

The technology of 3D laser scanning, which captures scan data, offers the possibility to fast and accurate create a virtual representation of an entire factory. With access to this virtual representation, future changes can be developed and evaluated virtually in the actual factory environment.

The aim of this thesis is to show how scan data can be integrated in the manufacturing development at Volvo Car Corporation in order to shorten development and implementation lead times. Three case studies were performed based on an initial current state study in order to investigate how scan data can support the development process. Based on the results from the case studies a conceptual model for how to work with scan data was developed. The conceptual model was anchored within the organisation during a workshop with internal experts from the fields of IT, scan data and method development.

The conceptual model present a way of working with scan data throughout the whole manufacturing development process at Volvo Car Corporation.

Keywords: *Production systems, Manufacturing development, Virtual verification, Virtual tools, 3D laser scanning, Scan data, Point cloud, In context development*

Definitions

Scan data – Data captured with a 3D laser scanner

R&D – Research and Development

ME – Manufacturing Engineering

MDP – Manufacturing Development Process

In context – An accurate virtual representation of the factory environment

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1 Introduction

This chapter includes an introduction to what the reader can expect from this thesis and its background.

1.1 Background

Manufacturing companies of the 21th century are today facing new challenges on an unpredictable market driven by a growing global competition. New products and variants are today being introduced more rapidly on markets than ever before. In order to stay competitive, companies have to focus on designing manufacturing systems that allows for a high level of responsiveness towards market changes and customer needs [1]. This can be done by focusing on developing a reconfigurable production system and decreasing lead times concerning the product and process development [2]. Shorter development cycles and ramp up periods decrease the room for error and increase the need to verify both the product and the process before implementation [3].

By integrating virtual tools into the planning process it is possible to visualize, analyse and forecast the impact a change in design has on the system [4]. Virtual tools does not only speed up the development process and lower its cost but introduce fundamental changes in the nature of problem-solving and has the possibility to further increase the development performance. Being able to make design assessments virtually in an early stage, enables identification of potential problems and the possibility to solve these problems [5].

However, it is still possible that problems occur after the developed solution has been implemented in the factory. These problems derive from decisions being made based upon inaccurate information and visualisations that were hard to interpret and understand [6]. If such a misunderstanding occur it can result in errors being included in the implemented solution instead of eliminating them. These errors are often only evident once the installation has been made [7]. In order to avoid these misunderstandings a realistic virtual representation of reality must be created. Virtual representations created with traditional virtual tools often lack a holistic approach, details are either lacking or are inaccurate and/or unrealistically portrayed [4].

Therefore the technology of 3D laser scanning is introduced. From 3D scan data that has been captured a point cloud, or a 3D model, is created which is a virtual representation created with spatial data of the real world. The technology offers great speed and accuracy which makes it possible to create a 3D model of a whole factory. With access to this model future changes can be modified and evaluated in the factory setting environment [6]. A hybrid model is then created, a model where CAD objects are imported to the point cloud in order to visualise the future factory – in context.

1.2 Aim

The aim of this thesis is to show that scan data can support decision making concerning process compatibility in the manufacturing development process at Volvo. This in order to increase the efficiency of the processes and accuracy of the output.

1.2.1 Research questions

In order to reach the aim the following research questions have been formulated.

Research Question 1:

How is scan data today applied in the manufacturing development process at Volvo Car Corporation?

Research Question 2:

How can scan data support the manufacturing development process at Volvo Car Corporation?

Research Question 3:

How can scan data be implemented in the manufacturing development process at Volvo Car Corporation?

1.3 Scope and Delimitations

This study covers the investigation of the possibility to integrate scan data in the manufacturing development process. The development process within the manufacturing engineering department at Volvo Car Corporation consist of the following sub-processes:

- Manufacturing strategic planning and business compatibility
- Virtual product and process compatibility
- Physical product and process compatibility
- Current model process

The assembly system that will be investigated is the final assembly shop, here after called trim and final assembly, at Volvo's car production plant in Torslanda. Scan data and point clouds that are used in order to create a realistic visualisation of the assembly system have been captured prior to the start of this thesis, using available technologies and applications.

1.4 Research context

Volvo Car Corporation started their car production in Göteborg, Sweden 1927 and today Volvo produces cars in three countries, in Sweden, Belgium and China, as in Figure 1.4.1. In Malaysia Volvo has a so called knock-down plant where pre-produced cars are assembled. In the car manufacturing plants three different areas exist: body shop, paint shop and trim and final assembly.

There are four Volvo factories located in Sweden. In Göteborg the head quarter is located together with the Research & Development and the Manufacturing Engineering department which develop and industrialise new car models for all different plants and markets globally. In Göteborg Volvo also have a car production plant. In Skövde, engines are produced, in Floby engine components and in Olofström body components are manufactured. [8]

In Belgium, Gent, a car production plant is located and in China there are two car production plants which are located in Daqing and Chengdu. In Zhangjiakou, China, Volvo have an engine plant and in Shanghai an engineering and design centre. A research & design centre is located in

Denmark, Copenhagen, and in USA, Camarillo a design centre is located. Recently Volvo announced that a car production plant is going to be built in the USA [8], [9].

Figure 1.4.1 Volvo's car production plants in the world

By the year of 2020 Volvo Car Corporation (VCC) aim to increase their total sales figures by almost 100% compared to the year of 2013 [10].

The company has during recent years changed focus towards becoming a premium brand and as of today Volvo manufactures one of the world's safest premium cars. Globally Volvo is a rather small car manufacturer in the premium brand segment, compared to companies such as Audi and BMW. However, there is one aspect of Volvos' production system that makes it unique. As of today, Volvo doesn't have dedicated assembly lines for one model or variant instead the cars are manufactured on one mixed assembly line. This demands high flexibility due to reoccurring introductions of new variants and models. At times new innovative process technology is introduced with a new car model, which have to be adopted to fit present models and variants. Also, at times new car models needs to be adapted to existing technology within the factory. This in combination with a high demand of flexibility and a global expansion, rather complex situations are created. This situation calls for an increased efficiency and effectiveness during the development and production of both current and new car models.

In order to increase the sales volume new factories must be built and the existing ones rebuilt in order to increase the capacity and to allow for more frequent product changes caused by shorter product life cycle. This requires a more efficient and effective development process for the product and process.

2 Research Approach

This chapter contains the research approach which the process and applied methods chosen in order to answer the research questions.

In order to understand how scan data can support decision making connected to the manufacturing development process at Volvo this thesis has required several different activities. A flowchart of the different activities can be seen in Figure 2.1 below. The methodology used has mainly been of a qualitative approach, this since it offers the possibility to acquire personal data from the person of interest in the company [11]. Initially the project scope and delimitations were defined. An initial literature review was carried out in parallel with a data collection. This led to a current state study, which was performed in order to answer research question 1, covering the current use of scan data within manufacturing engineering at Volvo. The input data for the current state study consisted of semi structured interviews, internal corporate documentation and observations made by the authors. Based on the current state study a multiple-case study was conducted in order to:

- Gain understanding of the process for taking decisions in different stages of the Manufacturing Development Process (MDP) at Volvo and to
- Identify how scan data could support stakeholders within the MDP.

The result from the case study research will answer research question 2.

Parallel to the case studies a literature review was carried out in order to better understand how to design and develop production systems virtually, how to design and implement new IT systems. Based on the current state study, the results from the case studies and a literature review a conceptual model for how to work with scan data was developed. The conceptual model in combination with the literature review will answer research question 3. This conceptual model was then anchored within the organisation during a workshop with internal experts from the fields of IT, scan data and method development.

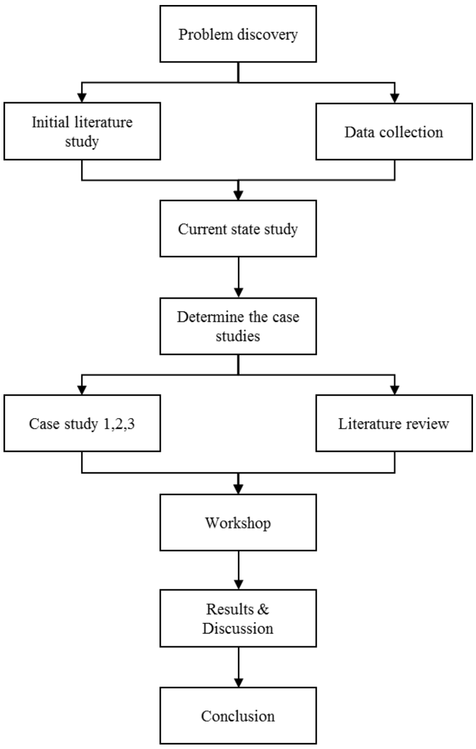

Figure 2.1 Flowchart of activities

2.1 Defining a stakeholder

The challenge to achieve success in a project is the art of managing stakeholders, or at least the conflicting wishes from different stakeholders. The question of timing is also essential. Satisfying all stakeholders' requirements at launch is almost impossible [12]. An example of this is the Oresund link between Malmö and Copenhagen:

> *"If for instance the initial build-cost of part of the bridge could have been reduced to save money by using inferior materials and make the construction project appear to have performed better, the impact would probably then be seen on the longer-term objectives – when maintenance costs are likely to be higher as a result."* [12, p. 76]

Seeing the project outcome as deliver of a value rather than a product is one approach to maximise the overall value of a project. This approach would consider the stakeholder analysis as an analysis made in order to maximize the overall value of the project [12].

A stakeholder is any individual or group with an interest in the project, process or outcome. This means that most projects have more than one stakeholder or group of stakeholders. Who are the stakeholders, what do they want of the project and how will this impact the process or the outcome? Different stakeholders have different focus of their attention; some focus on the input, others on the process or on the outcome. The internal stakeholders are typically those connected to the process, e.g. project members and their governances. Core external stakeholders are people outside the project itself but persons critical for to the success of the project.

2.2 Determining the stakeholders

In order to classify a participant from the case studies as a stakeholder a weighting of each role was conducted for each case. An index between one and five was determined for each role. One representing a low possibility to integrate scan data and five representing a high possibility to integrate scan data into their work methods. The index along with a focus of attention (reference chapter 2.1) was assigned to each project participant, for each case. Each focus of attention was assigned an importance factor of either 1 or 2. Input received an importance factor of 1, process a factor of 2 and output a factor of 1. The three different focuses of attention are defined as following:

- Input is defined as if the role contributes to the input.
- Process is defined as if the role contributes to the process.
- Output is defined as if the role is affected by the output.

Work responsibility	Focus of attention			Index
	Input	Process	Output	
Role	1 or 0	1 or 0	1 or 0	1-5

$$\text{Weighting of role } = Index * (Input + (2 * Process) + Output)$$

An example for calculating the weighting for role X if he or she is contributing to the input and process, but not to the output and an index of 4 is assigned:

$$Role\ X = 4 * (1 + (2 * 1) + 0) = 12$$

The role's weighting in each case was then added up to get a total score for the role.

2.3 Data collection

This chapter presents the methodology that was used in order to collect data during the thesis. A qualitative approach was considered suitable due to that the area of research was previously unknown to the authors and was relatively unexplored within the literature.

2.3.1 Case study research

Using a case study approach enables the authors to gather data from a variety of sources in order to gain understanding and insight on a specific phenomenon. This due to the fact that case studies allow the authors to compile and present data collected through multiple methods. When designing a case study it is important to take certain aspects into consideration. First off it is important to take necessary steps towards ensuring the validity and reliability in the study. People conducting case studies are also prone to overgeneralizing. Yin [13] is of the belief that in order to avoid overgeneralizing the authors should try to generalize findings to theories.

The case study research conducted in this thesis was designed according to Baxter [14] and is presented in Figure 2.3.1.

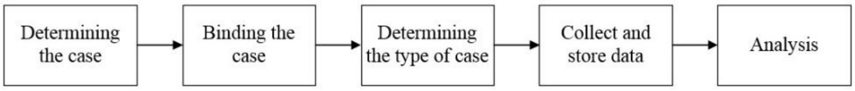

Figure 2.3.1 Case study design according to [14]

The five steps of the case study research model are presented below.

1. *Determining the case of analysis*
   Here the researchers are supposed to determine what the case is, what should be analysed, based upon the research questions.
2. *Binding the case*
   Once the authors have determined what the case will be, consideration has to be made regarding what the case will not be. Boundaries should be placed on the case in order to avoid trying to answer a question that is too broad, the case should remain relevant to the scope of the thesis.
3. *Determining the type of case*
   The researches should now determine what type of case study that will be conducted, according to definitions by Yin [13]. The purpose of the case study should guide the selection of the case type. The authors must consider which case design that allows for the best understanding of the phenomenon.
4. *Collect and store data*
   Data should be collected through the usage of either qualitative or quantitative methods, multiple data sources should be used in order to increase the credibility of the study. Using multiple data sources also contributes to increase the authors understanding of the phenomenon. One important aspect of collecting data is to effectively organize and store the data. Yin [13] suggest using Computer Aided Qualitative Data Analysis Software (CAQDAS) due to its possibilities to store and organize data.
5. *Analysis*
   An analysis of the gathered data is then performed.

2.3.2 Qualitative data collection methods

Less structured methods allows the authors to focus on the phenomena being studied and offer flexibility and the ability to individually tailor methods [11]. Therefore, semi-structured interviews, observations an internal documentation was chosen as means to collect data.

2.3.2.1 Semi-structured interviews

Semi-structured interviews was designed with certain main topics, in order to ensure that particular points were covered by each participant, and also to allow new issues or topics to emerge during the interviews. An interview guide was created, presented in Appendix 1, according to Wilson [15].

2.3.2.2 Participant observations

Participant observations were made by the authors during different activities and observations were recorded by using notes. Observations was used in order for the authors to overcome differences between what participants during the study said and what they actually do. This helps the authors explore and uncover different behaviour or connections which the participants themselves haven't identified [16].

2.3.2.3 Documentation

Internal company documentation was collected for the same reason as to why observations were made.

2.3.3 Coding: a qualitative research method

Coding or indexing is used in order to organize and conceptualize the data that has been collected throughout the qualitative study [17]. The coding in this thesis has been performed according to the methodology presented by [18]. The first step, once the data has been collected from the relevant interviews, is to identify repeating ideas. This is done by searching for words or phrases that were often used repeatedly by more than two interviewees. The repeating ideas that are carried over to the next step of the coding process should be related to the aim of the thesis. The second step of the process is to group common repeating ideas under themes. Depending on what the repeating ideas express the theme is then named [18].

3 Theory of reference

This chapter will present fundamental theory of scan data and applications for scan data as well as theory regarding Volvo's manufacturing development process.

3.1 Reconfigurable and Flexible Manufacturing Systems

In the 1980's the concept of Flexible Manufacturing Systems (FMS) was introduced in order to satisfy the customers need for mass customization, and the increase in product variants which followed [19]. The traditional manufacturing system, the Dedicated Manufacturing Line (DML), which purpose is to produce a single part or product was ill suited to meet the new shift in customer needs [20].

Flexibility within a system can be viewed as the ability to assume different states in order to adapt to different requirements with little effort, without loss of performance, for a negligible cost and in a short amount of time. However, it's quite common to build in too much flexibility within the manufacturing system, which results in that the customers has to pay for unused flexibility. DML represent a possibility of high productivity but no flexibility, FMS on the other hand offers the flexibility but is not as cost effective as DML [20].

During the 1990s the Reconfigurable Manufacturing System (RMS) was introduced in order to address the problems of the FMS and DML. RMS intend to reduce excess capacity and functionality of the manufacturing system in a cost efficient way while maintaining a high productivity [2].

Today manufacturing companies face global competition with a rapid introduction of new products and constantly varying product demand [19]. In order to stay competitive in this environment companies must design manufacturing systems that allows rapid response to market changes and customer needs. Responsiveness is expressed in what speed a plant can meet changing business goals and produce new product models. By adopting the design principles of RMS a higher responsiveness can be achieved [2].

3.2 Digital Factory

The concept "Digital Factory" describes the idea of a network with digital models, methodologies and different applications that integrates the planning and design of a production system with the production process itself [21]. It represents an environment where virtual models replace reality [21]. Virtual models enables the possibility to optimise the design of a solution and also to verify different conflicts before implementation. The development and production of a product will only be initiated if a simulation show that both the product and production will meet pre-defined requirements [22].

3.2.1 Application areas of a Digital Factory

The basic work object within a digital manufacturing environment is the 3D digital model of a product, a so called digital mock up (DMU) [22]. Already within the development phase it is possible to evaluate and optimise products, processes and production systems by applying 3D visualisation tools and modelling techniques. The result that can be achieved by applying this methodology is a reduction in time to market and a significant cost reductions [23]. Today it is possible to create 3D models of shop floors in CAD systems, which is advantageous when designing non-existing productions systems. However, there exist no system for designing 3D layouts of an already existing production system [24]. Reverse engineering and 3D laser scanners are therefore introduced in order to create a 3D layout and generate 3D models of the shop floor. The internal logistics chain can be analysed through material flow simulation which enables optimisation of the movement of material in order support value adding activities and reduce inventories [25]. Verification of how a human interacts with the workplace can be analysed with the help of ergonomic simulation. Optimisation of information, material and financial flows in the factory can also be analysed with the help computer simulations of the production system [22].

3.2.2 Advantages of a Digital Factory

The main advantages that can be gained by implementing the digital factory solution according to [22] are the following:

- Possibility to virtually "visit" the factory shop floor
- Process verification before start of production
- Reduction or full elimination of prototypes
- Optimisation of production equipment allocation
- Better utilisation of existing resources
- Reduction in required area

3.3 Introducing change

The introduction of new methods and IT systems can result in different consequences, some of which can be very obvious and easy to handle but others can be subtle and not so straight-forward to deal with. New skills might be required by end users due to that their current job position might disappear and they will be assigned to new roles. The new role may call for another approach than their previous one. For example they might have more responsibility and are therefore asked to make decisions that was previously left to others. The new role could also mean a wider range of tasks.

3.3.1 The business change lifecycle

When implementing a change within an organisation it goes through a lifecycle of five stages: alignment, definition, design, implementation and realisation [26]. The lifecycle is presented in Figure 3.3.1. The business change lifecycle presented below is according to [26].

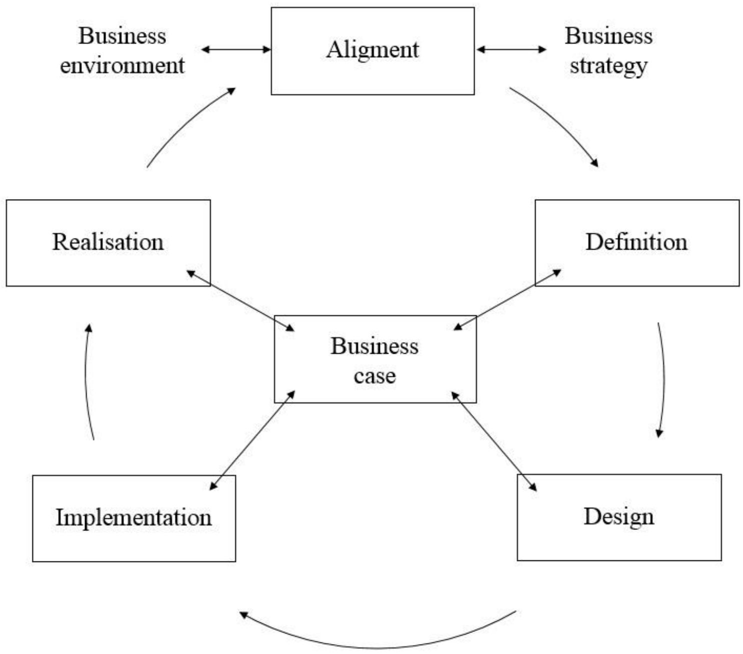

Figure 3.3.1 The business lifecycle as by [26]

3.3.1.1 Alignment

The main activity during the alignment stage is to perform a continuous check that the strategic direction of the organisation react to different challenges, the changes in the organisation and its external environment. The strategic direction of the organisation should connect the organisation to the external environment. This link is described in Figure 3.3.2.

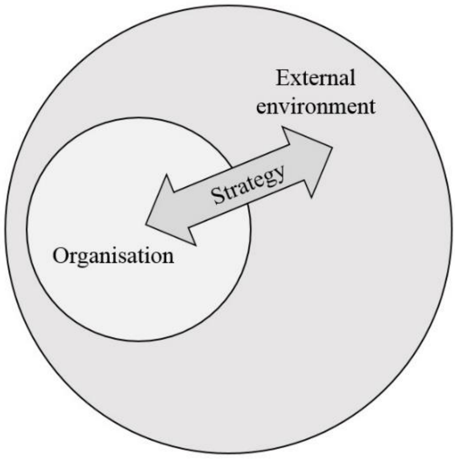

Figure 3.3.2 Strategy alignment model as by [26]

The strategy is to outline how the organisation is going to reach long-term objectives and describe how the organisation intend to change in order to achieve these objectives. The strategy should also help the organisation to identify changes in the external environment that are significant to the organisation.

3.3.1.2 Definition

If the change is to succeed it's necessary to plan for the human dimension of the change. The implementation of a new way of working is not a mechanical activity, the pace of it depends on the people. People are individuals and therefore the rate of the transition has to be adapted to each individual. The change plan can therefore not be set in stone, is has to be flexible enough to handle different problems that can occur.

Another important aspect of the human dimension of the change is the trust between those affected by it and the initiators of the change. If this trust doesn't already exist it has to be developed and in either case, ensure that it remains throughout the change. The project should be based upon a set of ground rules which describes how the project is going to be conducted. These ground rules can be described as principles and should according to [26] cover the following aspects:

- Business values
- Customer focus
- The project itself
- The impact of the project on the employees
- Management behaviour

It's important to incorporate the business values into the project due that the employees are then assured that the organisation is fundamentally the same after the change as before.

3.3.1.3 Design
During this stage the development and design of the new or refined process and different support functions take place. These support functions include:

- IT applications that are to be used in the new process,
- new job definitions connected to the change,
- an updated organisation structure describing the changes in management responsibilities

The aim is to design the process for the actual user and his or hers needs rather than the needs perceived by others. According to [26] this is done by applying techniques such as design workshops, prototyping and demonstrations.

3.3.1.4 Implementation
Throughout the implementation stage of the project it is important to consider the involvement of key staff members and the need for professionalism in the delivery of the change. Key staff members exist in every organisation and doesn't have to be a part of the management structure. However, their experience, personality and contacts employees reach out to them for help and advice, the employees place their trust in these persons. If the change can receive support and be endorsed by the key staff members, the implementation process can speed up significantly. The professionalism of the implementation is important in two aspects. First off, the change team are trying to gain people's confidence and trust. Inconsistent material in presentations, bad attitude and an inability to handle confrontations and questioning will result in that people's confidence and trust will not be gained. Secondly, the implementation process requires communication which is a two way process which require the ability to be flexible and adapt to problems perceived by the employees throughout the implementation.

3.3.1.5 Realisation
The change process was first initiated in order to improve performance in some way. Realisation ensures that the predicted performance actually has been achieved. This is done according to [26] by answering the following questions:

- Has the change been implemented appropriately?
- Have the anticipated benefits been achieved?
- Will the change be sustained? Is it embedded in the organisation?
- Can the change become the basis of further refinements and improvements?
- Can the change be adopted elsewhere within the organisation and hence result in further benefits?

3.4 Technology Acceptance Models
The research area of technology acceptance modelling was initiated by Fishbein and Ajzen in 1975 with their Theory of Reasoned Action (TRA) and since then several different models have been designed and existing models extended [27]. The Technology Acceptance Model (TAM) was introduced 1986 by Davis as an adaptation of TRA to specifically explain computer behaviours [28]. For nearly 30 years TAM have been extended and used in a wide array of applications, mainly in the area of computers and softwares. TAM has been used in areas such as e-commerce, e-governance, e-banking and e-learning and withstood testing across different individuals, settings, cultures and time [29]. This piece of theory will present the TAM model as well as two of its successors, TAM2 and TAM3.

3.4.1 TAM

The outset of TAM, presented in Figure 3.4.1, is that a system's usage can be explained or predicted by the user's motivation, which in turn is affected by the system's design and functionality [30].

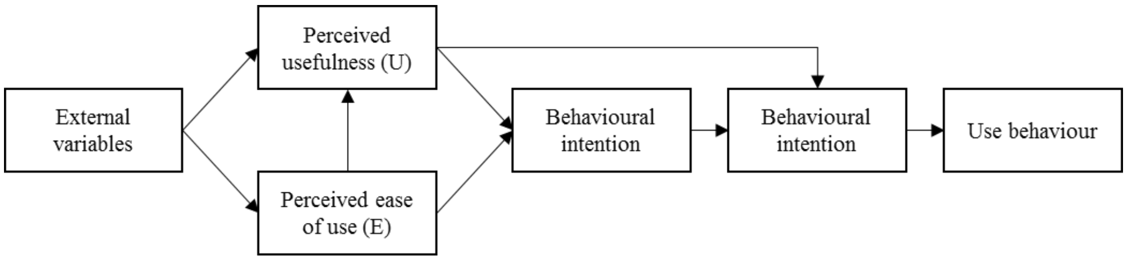

Figure 3.4.1 Technology Acceptance Model as by [28]

TAM uses a socio-psychosocial approach in order to understand the end-user's acceptance towards a new piece of technology using two different belief determinants: *perceived usefulness* (U) and *perceived ease of use* (E) [29]. U is defined as the degree to which a user perceive that a piece of technology will help satisfy his or hers own personal goals [29]. E is according to [29] defined as to which degree the user thinks the use of the new piece of technology will be free of effort.

By combining several studies [29] suggests that researchers generally privilege U over E and are of the belief that U has a more significant influence than E over the actual system use. This relationship was later confirmed by [29] in a study of online communications.

3.4.2 TAM2

The goal with TAM2 is according to [27], to present key determinants to U, based on the original TAM model. These key determinants were added in order to better understand the driving factors to U. TAM2 includes *social influence* and *cognitive instrumental processes* which are believed to be the driving factors to U and is presented in Figure 3.4.2 below.

3.4.2.1 Social influence processes

The social influence processes connects the social factors affecting a person's attitude to use a new piece of technology and is defined as following by [27] and [31]:

- *Subjective norm* – a person's perception that he or she should use a piece of technology, based on what people around him or her thinks.
- *Image* – the degree to which an individual perceives that the use of a new piece of technology will enhance his or her status in their social system.

Voluntariness and *experience* are two moderating factors for TAM2. With direct experience from a piece of technology the *subjective norm* will be less significant and *experience* will be a basis for continual use. *Voluntariness* in the context of TAM2 is a measure that takes the compliance-based effect into consideration. According to [27] the *voluntariness* had a significant effect on the *subjective norm* in a compliance-based, mandatory setting while the effect was non-significant in a voluntary setting.

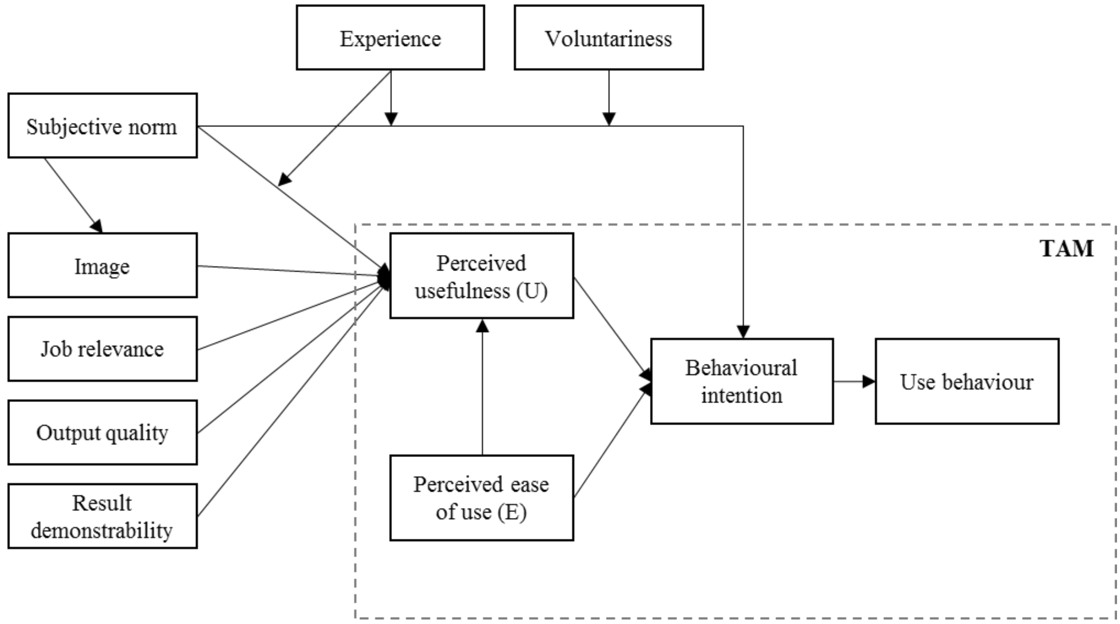

Figure 3.4.2 TAM 2 as by [27]

3.4.2.2 Cognitive processes

In addition to the factors influencing the social processes [27] identifies three different cognitive mechanisms:

- *Job relevance* is as it sounds, the perceived degree to which a person can identify themselves with a new piece of technology in his or her work tasks.
- *Output quality* is to which level the new piece of technology is capable of performing the job tasks well.
- *Result demonstrability* is a factor implying that a user will form a more positive perception of usefulness if a new piece of technology is capable of showing how the software use will have a positive impact on the result.

During four case studies conducted by [27] TAM2 was tested in four different organisations. TAM2 was according to [27] strongly supported in all four of them at three points of measurements. These points were prior to the implementation of a new system, one month after and three months after the implementation. The results show according to [27] that TAM2 extends TAM by showing that the *subjective norm* has a great influence over U. The *subjective norm* did not only have an influence over U, also actual intention to use was moderated by the *subjective norm*, but only for mandatory settings [27]. *Job relevance* and *result demonstrability* was also two strong factors in order to explain U. During the study it was also seen that E had an influence over U [27].

Over time [27] saw that with direct hand on experience users less relied on what other persons thought. Although they still judged the *perceived usefulness* of a system on the potential status that could be gained from using the system. In addition it was also found that a connection between *job relevance* and *output quality* was present. That if the *job relevance* was high the *output quality* became a stronger determinant to U [27].

3.4.3 TAM3

TAM3 is an integrated model of technology acceptance presented in Figure 3.4.3. While TAM2 focused on how and why persons want to use a new system, TAM3 was designed to assist managers to take better informed decisions to support the design of new Information Systems (ITs) [31].

With TAM3 it is proposed by [31] that an increased understanding of user reactions to implementations of new ITs can be accomplished. While TAM2 focuses on a better understanding of the perceived usefulness of a new system TAM3 focus on better understanding the underlying factors of the perceived ease of use. The identified determinants of E presented in [31, p. 279] are:

- *Computer self-efficacy* – the degree to which an individual believe he or she have the ability to perform a specific job-related task using the computer.
- *Perception of external control* – the perceived level of organisational and technical support available for a new system.
- *Computer anxiety* – the degree of nervousness or fear an individual is faced with when using computers.
- *Computer playfulness* – to which extent a user interact spontaneously with a computer.
- *Perceived enjoyment* – the extent to which a system is perceived enjoyable by itself.
- *Objective usability* – a comparison of the actual effort required to complete a task in the compared systems.

In a study by [32] from 1996 it was found that *computer self-efficacy* was a determinant to E, independently of hands on experience from a new ITs. *Objective usability* was on the other hand found only to be a determinant if hands on experience had been gained. According to [31] it can be stated that with increased user experience the impact on the behavioural intention will be smaller and less affect the actual use of a ITs [31]. Finally also users of a ITs base their perceptions of E on *computer self-efficacy* rather than hands on experience and E is therefore still important to take into consideration when designing new IT [31], [32].

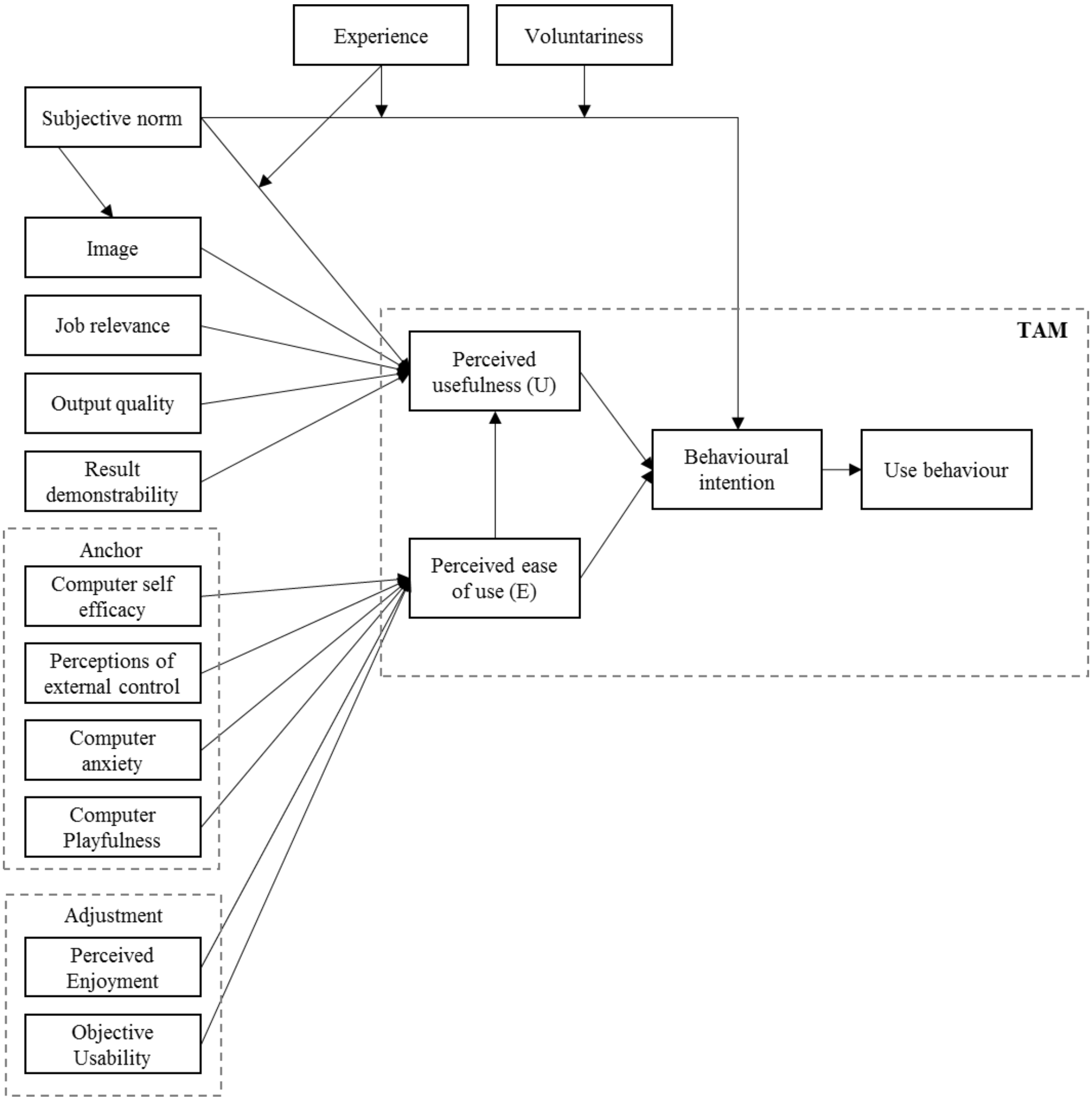

Figure 3.4.3 TAM3 as by [31]

3.5 3D laser scanning data

Laser scanning is a broad field with many different techniques and application areas. This section of the thesis will briefly describe the technology used to capture spatial data at Volvo as well as how to process it into point clouds. A brief explanation of different types of software for scan data is also included.

3.5.1 Generation process

Scan data is obtained using a 3D laser scanning device and the technology covered in this thesis only focus on LIDAR, Laser Illuminated Detection And Ranging, technology. Essentially LIDAR is a non-contact technology for point measurement. By sampling these measurements and aligning them into a common coordinate system a cloud of measurements can be established, a scan. According to [4] the most suitable technique for capturing larger objects is the time of flight technique. Although phase-based scanners are up to 20 times faster [33]. By measuring the time for a laser beam to be sent out and to be reflected back into the scanning device the distance can be calculated for the time of flight technique. The phase based scanners constantly emits laser energy and by measuring the phase shift the distance can be calculated [34]. In Figure 3.5.1 a phase-based laser scanner from Faro, intended to capture spatial data, is shown.

Figure 3.5.1 Faro Focus 3D laser scanner from [55]

Each scan can consist of tens of million points which are captured by the scanning device, the point density depends on the selected resolution. The scanning device typically have a 360 degree field of view in the horizontal plane and 300-320 degrees in the vertical plane, as presented in Figure 3.5.2. After the measurements have been sampled it is also possible to assign each point an RGB colour code, hence creating a realistic dimension to the scan. This is made possible by taking pictures which are aligned with the points captured with the scanner after the capturing of points has been completed. By aligning each point of measure with the picture a corresponding point in the picture can be extracted and an RGB code added to the point.

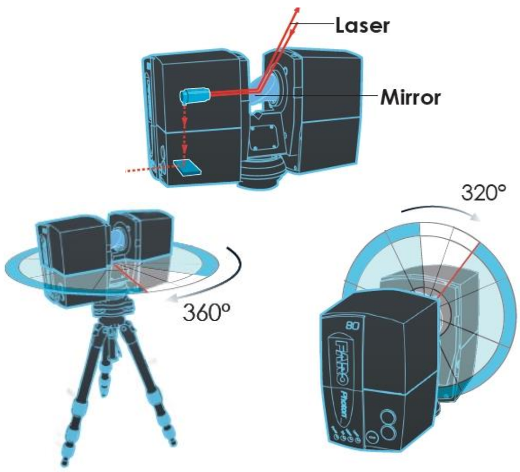

Figure 3.5.2 Basic capturing principles [56]

Several scans often have to be combined and this can be accomplished by having at least three common reference objects in the overlapping scans [4]. The reference objects which e.g. can be white spheres are fixed in the environment while the scanner is moved to another related location as in Figure 3.5.3. Using these reference objects several scans can be merged into one new dataset of all the isolated scans, creating a point cloud, this will be described further in chapter 3.6.1.

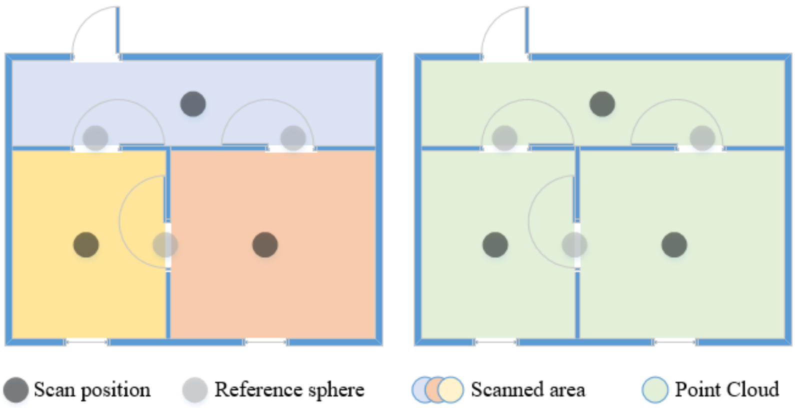

Figure 3.5.3 Combination of scans

3.6 Scan data software solutions

During the next coming years the interest of scan data is believed to increase [35]. Software companies are steadily increasing the possibility to integrate and work with scan data and in their software. Siemens PLM is one of the largest software developers in the PLM market and their newly announced cooperation with Bentley Systems is an important statement to the public, that it's profitable to develop software with support for scan data [36]. In addition to Siemens PLM, Autodesk and Dassault Systèmes are two other large software developers on the virtual design tool market which also provide software with the possibility for the user to import scan data to the design environment [37], [38]. Autodesk provide different software for the whole workflow from scan data registration, point cloud creation, to integration with their post-processing programs such as Auto-CAD and Inventor [39]. Beside these three large providers of virtual design tools there are also smaller developers on the market, often niched into a specific type of application.

It is possible to generalise and say that there exist four main scan data software types, pre-processors, web-based viewers, client-based viewers and post-processors. In the following sub chapters the intention of each type of software is described.

3.6.1 Pre-processors

In the pre-processing process the different scan positions are registered and aligned in order to create a point cloud, this can be done automatically, semi automatically or manually [40], [41]. A point cloud is a data file which represents the surface of 3D scanned objects or space. Depending on the purpose for creating the point cloud, different filters can be applied in order to adapt and enhance the point cloud towards the purpose. From this type of software it is then possible to export scan data files or point clouds which can be used in either a web-based viewer, a client based viewer or in post-processing applications. In Figure 3.6.1 a point cloud from a final assembly shop is shown. The point cloud is pre-processed in the software Faro Scene together with a number of dedicated applications developed by the external consultant firm Volvo has contracted for the pre-processing, further explained in chapter 4.3.1. The boxes around the data enables the user to hide or display the data inside or outside the box as well as to export the content within it.

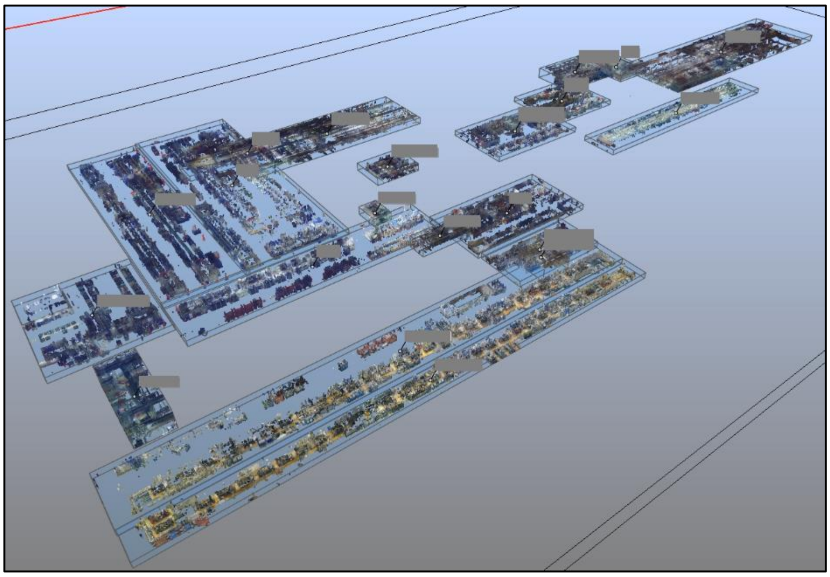

Figure 3.6.1 Point Cloud of a final assembly shop

3.6.2 Web-based viewers

In the web-based viewers scan data can be visualised and moved through basically like in Google street view directly in the web-browser, and is further described in chapter 4.3.2. In the web-based viewer it is possible to move around in 2D and between different scan positions in 3D. Point to point measures and area measurements can be made both in 2D and 3D. An annotation window can also be created in the 3D environment. [42]

In Figure 3.6.2 below an example of how Volvo's web-based client Faro Webshare looks like. In the bottom rectangle the 3D view is shown, in the upper right rectangle a 2D view of the scan data is shown as well as all the different scan locations. In the upper left corner the names of the scans is displayed together with a thumbnail of the scan.

On the market there is also software with functionality to view so called hybrid models in the web browser. A hybrid model is a model where both scan data and CAD geometries are combined

[43]. Also new functionality is available for we based viewers, making it possible to move around freely in 3D [44] [45].

Figure 3.6.2 A web-based viewer

3.6.3 Client based viewers

This type of software has the same basic intention as the web based viewers. Although the user can here import offline scan files and projects directly from a file. The client based viewer also has more advanced functionality e.g. the ability move around freely in 3D and to import CAD models, make movie animations and make changes to the point cloud. This type of functionality is often also included in pre-processors. [46] [47]

3.6.4 Post processors

Software application such as Autodesk's AutoCAD, Inventor, Fraunhofer-Chalmers Centre's IPS and Siemens's Process Simulate can handle point clouds [48], [38], [49], [36]. The point cloud is imported into the software and can be used for modelling, simulation and visualisation. By incorporating point clouds to the simulation a realistic dimension is added as well as a more exact representation of the reality to simulate against [4].

3.7 Manufacturing development process at Volvo

At Volvo the Manufacturing Engineering department (ME) acts as the critical link in the chain of producing cars. When a new car model is developed ME ensures that the new model will be able to be manufactured in the car production plants. The manufacturing development process (MDP) within ME is divided into three main areas; Annual, Program and Production, as in Figure 3.7.1. The work connected to the car program area is governed by Volvo Product Development System (VPDS).

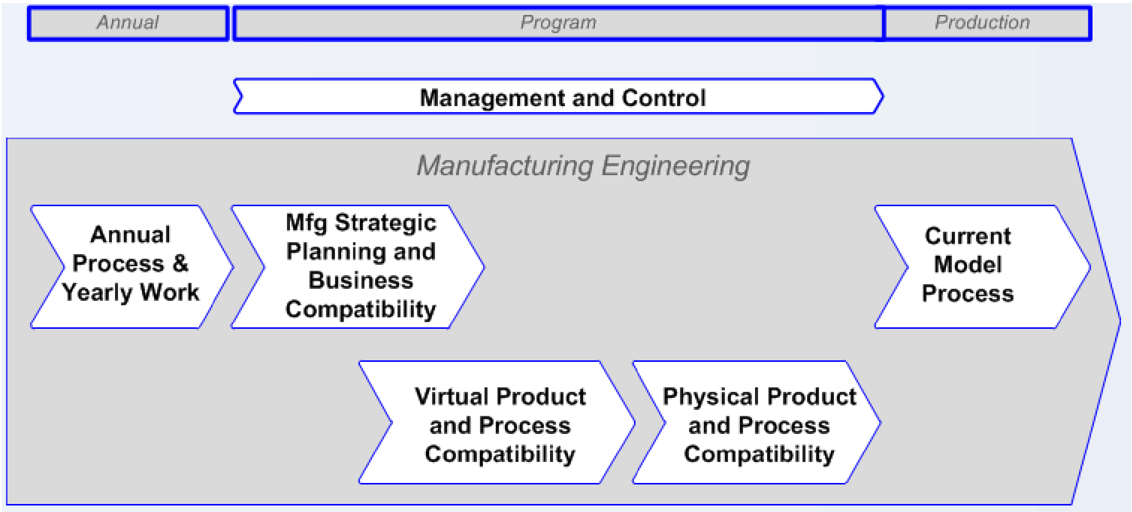

Figure 3.7.1 Volvo's Manufacturing Development Process

VPDS is the standard model for developing and industrialising new Volvo car models. The system is based on a stage gate model with a philosophy that decisions made in one gate should not be changed in a later gate [50]. Several different processes run concurrent in each stage and some stretches over several gates.

"VPDS, Volvo Product Development System, is our cross-functional logic to develop vehicles in time with the right quality & cost." [51]

VPDS consist of three main phases, product definition, concept and industrialisation. During the industrialisation phase both the product and the process are verified virtually and then later on the manufacturing process is implemented physically.

3.7.1 Annual stage

On a yearly basis risks and opportunities is identified for existing manufacturing strategies. New strategies and solutions are reviewed, tested and compiled each year.

The annual process is divided into three different phases. Phase 1 focus on drafting new strategies which then can be studied further. First a review of opportunities and risks is conducted, secondly targets are developed based on the manufacturing strategy and from that proposals for improvements are defined. These proposals are then to be studied in phase 2. In phase 3 the studies from phase 2 are reviewed and the operational strategies are updated based on successful studies.

Aside from this a continuous process of reviewing process requirements and selections is conducted together with volume capacity planning and review of new business plans.

3.7.2 Program stage

New car models are at Volvo taken from the design board to the car producing plants in programs. ME starts their work before the car design is finalised and ends after stable mass production volumes have been established.

3.7.2.1 Strategic planning and business compatibility

In the concept phase manufacturing engineers takes part in deciding overall system selections; where to produce, which car concept to produce, for which markets and how everything will be financed. This is done in a cross functional group where except from ME also research and development (R&D), finance and purchasing departments participate. The selections and decisions from this concept phase are compiled in three different binders; the red, blue and green binder. ME has responsibilities within the red technical binder, which describes how the new car model will be produced in order to meet the requirements on quality, cost, weight and functionality. The red binder describe system selections as e.g. the instrument panel is going to be mounted using a robot in Sweden, while it may be manually mounted in China. The other two binders are the blue and green binder. The blue binder describes in which markets the car is going to be sold and the green binder describes the business case for the new car model.

3.7.2.2 Virtual product and process compatibility

After the concept phase an industrialisation phase follows, where the car is manufactured virtually. It is here the major engineering work from ME takes place, concurrently. All different systems are to be assembled to one final working product. This is done in three different cycles, V0, V1 and V2. In each cycle the maturity of all systems and the final product and process increases and when V2 is finished the entire car and its systems are virtually verified. It should now be verified that the new car will be possible to manufacture to the right quality, within the specified takt time and to the right cost. One possible sequence of how to assemble the car should be established as well as instructions for how it should be done.

To support the virtual verification, flow and ergonomic simulations are performed, as well as path planning and offline robot programming, to ensure that all parts can be assembled to the car. In the body shop robot cells is the main verification area, in the paint shop the main verification area is application of primer, paint and sealing. In the final assembly work ergonomics and path planning are the main verification areas.

3.7.2.3 Physical product and process compatibility

After the virtual phase all major engineering work is completed and only the physical installations and verifications are to be done before mass production can be initiated.

First the car is built in a prototype workshop where the car and its dedicated equipment is physically verified. The equipment is then installed in the car producing plant and slowly ramped up to mass production volumes in order to ensure that the equipment works according to specification after installation, and that it delivers the right quality. The industrial phase is finished when the car production plant signs off that the new car model has been successfully implemented in the plant.

3.7.3 Current model process

In a car model’s life cycle changes to the initial solution are made in order improve the car and the process. Changes in the different shops, design changes on the car or process improvements can initiate change. Improvement potential for both the product and process is taken into consideration in order to increase sales, to gain process efficiency and cost savings both concerning the product and the process.

4 Current state

In this chapter the current application of scan data at Volvo will be described as well as the equipment development process in Trim and Final assembly.

Scan data has been captured at Volvo in Torslanda since the late 1990s and the first area of application for scan data was to verify robot installations within the body shop [52]. This chapter will present the current application of scan data within the Manufacturing Engineering department. As well as a, by the authors, compiled overview of the equipment development process towards Trim and Final assembly. The data presented were gathered in the early phase of the thesis and presents a snapshot of how it was interpreted by the authors.

4.1 Overview of scan data application within Volvo

As of today robot cell verification is still the main application area of scan data but there is an interest and willingness to expand it to a broader field of application within Volvo. Based on semi structured interviews, observations made by the authors and internal corporate documentation the current state regarding the application of scan data at Volvo have been studied. Engineers from the manufacturing engineering department in Torslanda have been interviewed to acquire a holistic picture on the use of scan data within the manufacturing engineering department.

Scan data is today captured by an external consultancy firm, by the name of ATS, for Volvo together with line builders as a contractual part after the new line has been installed. ATS also handles the pre-processing of the captured data. Today scan data exist for large parts of Volvo’s factories in Europe and in China.

Today the most mature area of application for scan data is the verification of robot installations and the offline programming of robot cells. Scan data has also been applied with great success in order to simulate and ensure a collision free path for e.g. a car body being transported on a conveyor. However, using scan data this way has not yet been implemented as a standard way of working, except for robot applications and pre-treatment lines in the paint shops. The least explored area of application of scan data at Volvo concerns the development of a manual work station.

4.2 Capturing and accessing scan data at Volvo

At Volvo the capturing is performed by ATS and the line builders. The line builders are obliged to scan new lines they have built, this is regulated by a commercial document. The scanned data is stored at Volvo on disk drives and can be accessed from a web based viewer and on from a file server.

Already when Volvo started capturing scan data it was coordinated towards a factory coordinate system [52]. Fixed positions for reference points are mounted in the factories and new scans are aligned with the factory’s coordinate system. This infrastructure enables the use of incremental updates to be performed on parts of the factories where physical changes has occurred, without losing the positioning accuracy of the scan data. Via *registration quality reports* the quality of the scan data is controlled. These *registration quality reports* are one of the outputs from the pre-processing process described in chapter 4.3.1 and is one important part of the quality assurance.

Plant alignment is a method to define the installation position of equipment and describes how all Volvo’s different factories are aligned in a master coordinate system. The scan data at Volvo is today captured and aligned with this coordinate system. Line builders can access this information and by using a laser tracker the position accuracy and equipment geometry of new installations can be verified towards the modelled position and geometry during installation. [51]

4.3 Scan data software at Volvo

Today the strategy is to capture data in a very well defined way with fixed a coordinate system and documented accuracy. This data is managed and updated to continuously present the latest correct 3D-representation of the car production plants. Data can be exported in open formats and the software for analyses can vary over time.

4.3.1 Pre-processing

ATS who captures the scan data also handles the pre-processing of it for Volvo. They use the full version of the Faro Scene software for their pre-processing together with a number of dedicated applications developed by the firm to create a scan project. Faro Scene is a tailor made program for scan data captured with Faro laser scanners [46].

The scans are semi-automatically registered and point clouds can be created for a project. The dedicated applications, in combination with Faro Scene makes it possible to incrementally update the projects and to acquire quality reports of the registration process. This process enables Volvo to work with scan data from different occasions in time in one single project. Filters are applied to the point clouds to enhance the data, e.g. adjustment of lightning or decreasing the point density. Shadow points, reference spheres and moving objects are removed from the point cloud which then is uploaded to a web service and the projects on a file server.

In the case where the possibilities to work directly in the scan data is insufficient and a point cloud is needed, ATS creates one for the specific case up on request and each request results in a new scan project. For the car production plants, such as in Torslanda, one master scan project for each one of the three shops exist. These projects consist of several small scan projects that have been combined into one large, master project, one for each shop.

4.3.2 Web based viewer

The current web-based solution for displaying the data in a web browser is called FARO Scene Webshare and is maintained for Volvo by ATS. In Webshare it is possible to move around within

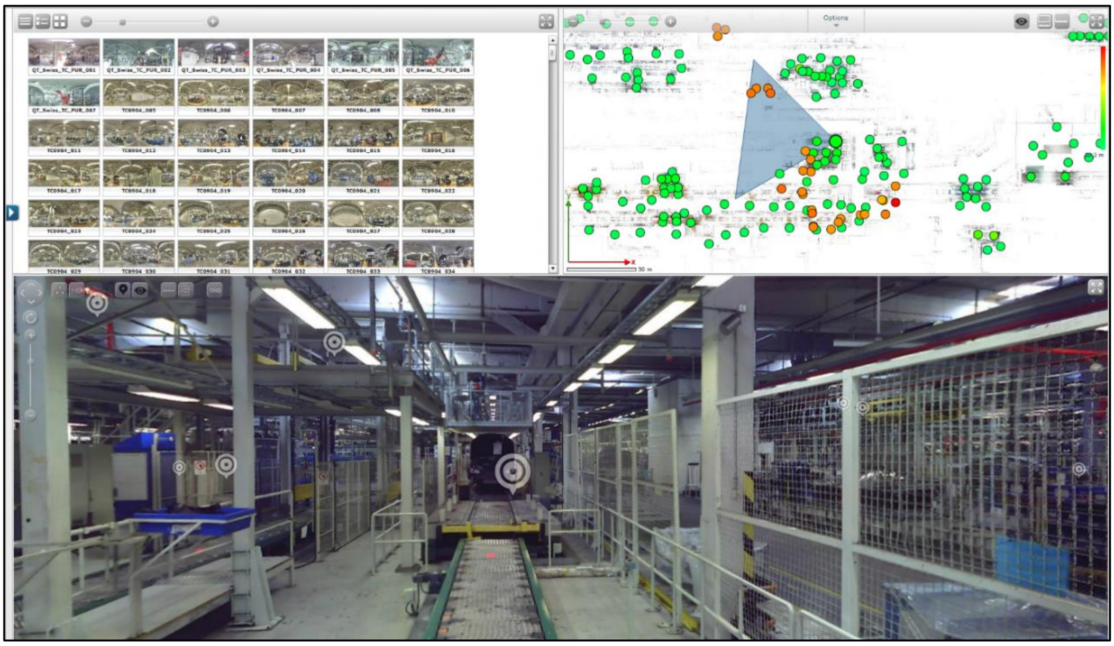

Figure 4.3.1 Faro Webshare at Volvo

a shop, from one scan location to another, like in Google street view, as in Figure 4.3.1 above. Moving from one scan location to another can be done either in 3D by double clicking the grey symbol in 3D or by selecting another round circle in 2D. Distance measurements from one point to another as well as areas can be measured directly in Webshare. If Webshare are to be accessed outside of Volvo, a request for an external access has to be made.

4.3.3 Client based viewer

In addition to the web based viewer, a client based viewer called FARO Scene LT Enterprise is available at Volvo. Scene LT is a *freeware* software which has an increased functionality compared to Webshare. As the name suggests it's a light version of the full Scene software where the pre-processing capability is restricted and the function to create point clouds is removed. In Scene LT scan data files can be imported manually from a file server. After the files have been imported the user can choose to have the same viewing mode as in Webshare, but also move around freely in 3D inside the scan data like in a CAD model. In Figure 4.3.2 a point cloud has been imported, a clipping box has been used to hide the data outside the station and the black car is an imported CAD model. An annotation is connected to the CAD model which contains a link to the CAD model.

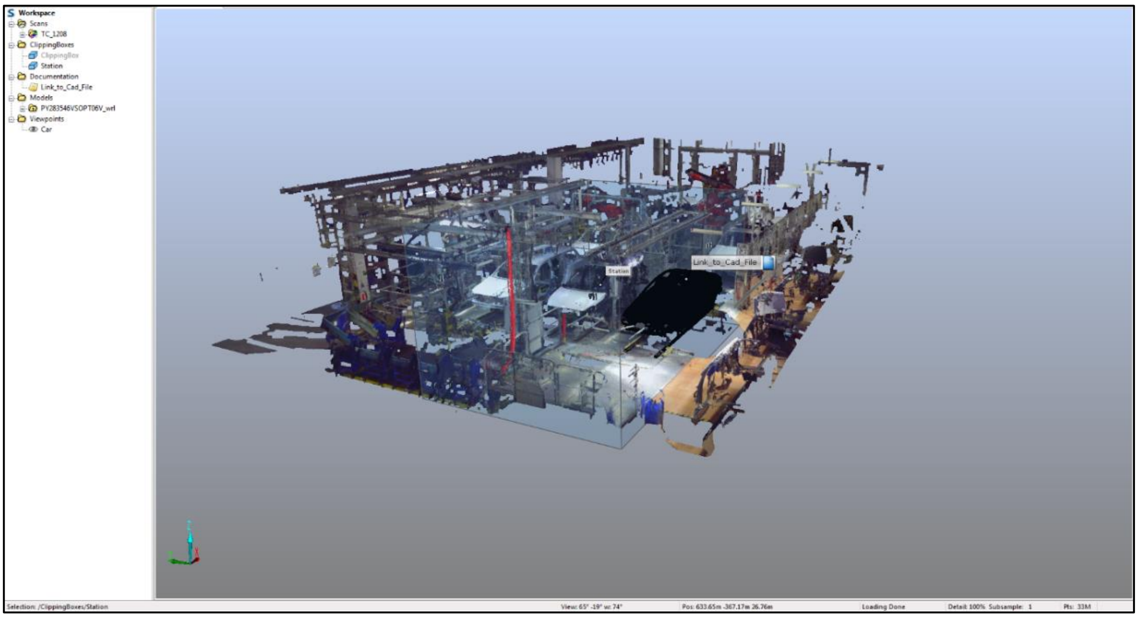

Figure 4.3.2 Client based viewer, Faro Scene LT

4.3.4 Post processing software

Except from the dedicated software above Volvo also has software for simulations and CAD modelling with point cloud support. Siemens Tecnomatix and FCC's Industrial Path Solutions (IPS) is mainly used for manufacturing simulations.

- *Tecnomatix*
  The version available at Volvo during the current state study only supported visualisation of point clouds. Point clouds could be imported into the simulation environment but the simulation could not interact with the point cloud. In the next version of Tecnomatix it will be possible to perform measurements and perform simulations towards the point cloud.

- *IPS*
  The possibility exist within IPS today to perform simulations that can interact with the point cloud. The point clouds that can be imported can be of whole stations or a part of an assembly line. The possibility to import point clouds in order to perform ergonomic simulations are today limited in the ergonomic simulation tool within IPS, IMMA. Compared with IPS very small parts of a station can be imported as a point cloud into IMMA.

Today an issue with the scan data in the case of simulations is so called shadow points, these points are registered by the 3D laser scanner while they in fact does not exist. Shadow points can be registered due to reflections around sharp edges. In order to perform accurate simulations these points must be removed, or the software programmed to work with them. Today a collision simulation will say that a collision has occurred based on a collision with only one point in the scan data.

4.4 Current areas of scan data application within Volvo

The use of scan data is different depending on in which shop in a car production plant it is used in, this is connected to the type of engineering work mostly conducted towards these factories. In the body shop where the density of robots is high the scan data is used to verify robot cell installations and perform offline programming. In the paint shop scan data have been pilot tested for transporter simulations and is used for verification of robot applications. In the trim & final assembly scan data has been pilot tested within equipment development and is used for verification of robot applications.

4.4.1 Body shop

The simulations performed today in the body shop mainly intend to verify the offline robot programming and its functionality. The focus is today mainly on product verification, but there is an interest for verifying the process itself in a more detailed manner. Connected to a robot cell there are many other interested parties which recently have shown a growing interest in knowing more about how the robot cell will interact with other functions of the factory according to the robot simulations team for the body shop.

The main application of scan data in the body shop is to verify robot installations and to perform offline programming. Scan data is captured after the physical installation for a new line or cell and the 3D CAD models are updated according to the actual installation. By doing this the CAD models represent the actual factory for future updates. This is regulated in the commercial documents Volvo settles with the line builders responsible for building new production lines in their plants.

Scan data is also used when CAD models for robot cells are not available in 3D. Simplified geometries of the equipment present in the station today can be modelled based on the scan data in a hybrid model, where the 3D models are created on top of the scan data. The creation of CAD models is needed since the robot simulation software Process Simulate today only visualise point clouds and therefore clash detection cannot be performed against the scan data.

4.4.2 Paint shop

The use of scan data in the paint shop is today limited except for the installation verification and offline programming of paint and sealing robots. Pilot tests have been performed on simulations regarding collision free car body paths, at Volvo called body window simulations. In the paint shop today there is according to a project manager more than 10 km of conveyor tracks only for buffers. These conveyors are not usually modelled in 3D and the body window is today mainly verified during physical tests where the clearance between the car body and the factory itself is verified.

Pilot tests have been performed with scan data to virtually verify the body window on some parts of the conveyor system containing manufacturing equipment and these tests have been successful. Locations in the shop where the physical body would have collided with equipment or the building itself were identified virtually and could be solved by the manufacturing engineers early in the development process.

4.4.3 Trim & Final assembly

The use of scan data in trim & final assembly is as in the paint shop today limited. Pilot studies have been performed but the use is not widespread. In trim & final assembly ergonomics, flow and mountability simulations are performed on a regular basis today, although not with the support of scan data.

Ergonomics simulations are performed for stations where an ergonomic simulation has been ordered. The ergonomics simulation is today performed on a piece of equipment and a CAD model of the car on a given working height. The simulation engineers expressed during a meeting a need to work with scan data in order to enhance the simulation outcome.

Pilot studies have been conducted for the equipment development process. After a supplier has received an order of a new piece of equipment they get the possibility to access the scan data. The supplier can then better get to know the environment where there equipment will be placed; measurements can be taken virtually instead of visiting to the factory physically. Factory visits are also often connected with production disturbances if they are not performed during weekends. Guidelines for this way of working are being developed.

4.5 Comments from interviewees regarding scan data

During the current state study not only the current way of working with scan data was investigated. Ideas and comments regarding scan data were collected as well.

At Volvo there is today an array of virtual tools available and many interviewees did wish a portal from where engineering activities could be initiated. A comment from one interviewee which covers this rather well is:

"We don't need a new tool, we need one tool for everything"

From an external perspective it is easy to underestimate the importance of visualisation and focus more on the technical applications of scan data. The most common view the interviewees shared was the usefulness of scan data for visualisation. Although the utter most stressed topic discussed with the interviewees was an updated database with scan data, with the possibility to verify the age of the scans. Also a visual tool to verify the position accuracy of the scan was discussed, but not to the same extent as the age.

Beside issues concerning trust of the scan data easy access was a heavily discussed. Today the process necessary in order to extract and combine different scan data sets to a point cloud was seen as complicated and time consuming. A need for a function making it easier to export point clouds of specific sections of a shop to other types of software were expressed.

Some ideas were more innovative than others and suggestions to combine asset management with scan data were discussed.

4.6 Equipment development towards Trim & Final assembly

In order to better understand the equipment development process within the trim & final assembly area of the MDP a suggested model of the process was created and is presented in Figure 4.6.1. The model aims to describe why a development project for a new equipment is initiated, how the equipment is developed and implemented and at last how the equipment is maintained during running production. The model is based upon MDP and VPDS (chapter 3.7*)* as well as internal documentation.

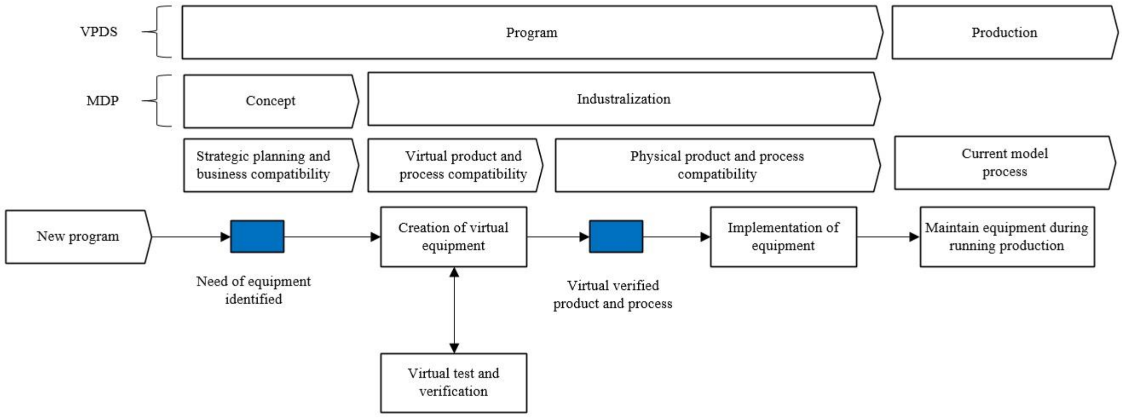

Figure 4.6.1 Suggested equipment development process in T&F

5 Case studies

This chapter presents the case study research performed in order to map the Manufacturing Development Process.

This chapter presents the case studies that was decided to be performed based on the data collected during the current state study. The aim of the case studies is to describe how scan data can support the development process within the Manufacturing Development Process (MDP) as described in chapter 3.7.

5.1 Determining the cases

When a new car is going to be developed, it goes through the three development cycles in the program area of the MDP. In order understand the current situation concerning needs, thoughts and problems within MDP, one current active project was selected within each development cycle of the program phase. The development cycles are presented below and in Figure 5.1.1.

1. Strategic planning and business compatibility, referred to as concept development
2. Virtual product and process compatibility, referred to as equipment development
3. Physical product and process compatibility, referred to as equipment implementation

For the projects in the equipment development and implementation cycles the active projects selected was being developed and implemented within the trim & final assembly shop (T&F). For the concept development no suitable projects towards the T&F at the time for the thesis were found. Therefore a concept development project towards the body shop was chosen instead. For this case no stakeholders will be mapped, this since it was discovered in the current state study that T&F does not work the same way as in body shop.

The projects were studied during a period of four weeks. However, all three projects that were selected have a run time of significantly more. In order to map the work method within these projects from start to finish information was compiled from observations, documentation, semi-structured interviews and data from the current state study.

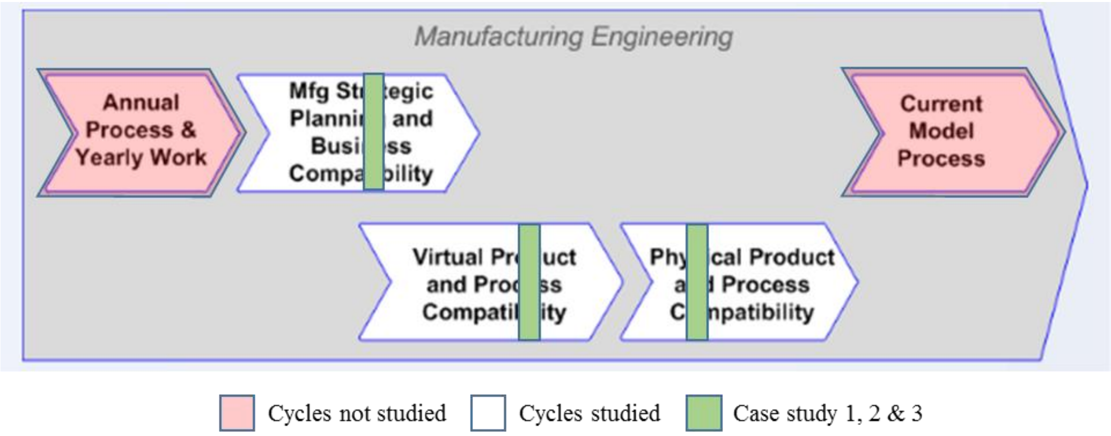

Figure 5.1.1 Cycles and cases studied

5.2 Case descriptions

This sub-chapter includes the description of the three cycles that were studied and contains an explanation regarding the work flow and different methods used and also the case study participants.

5.2.1 Case 1: Concept development

The aim of the concept development in the body shop is to create a basic layout of how a car body is going to be assembled. This is done by the core manufacturing engineers at Volvo and is done early in a car program. The project studied was a project connected to an empty part of the body shop in Gent and no existing equipment were present in this area, this is at Volvo referred to as a green field layout. In the case where a current process already exist the new process steps is designed in a way so that it will be able to integrate with the existing equipment and is at Volvo referred to as a brown field layout.

Initially in this phase of the project the body components are identified and different build steps are theoretically decided upon. These build steps tell in which order the parts are going to be assembled. Next a schematic flow of the process steps is defined, including necessary equipment, based on the system selections decided upon for this car program. In this stage it is known the amount of spot welds and glue that is needed as well as the cycle time for these operations. A simplified example of this look like:

1. Part A and part B is going to be joined together with four spot welds using two robots
2. Part A and part B is then glued onto part C using gluing-machine Y

Based on the defined process steps the actual layout in the factory is created, preferably in 3D but often this is done in 2D. In this stage of the project no detailed models of the equipment are available, only standard models in three different sizes; small, medium and large. The overall goal with this is to ensure that the car body is assembled in the right order with the right process, e.g. welded or glued, within the given cycle time.

Later in the equipment development cycle this layout is further developed with the actual robot and equipment models, e.g. fixtures and conveyors. The actual installation is performed using these models and plant alignment, which is described in chapter 4.2. After the installation the virtual models are updated so that they represent the real factory and this is regulated by the commercial documents settled between Volvo and the line builders.

5.2.2 Case 2: Equipment development process

The aim of the equipment development process is to create a virtual verified product and process. The role with the responsibility to secure both the product and process virtually is a manufacturing engineer.

For this case a project was studied where a new station was to be created in T&F, where a part is going to be mounted to a new car model. The manufacturing engineer’s responsibility is to ensure the mountability of the product through an iterative virtual process which include several engineering tools. The manufacturing engineer is also responsible to ensure that the new process solution is possible to integrate with existing factory processes and its equipment.

The whole process is initiated during a new car program, when a need is identified for a new type of equipment solution. The first step in the process is to plan where in the factory the part is going to be mounted to the car. T&F is divided into different process areas where different strategies for how to mount or assemble a part is used. The manufacturing engineer identify and define which strategy or strategies that is required in order to mount the part and therefore know in which area of T&F the new part is going to be assembled.

For this specific project the part that is being introduced is not going to be mounted to the car in an existing station. Otherwise, if a new variant of an existing part is introduced in T&F the manufacturing engineer will try to integrate the new variant with the already existing equipment and process.

Once the physical space required in T&F for the new station has been decided upon it is time to introduce representatives from different departments to the project. The roles of the representatives are presented below.

- Manufacturing engineer
- Equipment engineer
- Material Planning & Logistics engineer
- Design engineer
- Simulation expert
- Production area representative

These representatives are stakeholders within the equipment development project and have different demands and/or requirements on the layout of the station. The stakeholders also have different demands and/or requirements on the design of the product and the design of the process. The manufacturing engineer is responsible to establish a dialogue between these stakeholders in order to decide upon different trade-offs to satisfy the stakeholders demands. The process is now being developed and verified virtually through an iterative process which consists of three loops, V0, V1 and V2, described in chapter 3.7. The R&D department supports the virtual verification process with 3D models of the product. After the last virtual test loop has been performed both the product and the process should be virtually verified so that the mountability of the product can be ensured.

5.2.3 Case 3: Equipment implementation process

The aim of the equipment implementation process is to manufacture and install the equipment developed during the previous development cycle.

For this case a project was studied where a new equipment was to be created in the final assembly shop due to the introduction of a new car model in the factory. An old equipment was going to be upgraded to work with this new car model and no major layout changes were required. Except from the equipment itself only safety upgrades were going to be implemented in the station. The equipment engineer’s responsibility is to ensure that the tool fulfil the function requirements set by the manufacturing engineer, in the equipment development cycle.

The equipment implementation process is initiated once the development process of the equipment is complete. A request for quotation (RFQ) is sent out to a set of external suppliers that are offered the possibility to manufacture the tool. Once the manufacturer of the equipment has been decided the equipment engineer introduce representatives from different departments into the project to provide them with necessary information regarding the project. The roles of the representatives are presented below.

- Equipment engineer
- Manufacturing engineer
- Maintenance engineer
- Industrial engineer
- External supplier

Based on the previous virtual verification from the equipment development process a design review is performed with a physical build of the equipment at the supplier. All different functions specified in the RFQ should be present. Any complications identified during the design review should be solved and verified virtually before the next review. The next step of the process is a factory acceptance test (FAT). The FAT is conducted at the external supplier and the test is supposed to be a replica of the operations that are going to be performed by the equipment in running production. This test is supervised by the equipment engineer, but the manufacturing engineer should ensure that demands concerning the ergonomics, the product and the process are up to specification.

The equipment engineer is now responsible to plan the equipment's installation and supervise it. A final test of the equipment is performed during a site acceptance test (SAT) in order to verify the functionality of the equipment. Once the equipment is verified the equipment engineer is responsible to secure plant and maintenance routines connected to the equipment. The equipment is now *taken over*, which means the equipment is built according to the RFQ and Volvo standards, the external supplier now has no responsibilities towards the equipment, except the warranty.

During the whole implementation process the equipment engineer must also drive meetings to make sure that the involved parties needs and requirements concerning anything that is relevant towards the implementation of the equipment is fulfilled.

6 Results

This chapter presents the results from the case study research, which have supported the understanding of the need for a holistic approach towards the implementation of scan data within the Manufacturing Development Process.

This chapter presents the stakeholders that were identified during the case study research presented in chapter 5. A stakeholder has been defined as a participant from the case studies that has a possibility to incorporate scan data in his or hers work tasks. Different functions regarding how the scan data should be utilized in order to support the stakeholders will also be presented. Based on the result from the case study research and the current state study, a workflow has been developed. The workflow aim to support working with scan data throughout the entire program phase of MDP.

6.1 Stakeholders in the program phase of MDP

In order to classify a participant from the case studies as a stakeholder the method presented in chapter 2.2 was used. Since no participants were mapped in case 1 a stakeholder mapping has not been performed for this case. The differences in the way of working between the body shop and T&F makes a translation from the body shop to T&F impossible and therefore it has been excluded. The results from case study 2 and 3 are presented in Table 6.1.1 and Table 6.1.2.

Work responsibility	Focus of attention			Index
	Input	Process	Output	
Manufacturing engineer	x	x	x	5
Equipment engineer		x	x	3
MP&L engineer	x		x	4
Design engineer	x			1
Simulation expert		x		4
Production area representative			x	1

Table 6.1.1 Stakeholder mapping Case 2

Work responsibility	Focus of attention			Index
	Input	Process	Output	
Manufacturing engineer	x		x	3
Equipment engineer		x	x	5
Maintenance engineer	x		x	2
Industrial engineer	x			2
External supplier		x	x	1

Table 6.1.2 Stakeholder mapping Case 3

Based on the focus of attention, the importance factor and the index for each of the two cases a total score was calculated. In Table 6.1.3 below the score is presented and based on this, the four highest scoring participants were classified as stakeholders for the study within the program phase of MDP.

Role	Score	Classification
Manufacturing engineer	26	Stakeholder in the study
Equipment engineer	24	Stakeholder in the study
MP&L engineer	8	Stakeholder in the study
Simulation expert	8	Stakeholder in the study
Maintenance engineer	4	Not stakeholder in the study
External supplier	3	Not stakeholder in the study
Industrial engineer	2	Not stakeholder in the study
Design engineer	1	Not stakeholder in the study
Production area representative	1	Not stakeholder in the study

Table 6.1.3 Stakeholders identified

6.2 Identified needs for a function in the program phase of MDP

To decide upon how scan data can support the identified stakeholders the gathered data was coded. All data collected during the case studies have been coded using the method presented in chapter 2.3.3. This method was used with the aim to create different categories which describe a function that will satisfy a need within the program phase of the MDP.

Figure 6.2.1 presents the number of times the need for a function was identified by the authors. The data presented is compiled from 20 interviews, internal documentation and observations gathered during the case study research. The functions are described in the following sub-chapters.

	Virtual trust	Visualisation tool: scandata	Planning tool: scandata	Measurement tool: scandata	Simulation tool: scandata	Illustration tool	Totals
Case 3: Equipment implementation	1	9	4	6	2	2	24
Case 2: Equipment development	3	9	8	3	3	3	29
Totals	4	18	12	9	5	5	

Figure 6.2.1 Code application from the case studies

6.2.1 Illustration tool

An illustration tool makes it possible to quickly create concepts. By being able to create the illustration in a factory context the realistic dimension will increase and questions regarding the possibility to implement it in reality can better be evaluated, compared to an e.g. PowerPoint picture. By being able to create concepts, ideas and solutions an increased level of understanding towards a situation can be achieved [53].

6.2.2 Planning tool

With the ability to visualise the development process a need was identified for a way to supervise this process in 3D. Scan data offers a possibility to plan and coordinate tasks within the development process in a virtual 3D environment.

6.2.3 Simulation tool

In order to test and verify different concepts and solutions simulations are used within the MDP. Two important aspects of a simulation are the accuracy of the data the simulation is based on and the way the result is presented. Scan data presents in an accurate way the existing factory environment and can be used as input data for simulations. Work heights and other necessary input data for a simulation can be acquired with high accuracy. In order to increase the understanding of a simulation it can be visualised in 3D with the help of scan data [54].

6.2.4 Visualisation tool

During the case studies, the need for the ability to visualise the current state of a plant was identified to be strong. Scan data offers the possibility to be able to visit the plant virtually as described in chapter 4.3.2. This enables the possibility to show someone the “as is” state of the production line without having to physically visit the production line and possibly disturbing running production.

6.2.5 Measurement tool

During the case studies it was identified that during development projects, in all cycles of the program phase of MDP, a need to perform measurements within a factory was present. With scan data, measurements can be taken virtually with high accuracy, without disturbing running production.

6.3 In context development model

During the case study research it became apparent that it wouldn’t be sufficient to only integrate scan data in one specific cycle of the MDP. The program phase in MDP as of today consist of several stand-alone areas which result in a divided organisation and development process. The need to create a homogeneous workflow from concept development until implementation of the final solution, supported by scan data at Volvo was identified. The conceptual in context workflow was anchored at Volvo during a workshop. Internal experts in the field of IT, scan data and method development participated to validate and improve the in context development workflow presented in Figure 6.3.1 below.

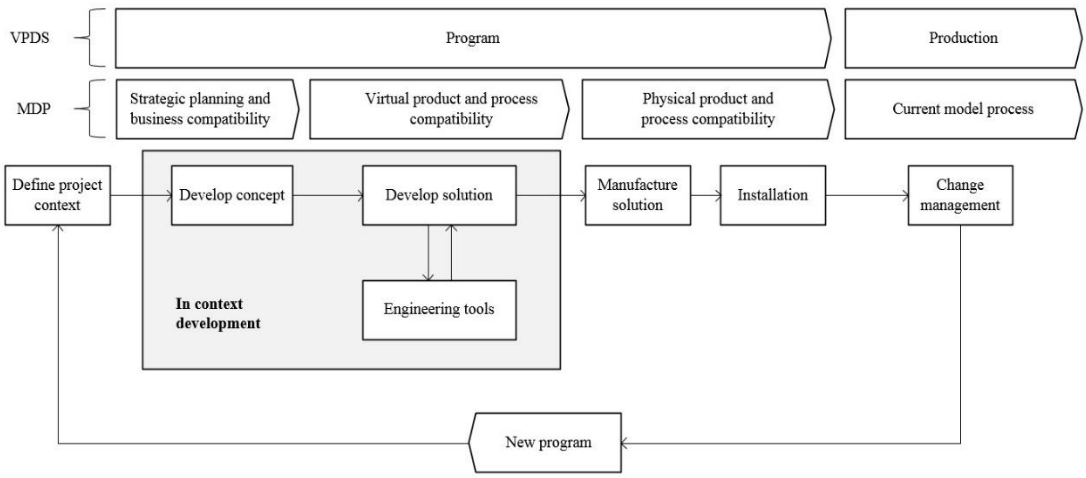

Figure 6.3.1 In context development model

The homogeneous workflow was developed in order to support a development process where scan data is integrated in the work methods which enables engineering activities to be performed in context. This workflow is designed for the stakeholders defined in chapter 6.1 and supported by the functions presented in chapter 6.2. The following sub-chapters will describe the workflow more in detail.

6.3.1 Define Project context

The first step in a new project, once the need for a new equipment has been identified within a new car program is to define the project context. The project context is the foundation upon which the concept and final solution will be developed, through an iterative virtual process. The main purpose is to define the physical space that is going to be allocated to the new station. The workflow that has been developed in order to define the project context is described in Figure 6.3.2 below. The first step in order to define the project context is to create a virtual zone, this is performed by the manufacturing engineer. Within the web based viewer the physical space required for the new station is marked up and a new project within the web based client is created, as in Figure 6.3.3 below. It is now possible to export the selected area as a point cloud, no pre-processing required, to a client based viewer in order to start developing the concept.

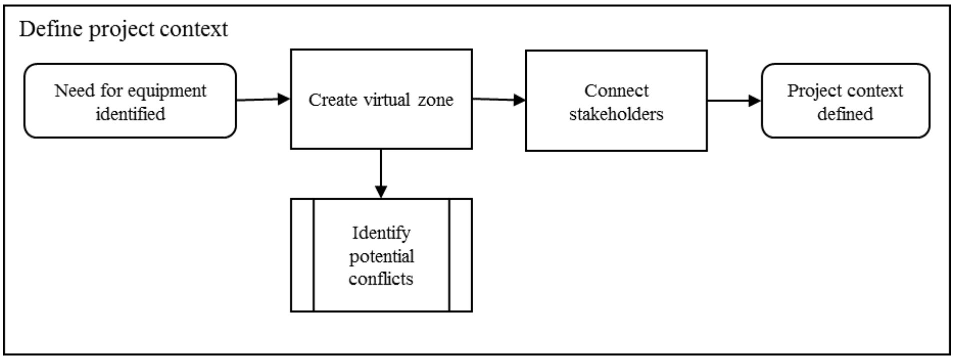

Figure 6.3.2 Define project context workflow

Within the web based viewer it is possible to view the physical space that is allocated to other active projects. This function enables the possibility to communicate requirements or needs that overlap between two or more zones. A possible conflict can be identified early and taken care of before physical issues have a chance to occur. In Figure 6.3.4 a virtual zone has been created and an area of conflict has been identified. The manufacturing engineer can now establish a dialogue with the manufacturing engineer responsible for the conflicting project and investigate if the overlapping area will result in a conflict.

Participants within the project are now connected to the project and given access to the point cloud within the web based viewer. The project context is now defined.

The responsible stakeholder for defining the project context is the manufacturing engineer and he/she is supported by the following functions:

- Visualisation tool
- Planning tool

Figure 6.3.3 Virtual zoning in a web based viewer

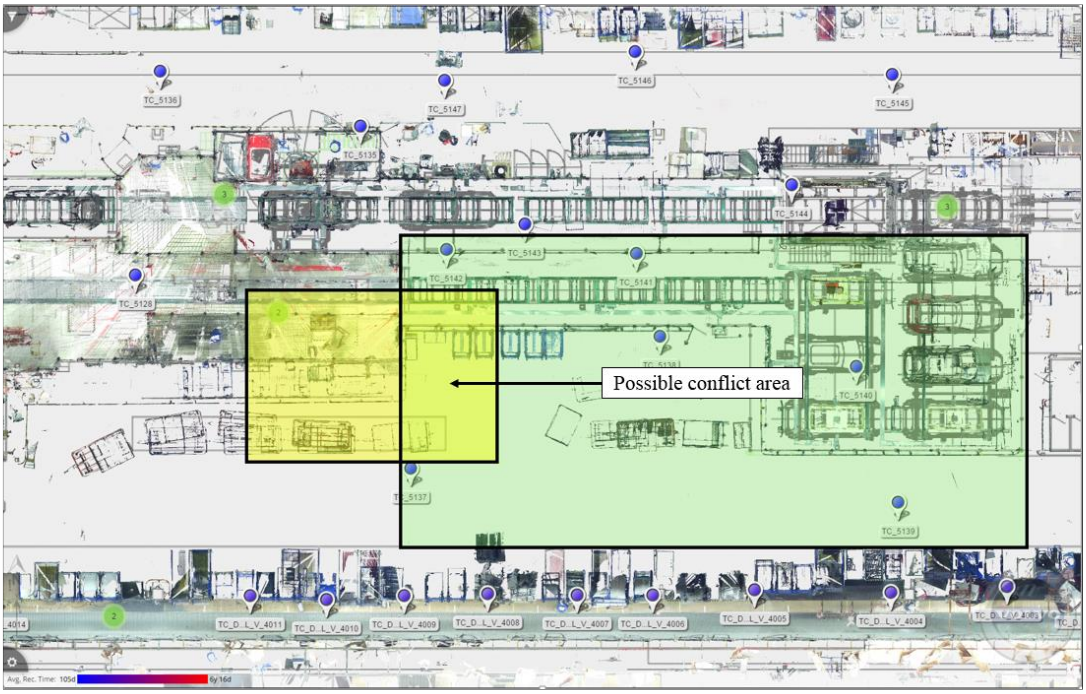

Figure 6.3.4 Identification of possible conflict area

6.3.2 Develop concept

Based on the virtual zone created when the project context was defined a conceptual solution is to be created in 3D. The concept is created in a hybrid model based on the point cloud, which was created with the virtual zone in the web based viewer, together with standard CAD models and/or simplified CAD volumes. The work method to develop the concept is presented in Figure 6.3.5.

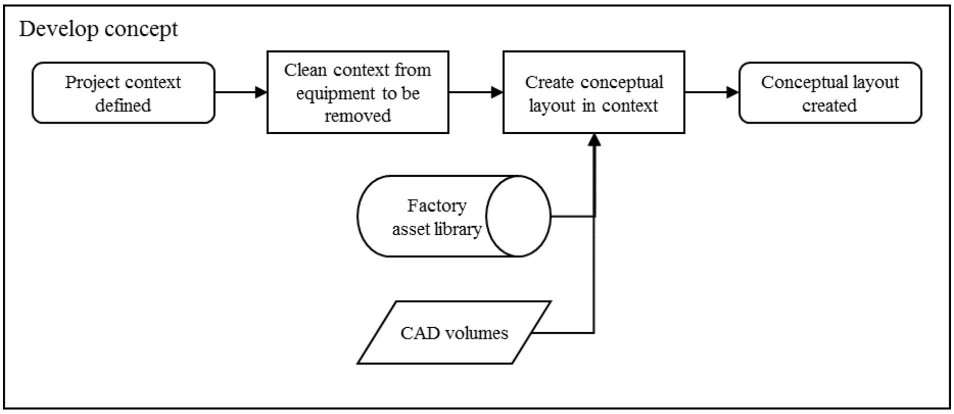

Figure 6.3.5 Develop concept workflow

In Figure 6.3.6 a point cloud imported from the web based viewer to the client based viewer is shown. First the equipment that is going to be removed or modified in the zone is marked up in the client based viewer. The marked up equipment can be hidden from display or removed entirely from the point cloud, if the equipment is hidden it can later be shown again.

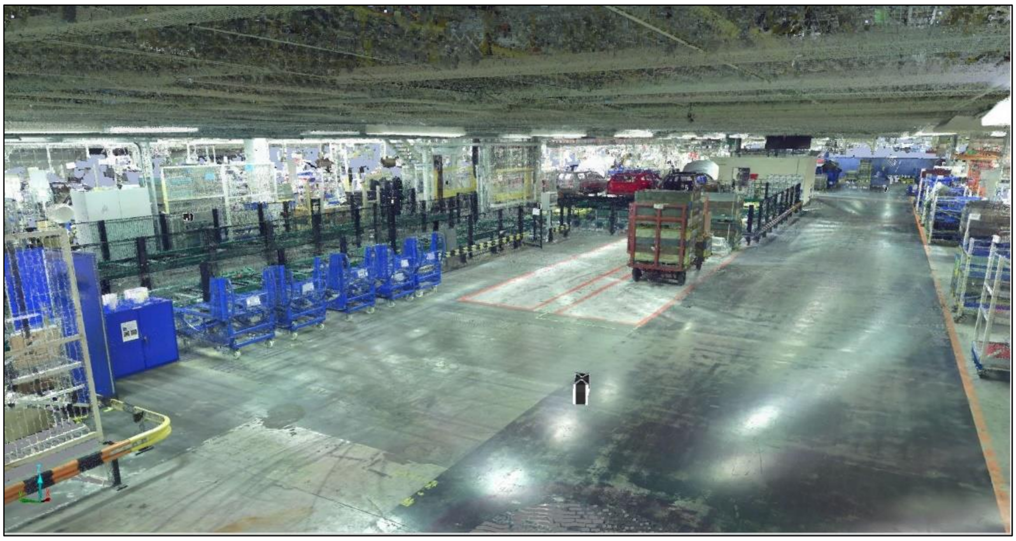

Figure 6.3.6 Exported project context in 3D

In the now clean zone a conceptual future state is created using simplified CAD volumes and a factory asset library. In the case where no standard assets exists, simplified CAD volumes are created to visualise the future state. In the asset library, existing standard equipment can be found and imported directly into the hybrid model. In Figure 6.3.7 below an example of a conceptual design is shown. Stakeholders in the development project can now share a common picture of the intended future state and cross functional discussions can take place based on this conceptual layout in order to develop different solutions.

The responsible stakeholder for developing the concept is the manufacturing engineer and he/she is supported by the following functions:

- Visualisation tool
- Planning tool
- Illustration tool

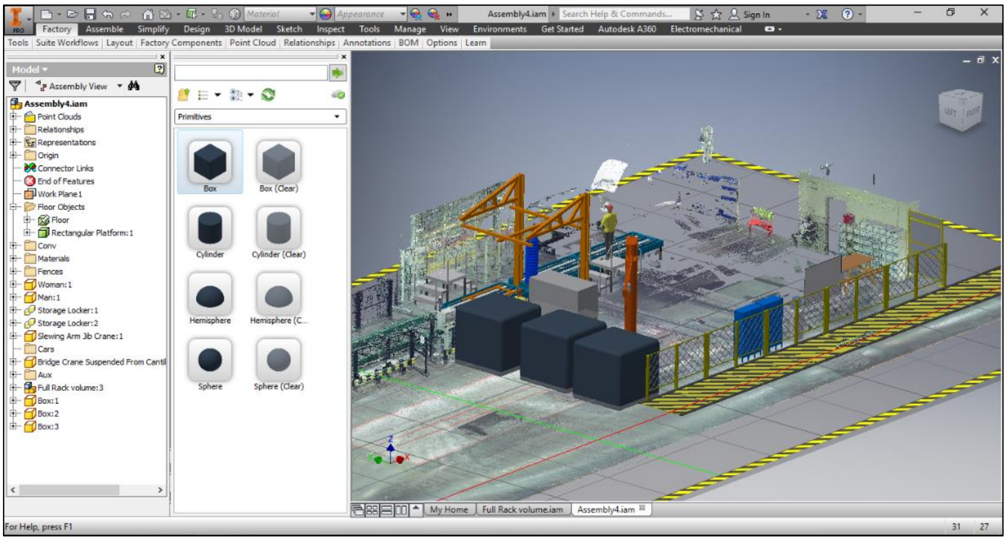

Figure 6.3.7 Conceptual design

6.3.3 Develop solution

After the conceptual design has been created the hybrid concept model will be refined during the virtual verification cycles V0, V1 and V2 presented in chapter 3.7. Due to that a hybrid model is created the final solution is developed in its actual context. The workflow for developing the final solution is presented in Figure 6.3.8.

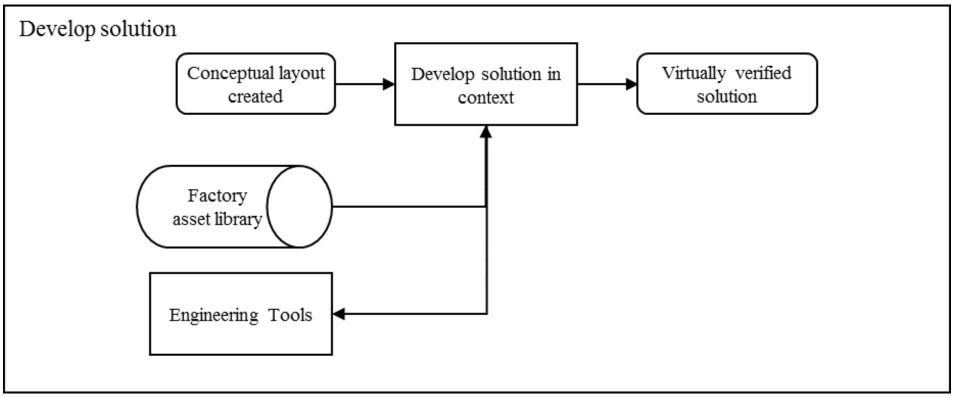

Figure 6.3.8 Develop solution workflow

During the development process different solutions are developed and evaluated through the virtual verification cycle. The 3D models from the conceptual layout are developed and refined through the virtual verification process. The 3D models that are being developed are continuously updated and revised through the asset library and the hybrid model acts as a communication tool.

In case dedicated equipment or unique system solutions are needed a link to more powerful engineering tools such as a full CAD modelling software packages or a simulation software is available. In these software packages a more detailed modelling and verification can be performed. If this is the case the manufacturing engineer will order the required simulation in order to evaluate and analyse the potential solution. The simulation order is communicated to the simulation expert through an external portal, already available today at Volvo. The link to these more advance engineering tools is further explained in chapter 6.3.3.1.

After the virtual verification cycle is finished a final solution has been chosen, which process now is virtually verified together with the product. An example of a final solution can be seen in Figure 6.3.9 below.

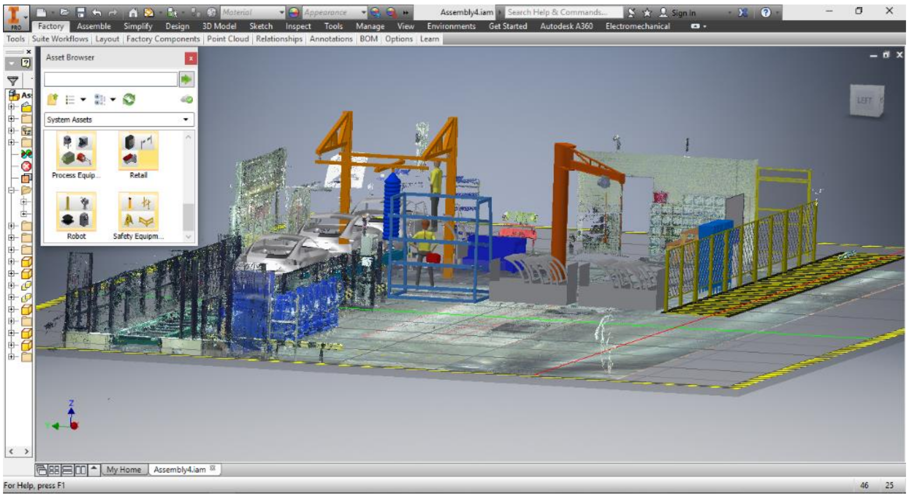

Figure 6.3.9 Virtually verified solution

The responsible stakeholder for developing the solution is the manufacturing engineer and he/she is supported by the equipment engineer, MP&L engineer and a team of simulation experts. The following functions support the stakeholders in the equipment development cycle:

- Visualisation tool
- Planning tool
- Illustration tool
- Simulation tool
- Measurement tool

6.3.3.1 Engineering tools

To develop and verify the solution, post-processing software such as CAD modelling and simulation software is used in order to perform detailed modelling and simulations. In Figure 6.3.10 the workflow for using post-processing applications during the solution development is visualised.

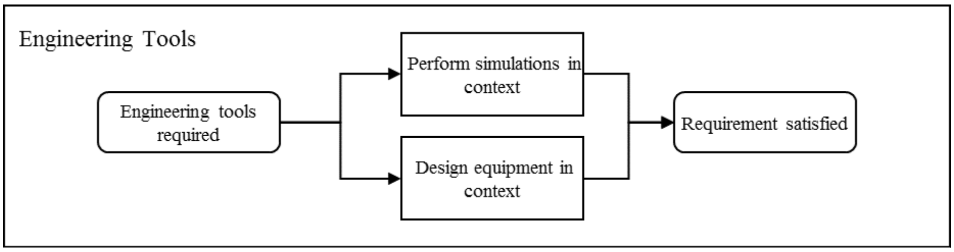

Figure 6.3.10 Engineering tools workflow

Before using the post processors the area and relevant equipment is imported from the hybrid model to the post processing software. After post-processing, the updated solution or part of it is imported back into the hybrid model in the client based viewer.

6.3.4 Manufacture solution

After the process has been virtually verified request for quotations are sent out to manufacturers which are given the opportunity to build the solution. In this manufacturing phase, when the solution already is virtually verified and drawings of the equipment that is going to be manufactured have been created, the use of 3D scanned data is limited.

6.3.5 Physical installation of an equipment solution

After the solution has been manufactured and it is time for installation the developed hybrid solution is used. The workflow for utilizing the scan data during the installation process is visualised in Figure 6.3.11 below.

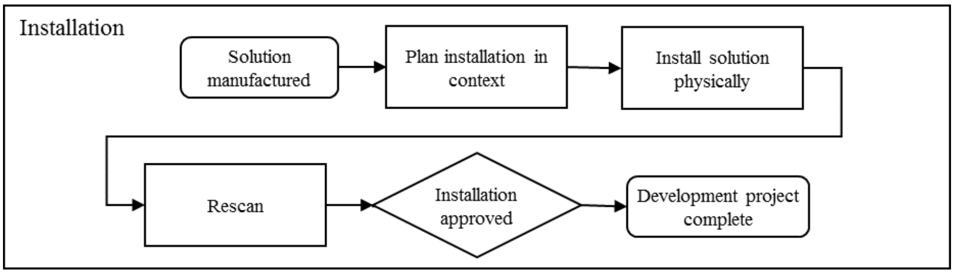

Figure 6.3.11Installation workflow

The manufacturer can now use the point cloud in order to get familiar with the setting where the installation is going to take place. Before the physical installation, measurements can be taken and auxiliary connections to e.g. compressed air and electricity can be identified within the point cloud.

The new equipment is now positioned and installed with the coordinates from the hybrid model, which are based on the factory coordinate system as described in chapter 4.2. After the installation a rescan is performed of the new installation which then is verified towards the hybrid model. When the rescan has been verified towards the hybrid model as well as all other requirements are fulfilled, the installation is approved and the master scan data project is updated with the new scan data. The car program is now finished and the new equipment is ready for start of production.

The responsible stakeholder for installing the final solution is the equipment engineer and he/she is supported by the following functions:

- Visualisation tools
- Planning tool
- Measurement tool

6.3.6 Change management

After installation is completed the responsibility for the process is handed over to departments within the factory, who are to maintain and optimize the process in running production. During the process's life cycle, changes can be made to the process. These changes need to be imported into the master scan data project and changes to the process rescanned in order to keep the system updated. A need was identified to determine which changes that should initiate a rescan and which role that should be responsible for performing this. It must also be determined who is responsible for the scan data, who owns it. However this was not a part of the scope for the case study research and has therefore not been determined.

7 Discussion

This chapter will elaborate on the topics covered previously in the report as well as factors that are of importance when implementing the result at Volvo.

Volvo is currently expanding their business following the shift in the production paradigm towards rapid introductions of new models on a market with growing global competition. In order to be able to meet these new requirements Volvo must be able to design their production systems with a high level of responsiveness [2]. As a result of this, Volvo has to decrease the time required for the development and implementation of a new car model within their factories all over the world.

During the current state study and the case study research it became apparent that the use of virtual tools was connected to the level of automation (LOA). For stations with a high LOA the usage of virtual tools is high and it is also a part of the standard way of working, both internally and for line builders developing stations with a high LOA. For stations with a low LOA the usage of virtual tools is not as high, concerning both the development and the implementation process. For stations with a low LOA more physical testing is performed than for stations with a high LOA. For stations with a high LOA the entire process is verified virtually while for stations with low LOA mainly the possibility to assemble the product is virtually verified, not the entire process.

These findings aligns with the use for scan data. For a station that is being developed that has a high LOA the application of scan data is high throughout implementation process compared to a station that is being developed which has a low LOA. The usage of scan data within the development and implementation process for a station with a low LOA are very limited.

The conceptual *In context development model* provides a suggestion for a workflow, where scan data is integrated, concerning the development process within the manufacturing engineering department at Volvo. The manufacturing engineering department's vision is to replace a large part of the physical testing with virtual tools. Performing physical testing is a very time consuming process and there could be problems that aren't apparent until the solution has been fully installed in the factory.

The manufacturing engineering department is responsible to ensure the mountability of a new car model. The meaning of this is to verify the product and the equipment interface. This verification is often performed in a CAD environment based on nominal values. There is a difference between this nominal CAD environment and the real world that doesn't have any implications on the verification of the product however it does affect the verification of the process. As mentioned before, the process is generally only verified by ensuring that the product can be mounted onto a fixture and thereafter assembled to the car. This, in combination with the nominal CAD environment, results in that only a part of the processes is verified virtually. In order to be able to fully optimise the process, and not sub optimise the process, the whole process has to be modelled and more importantly, it has to be done with a connection to the real world. Another important aspect of verifying the process, especially in the T&F area is that operations on the production line overlap with each other. It's important to be able to model and simulate the whole flow in order to identify unique interactions between the processes.

3D scanning is a fast and easy technology to use in order to get an accurate view of the real world. By implementing scan data into the development process the process can be verified before start of production. The *in context development model* also promotes the ability to reuse previous equipment due to the possibility to develop the new product within the actual process where the product is going to be assembled.

7.1 Stakeholders in the "In context development model"

The conceptual *In context development model* has been developed in an attempt for Volvo to increase their virtual verification and to shorten the development cycles for preparing a new car model for production. But why should the identified stakeholders work with it?

7.1.1 Manufacturing engineer

Today the manufacturing engineers working towards the trim & final assembly shop have to work with simple tools for visualising the solution he or she is developing. Designs and layouts for new solutions made in PowerPoint have been seen during the thesis and sometimes these tools are sufficient for simple projects. It is believed that if the tools proposed in the *In context development model* are used when developing the solution an enhanced output can be achieved.

If the manufacturing engineer would work as described in the *In context development model* it is believed that cross functional teamwork and communication can be increased and that the development lead time can be decreased. This can be achieved because problems can more easily be identified and communicated due to the power of visualisation. The hybrid model within the *In context development model* will enable visual planning and progress control of the equipment or fixtures that are to be developed.

7.1.2 Equipment engineer

Equipment engineers' participate today in the whole development process for a new car program. In the concept development and in the equipment development cycle they assist with expert knowledge concerning equipment solutions and cost calculations. Based on the concept made by the manufacturing engineer it is believed that the equipment engineer will be able to better understand the intended functionality for an equipment or entire solution earlier than today. Both time and money can be saved due to that both concepts and solutions created using the illustration tool proposed. Time can be saved through shorter development cycles due to that the equipment engineer can create the detailed equipment designs based on data in the hybrid model. Money can be saved since the data from the hybrid model also will help the equipment engineer to establish more accurate cost calculations and develop more well-reasoned designs.

During the installation phase the equipment engineer can use the hybrid model generated within the *In context development model* in order to efficiently plan the installation together with the manufacturer of the new equipment in the virtual model. Instead of having to physically go into the factory the planning can be performed virtually in the hybrid model. This allows the equipment engineer to not having to stop the running production in order to gain access to a station. Also, by placing new equipment aligned in the factory coordinate system the risk for unexpected errors are minimized since their placement already have been virtually verified as described in chapter 4.2.

7.1.3 MP&L

The MP&L engineers are at times excluded from the work performed by the manufacturing engineer. They are often not included in the discussion when evaluating different solution alternatives. A reason for this, according to the MP&L engineers, could be that they today lack a proper way to express their needs and the ability to visualize and determine how a specific solution affect the material flow.

Most of the work performed by MP&L is today performed in 2D. They expressed a need to be able to work in 3D and in an easy way visualize the work they've done in 2D in 3D. This in order to be able to communicate with the manufacturing engineer who *mostly* works in 3D. The authors are of the belief that the MP&L engineers are in need of a material flow simulation tool in which they can simulate and evaluate different material flow solutions, both in 2D and in 3D. With the *In context development model* MP&L engineers can participate in the solution development and contribute with important knowledge in order to optimise not only material flow within the station but in the whole logistic chain.

7.1.4 Simulation expert

Today simulations are often only intended to verify the product and equipment interface, except for automated robot stations where the whole robot cell is simulated to ensure that e.g. collision free paths can be established. Before performing an ergonomic simulation today, the simulation expert or someone else has to visit the station that is going to be simulated in order to gather necessary input data such as working heights and walking distances.

If the conceptual model is implemented the simulation experts can import the hybrid model, generated throughout the *In context development model*, and then perform the simulation. Work heights, walking distances and other necessary data required in order to perform an accurate simulation are then already present, in the hybrid model. When the simulation can be performed and visualised in its actual factory environment it will increase accuracy and quality of the result. The ability to visualize the simulation result leads to an increased credibility, due to that the result is easier to understand.

7.1.5 What are the technical limitations as of today?

The software functionality presented in the *In context development model* is today not yet available on the market. Functions for virtual zoning in a web based viewer and developing both the concept and the solution in a client based viewer are still to be developed. The client based software needed is a software interacting with both the web based viewer and post processors. It must have proficient manipulation and visualisation functionality as well as an updated factory asset library to make it easy to create illustrations using standard CAD models and volumes.

The basic functionality mentioned above is available in different software solutions on the market. The development that needs to be performed is to combine and refine available technology into a solution that enables working with scan data throughout the entire development process. The authors are of the belief that Siemens have taken a step in the right direction by starting to cooperate with Bentley Systems [36]. The function for organising large point clouds in the recently released Process Simulate version 12.1, which not have been tested, looks in theory to be of great use when working with large point clouds. The function makes it possible to take one large point cloud and define different layers in a way that allows the user to hide and show specific areas of the point cloud that are of interest.

In Faro Scene LT Enterprise the selection functions has become well-functioning compared to Pointools V8i. The weak point according to the authors in Scene LT is the visualisation and manipulation functionality, compared to Pointools V8i and the Autodesk's software package.

Autodesk Factory design suite in Inventor 2016 has a well-functioning factory asset library which is easy to use, it is possible to just select and place parts in the hybrid model. For both the concept and the solution development examples presented in chapter 6.3, the authors used the factory asset library to place new equipment. Many of the standard models in the asset manager is parameterised so that heights and lengths can be altered for the standard models. The possibility to link the standard asset library with TeamCenter is believed by the authors to be a corner stone in order for the *In context development model* to function as intended.

Concerning IPS the authors are of the belief that the work Volvo has done concerning body window simulations in the paint shop is impressive and really show which potential scan data has in order to better virtually verify the process. Today in the beta version of IPS's ergonomics simulation software IMMA, the point cloud support is limited to small point clouds and can only be used for visualisation. The authors are of the belief that with more time spent on developing IMMA, the same results as those that have been accomplished in IPS for automated equipment will be possible in manual stations as well.

Expect for the lack in software functionality the performance available for Volvo employees concerning hardware and download and upload bandwidth is an issue. Scan data and point clouds are made of millions of points. The examples presented in chapter 6.3 consist of over 100 million points and require powerful hardware in order to render the graphics smoothly. Today not all computers have sufficient hardware for this at Volvo and for the *In context development model* to function as intended this is required. The *In context development model* proposed will require large amount of bandwidth to function. This is today a problem for Volvo especially when working in China due to that all scan data is stored in Sweden. In order to be able to work from locations with poor IT infrastructure, the scan data must be stored in an efficient way.

7.2 CAD models and scan data

If scan data is compared with CAD models there are some major differences. Scan data is an "as is" capture of the current state while CAD models are modelled in a computer with fully defined surfaces.

It is important to decide when scanning what information that is required from the scan, what is important to capture. This due to that the scanner cannot capture an object that is hidden behind another object. Therefore, either the scanner or the object, has to be moved so that the object of interest can be captured. Another aspect of this is that some objects, or part of objects, has to be modelled within a CAD software. This due to that some information cannot be captured by the scanner. An example of this is when an equipment is fastened to the ground and the equipment covers the holes in the ground, it's not possible to determine the diameter of these holes based on the scan data.

Each scan takes time, and time is money. It is impossible to gather all the data so the person performing the scanning has to know which data that is important and what can be left out. This is an issue that has to be considered when working with scan data. Although the authors are of the belief that if comparing the cost of capturing and maintaining the scan data it will still be more sufficient to scan the factories then modelling them in a CAD software. The cost and time needed for keeping the different factories up to date is believed to be lower and the data more accurate if it is scanned, which is supported by [6].

Although the scan data only cover parts of Volvo's factories and the application of scan data is often connected to robot applications, where there today exist a work methodology which incorporates scan data. In order for the *In context development model* to function as intended a more comprehensive scan data database is needed, and the previous scanning needs to be verified so that updates that have been made are not neglected.

7.3 Implementing the "In context development model"

In order to implement scan data as a data set and the *In context development model* at Volvo it is by the authors considered of highest importance to ensure the acceptance of the technology. Research have shown that poor acceptance of a new IT system often result in great economic damages to companies and that a large portion of this can be explained by the users *perceived usefulness* and *perceived ease of use* for the new IT system [31]. These two factors can be controlled, therefore the authors suggests that Volvo have to focus on not only the technical aspects of the *In context development model* and scan data in general. Volvo also have to focus on social and cognitive factors as well as general computer knowledge, this is based on the research studied in the area of technology acceptance presented in chapter 3.4. According to [32] users base their *perceived usefulness* upon what other thinks of an IT system. Also [32] state that general computer knowledge is of higher importance when implementing new IT systems than system specific learning in order to increase the *perceived ease of use*. Also by increasing the general computer knowledge other IT issues could be avoided at Volvo.

Another important aspect of the implementation process, aside from ensuring the acceptance of the technology, is to design support functions to the *In context development model* [26]. One of these functions, which also became apparent during the case studies, is that it’s very important to define new responsibilities before the implementation of the model. A support function, either a role or work method, has to be developed that ensures that the data present in the web based client are up to date.

7.4 Quality of research methods

The interview template, presented in Appendix 1, is believed to be structured in a way that has a positive effect on the result. The interview was structured so that it gives the interviewee the possibility to present different problems regarding their current way of working, without presenting the possibilities of scan data and virtual tools.

During interviews and observations notes were made by the authors. These notes were then interpreted and coded by the authors. Some of the results from the coding can be misleading due to that the authors have either misinterpreted the interviewee when taking notes or misinterpreted the actual meaning of a note. A solution in order to improve the quality of the collected data was to consult someone not connected to the project, in order to get a second opinion.

The conceptual *In context development model* is based on data collected through semi-structured interviews, observations made by the authors and internal documentation. The sample size of the interviewees is not representative for all work performed within the manufacturing development process. In order to make the result more generalised, a quantitative study involving the whole manufacturing engineering department evaluating the possibility to integrate scan data within the development process should have been performed.

In order to improve the quality of the data collected during the case study research, the authors should have participated in the chosen projects from start to finish. However, due to time limitation this was not possible.

8 Conclusion

Scan data is today implemented in parts of Volvo's manufacturing development process. By implementing scan data throughout the whole manufacturing development process the development lead time and cost can be decreased. By incorporating scan data a more detailed virtual verified process can be performed and a more optimised solution can be developed. To implement scan data in the whole manufacturing development process, Volvo has to further develop current software applications.

Research question 1:

Today the usage of scan data is connected to the level of automation in the station that is to be developed. For highly automated stations scan data is used in the development process to align the digital models with the physical installations. The scan data in combination with the digital models create a virtual representation of reality. The process is then verified virtually together with the product in order to ensure that not only the car is possible to assemble but also possible to assemble in the existing environment. At Volvo there are today tools available in order to virtually verify layouts and simulate collision free paths as well as work ergonomics.

For stations where the level of automation is low the virtual process verification is not as sophisticated as for the virtual verification of highly automated stations. For the stations with low level of automation mainly the possibility to assemble the product is virtually verified. Instead the process is verified physically through extensive testing later in the development process. For these stations the use of scan data is today limited.

Research question 2:

Scan data provides Volvo with the possibility to develop a low automated station in a virtual representation of reality i.e. in context development. The conceptual *In context development model* was developed in order to integrate scan data throughout the whole manufacturing development process, independent of a station's level of automation. The model suggest a platform where new stations can be developed based on scan data. The development takes place in the hybrid model which a combination of scan data and CAD models. The hybrid model will increase the level of visualisation which will enable the engineers to identify and communicate problems that today is identified after implementation of the solution. Simulations can be performed in context and alternative solutions evaluated, virtually. The *In context development model* enables engineers to interact with a factory located on another continent without physically having to visit it.

Research question 3

Implementing scan data in the manufacturing development at Volvo is a great challenge due to the size and complexity of the company. Volvo has today come a long way and much of the infrastructure needed to integrate scan data is developed. Today a large scan database and a work method to incrementally update it exist, although still a sufficient solution to store and access the data is missing as well as software functionality.

The conceptual *In context development model* suggest a proposal for how to utilise scan data and by further developing this model in means of software capability and technology acceptance an implementation plan can be established. For Volvo the main issue will be to gain the users acceptance for the technology and to develop and implement it in their standard way of working.

For this further research is needed both concerning the tools suggested in this thesis as well as the implementation regarding the workflow of the *In context development model*.

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Appendix 1

Interview template	
Activity	**Comments/Questions**
Introduction	Brief the participant. Introduce ourself. Explaint the goals for the interview. Review interview method, use of data, confidentiality.
Structured topics	**Topic 1: Background** What is your deparment responsible for? What's the input to your processes? Wha'ts the output of your processes? **Topic 2: The role** How does your work related to the input/output? What tools and software do you have at hands? Do you work individually or in group? Describe the typical problems you encounter. What are youre greatest challenges? **Topic 3: Virtual methods** How are your work related to VM? What issues are there today with VM? What are the greatest benefits working with VM?
Open discussion	General discussion and open dialogue with the participant
Closing comments	