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Supplier-Produced CAD
- from Enabler to Inhibitor of Successful Virtual Testing
Master of science thesis

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ABSTRACT

Usage of CAD models in product development has increasingly become a more and more important feature for companies to stay competitive. In a collaborative business, the inclusion of suppliers delivering CAD increases the complexity. This thesis investigated why a production company, ACME, is receiving insufficient CAD deliveries from suppliers, even though the issue is known in the company. To support this thesis two research questions were formulated: (1) In what way is the virtual delivery insufficient and according to whom? (2) How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?

Interviews were conducted with members of ACME and together with literature research it was suggested that it is the downstream consumers and the receivers of CAD at ACME who experience the insufficiency. Insufficiency is expressed as e.g. incorrect geometrical form or missing material information. Members of ACME and suppliers to ACME express various reasons as potential delivery inhibitors. It was suggested that e.g. difficulties in knowing requirements in an early phase, writing requirements, and following up on them are three potential reasons for receiving insufficient deliveries.

As the issue is known in the organization it is discussed how different identified inhibitors can contribute to the insufficient CAD deliveries and how to make a distinction of if some are more critical than others. It is also discussed how motivation and human behaviours are inhibiting solving the problem, and how they also could contribute to finding solutions.

As the usage of CAD in testing is a fairly new technique compared to the original testing of physical prototypes, requirements are not fully defined within the ACME organization, and also the different departments are yet to agree in some way as their requirements vary. The usage of CAD models in virtual development is becoming more and more important, hence our recommendation to ACME and researchers is to continue investigating this field.

Key words: CAD, Supplier, Organizational learning, Virtual testing

TABLE OF CONTENTS

1 Introduction

Virtual development and verification have become an increasingly crucial part of companies' product development. Crucial due to its cost benefits compared to its counterpart physical production verification. Physical production prototypes used for verification are costly and time consuming (Seth, 2011). There are also several limitations with physical models described by PS Brandon (2008) such as difficulties in building and modifying them. By using virtual CAD models, short for Computer Aided Design, development changes are easier and more efficient regarding aspects such as time, cost and material resources compared to physical testing (Seth, 2011). It is also easier to increase the number of tests run by testing several CAD models rather than several physical products (Tahera, 2019).

Usage of CAD shortens the product life cycle, enabling companies to be competitive in a rapidly changing global market (MC Leu et al., 2013), as is the case at ACME. In order to cut costs and time during product development, ACME, a production company has strived to decrease their physical product tests and replace them with virtual product tests. This means a greater number of tests can be run based on developed CAD models and saves the costs of producing physical test materials, which only can be tested a finite number of times.

Traditionally, CAD has been used for geometrical tests (e.g. verifying possibility to assemble in factory) and clash analysis (e.g. interference in between models) in general development processes, but in recent decades the CAD models have been used for more and more tests in other areas (Huizinga, 2002), as is the case at ACME. As the number of tests based on CAD, as well as the number of areas where used, have increased at ACME, the demands on the test input, i.e. the CAD models, have increased. This means that the traditional CAD models, only fulfilling ACME's geometrical tests, are no longer sufficient enough in other testing areas. ACME has also involved suppliers, to develop and deliver CAD in their development process, which adds a collaborative complexity to the virtual development.

In ACME's strive to replace physical product tests it has come to their attention that the CAD deliveries from suppliers are insufficient based on emerging dissatisfaction from different departments in the organization. Even though the problem has been known by at least some stakeholders for some time in the organization, ACME continues to receive insufficient virtual deliveries causing them to spend time adjusting the received CAD models in order to perform their virtual product tests. Therefore, ACME has called for our investigation.

1.1 Aim of Study

The purpose of this thesis is to investigate and explain the cause of the problem with insufficient CAD deliveries from suppliers to ACME.

1.2 Research Questions

In order to better understand how members of the ACME organization experience the insufficiency in the delivery, RQ1 is formulated:

- RQ1: In what way is the virtual delivery insufficient and according to whom?

In order to understand how members of the ACME organization explain the reasons for the insufficient delivery, RQ2 is formulated:

- RQ2: How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?

1.3 Delimitations

This thesis does not intend to supply a general truth about what sufficient CAD is. It explains the basics of e.g. what the definition of CAD is, and what it is used for, to be able to understand the issue and result at ACME.

Moreover, the thesis does not intend to supply any conclusion of the work performed at supplier companies, it focuses on the work described at ACME office.

Lastly, the study does not focus on how suppliers are selected for collaboration.

1.4 Thesis layout

This section describes the content of the thesis.

Theoretical Framework - chapter 2

This chapter will give a theoretical framework in the area of CAD and in the area of Organizational Learning.

Method - chapter 3

The following chapter will present the parts that formed the study. Firstly, the methodology approach will be presented, followed by a description of the data collection, data analysis and lastly a chapter about trustworthiness.

Supplier CAD at ACME - chapter 4

This chapter will present a more in-depth view of ACME's organisation and the process concerning CAD models.

Result - chapter 5

This chapter will present the results for research question one and research question two.

Discussion - chapter 6

In this chapter the two research questions are discussed by comparing and interpreting findings in the result and the theory.

Conclusion - chapter 7

The final chapter presents the conclusion of research question one and two, as well as a recommendation for future research.

2 THEORETICAL FRAMEWORK

This chapter will give a theoretical framework in the area of CAD and in the area of Organizational Learning.

2.1 CAD Theory

Since this study investigates CAD deliveries from suppliers, it is of interest to understand CAD and the challenges related to it. Therefore, this section will give an insight into what CAD is, the history of CAD, CAD in the development process, usage of CAD, CAD standard and CAD format.

2.1.1 What is CAD

CAD, short for Computer-Aided Design, is used to give a geometrical product definition and is the basis for three-dimensional virtual product models (Hirz, 2013). The CAD model is built up by using a 2D sketch and giving it volume in different directions, see fig 2.1. The volumes (or the geometries) are represented in a hierarchic tree structure where each geometry has its own branch (Hirz, 2013), see fig 2.1. According to M. Hirz (2013), this makes virtual models a good representation of the physical product in both shape and how it is structured.

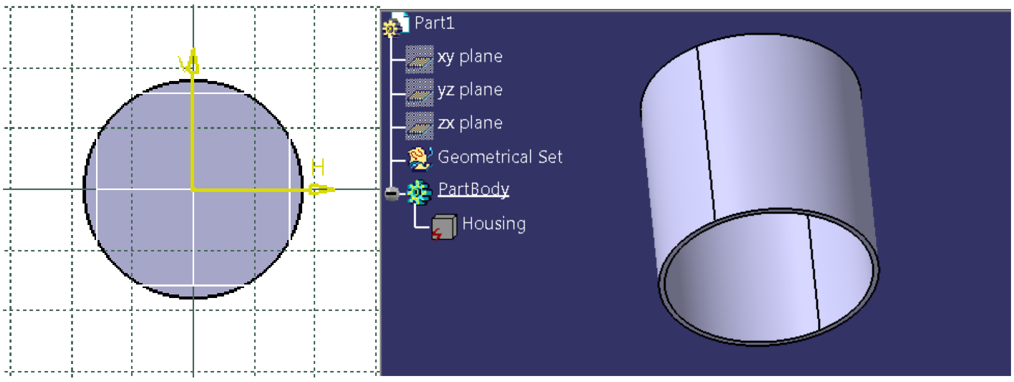

Figure 2.1: The 2D sketch (to the left) is the base for the 3D CAD model (to the right). The 3D model consists of a structure tree and geometry ("Housing").

In the initiation phase at ACME it was discovered that virtual testing based on CAD models enables finding errors in virtual simulations before the physical product is built. In order for the virtual testing to work properly it is important that the CAD models are built in a certain way. For example, there is a virtual simulation that tests whether the product can be taken apart as intended. In order to perform that simulation, the CAD model needs to be divided in different parts. Fig 2.2 shows a CAD model of a lamp that is built up in two different ways. The left one only consists of one part representing the geometry of the lamp, the right one is divided in several parts representing the lamp, as seen in the structure tree. When analysing if the cover can be lifted off the housing, the CAD model needs to be structured like the CAD model to the right, otherwise it is not possible to separate the parts in a virtual simulation. There are also other examples of virtual tests such as ensuring the lamp looks the way it should and that it fits in its surroundings without clashing with something else.

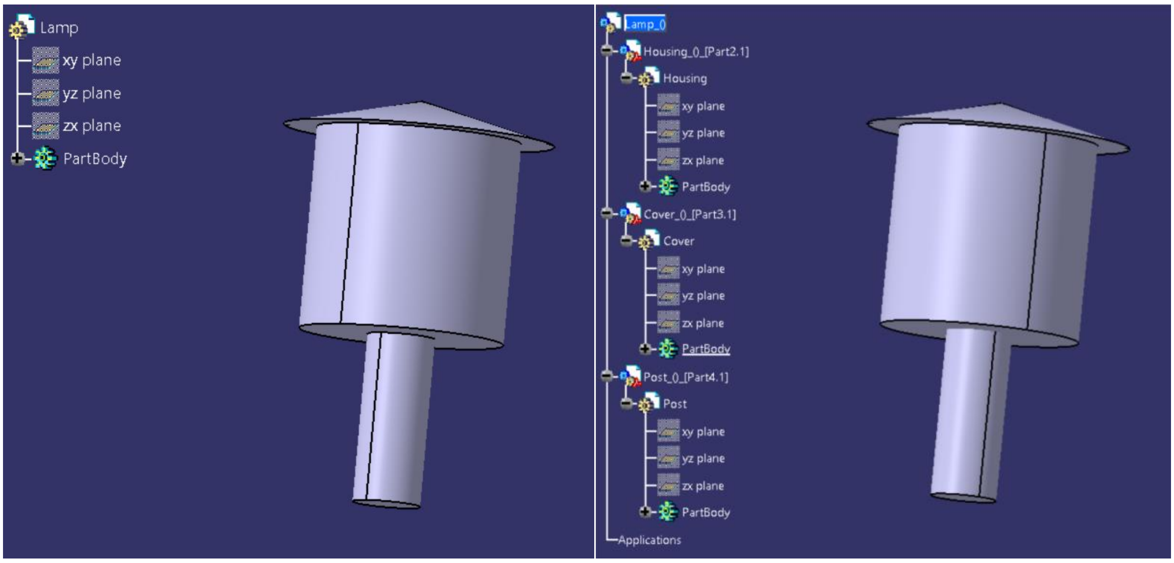

Figure 2.2: The CAD model of a lamp can be designed in two ways, either as a CAD model where the geometry of the lamp is represented in one branch in the tree structure (example to the left), or as a CAD model with multiple branches in the tree structure representing each part of the lamp, namely Housing, Cover and Post (example to the right). In both cases the lamp is fully represented geometrically, but the design approaches are different, and companies may have preferences on which design approach to be used.

M. Hirz (2013) further emphasizes that the CAD model not only is a detailed and near-real-life representation of the product's geometry but also includes a variety of additional information and characteristics. All this information needs to be added to give a complete virtual product model and not only a geometrical model (Hirz, 2013). Examples of information are surface finish, material (see fig. 2.3) and tolerances (Stroud, 2011).

Fatigue life and crash analysis can be carried out based on a Finite Element Method (FEM). In order to perform a Finite Element simulation and analysis of the results, the FEM model most often is generated from a CAD model and complemented with semantic data, e.g. material behaviour laws (Lou et al., 2009). In other words, a CAD model is not enough without the semantic data as it only gives the geometry of the component and the relation between the ingoing parts, rather than also represent physical product behaviour.

In the observations at ACME it was discovered that e.g. thermal testing is performed based on virtual models. To be able to perform thermal testing based on the CAD model of the lamp housing in fig. 2.3, material information is needed to be able to understand how the housing reacts in different temperatures.

According to R Lou et al. (2009) it is always problematic when the semantic data needs to be attached to the CAD model as it could be missed or not updated. Moreover, Stroud (2011) stresses that information handling is not easy as there is no convention as for building geometry and therefore the information handling tends to be a bit ad hoc, meaning there could be differences in how companies and individuals within companies handle additional information. Stroud (2011) also points out that the use of information in CAD is expected to increase in the future.

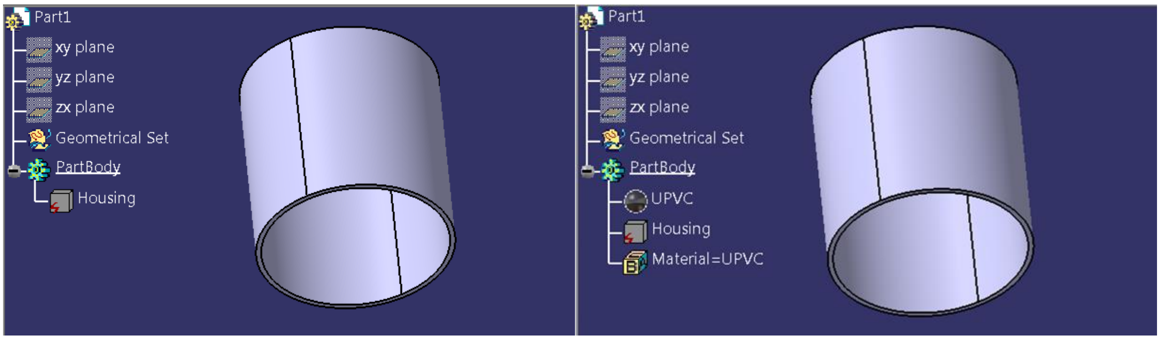

Figure 2.3: An example of additional information of a CAD model is material information. The CAD model to the right has additional material information added (seen in the structure tree).

2.1.2 The history of CAD

Traditionally, CAD has been used for geometrical tests and clash analysis, but in recent decades the CAD models have been used for more and more tests (Huizinga, 2002). Looking at automotive development, the usage of CAD has developed over the past four decades. In the middle of the 1980s, computer-aided design and simulations started to take over the engineering tasks based on hardware development (Hirz, 2013). Before that the automotive development was highly based on hardware and prototype-based optimization cycles, Hirz (2013) further describes. In the 90's it was possible to use geometry data developed by design for the definition of product geometries in simulation processes (Hirz, 2013). By starting to exchange CAD data in the 1990s a network-based development was enabled, bringing together design and engineering departments as well as partners and markets from different countries and regions (Hirz, 2013). By replacing at least one physical prototype loop with virtual prototypes the development time in automotive has been decreased (Hirz, 2013). Hirz (2013) points out the trend of full-vehicle development going from taking about six years including three prototype phases in the middle of 1980 to four years (sometimes even three years) in the beginning of 2010 and that we are moving towards an additional decrease.

2.1.3 CAD in the development process

An example where CAD is deeply integrated in the development is in the automotive development process, where the majority of the involved departments are working with CAD data. Hirz (2017) shows this in the diagram (fig 2.4), where the grey colour indicates to what extent the CAD is incorporated in the discipline's daily work. Medium grey indicates that the discipline's daily work is CAD based. Light grey indicates that the discipline's daily work is not fully CAD based, but there is some involvement of CAD. In the predevelopment phase a complete car is developed in 3D CAD (Hirz, 2017).

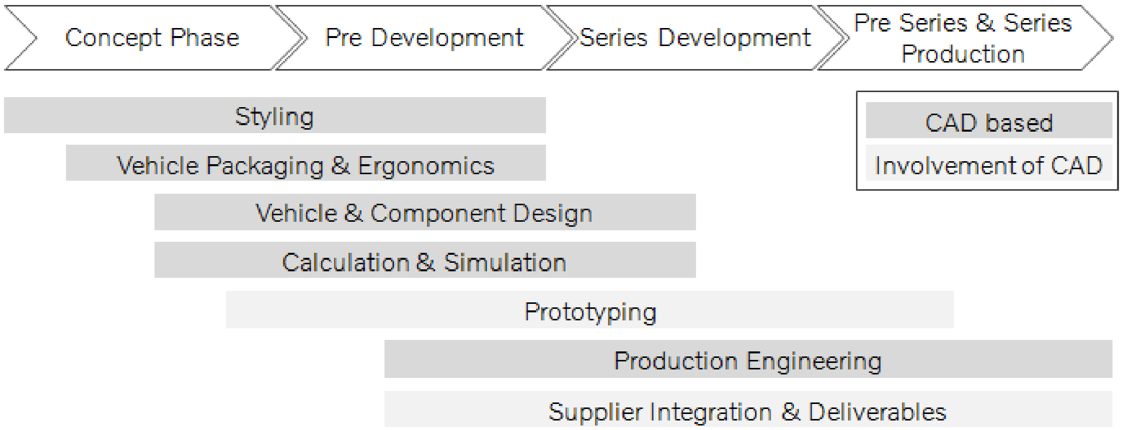

Figure 2.4: Diagram based on M. Hirz describes the integration of CAD in the automotive development process and how big the involvement of CAD is within different departments (2017).

2.1.4 Downstream usage of CAD

Tests based on CAD are used for a range of different purposes (Tahera et al., 2019). Focusing on Vehicle Packaging, Calculation & Simulation and Production Engineering in fig. 2.4 there are a lot of examples on how CAD acts as a base. Design departments use CAD in their intermediate discussions to negotiate over the use of common space and volumes (Stroud, 2011) in vehicle packaging.

The calculation departments use the CAD models to generate meshes for finite element simulations, the representation of dimensions and inertia characteristics are used for simulations. In the area of CAE (Computer Aided Engineering) CAD is used for analyses e.g. noise and vibration, fatigue life, crash behaviour (Huizinga, 2002). In complex products such as vehicles, F Huizinga (2002) further describes the vary of the tests from relatively simple strength tests of components to full-scale fatigue tests of complete vehicle models.

In production engineering the manufacturing departments use the CAD models for analyzing ergonomics and fine-tuning assembling (Hirz, 2017). CAD is used to identify potential assembly related issues via simulation techniques, described by MC Leu et al. (2013) and A

Seth (2011). Another purpose is to analyse the best assembly and disassembly path (Gironimo et al., 2004) which ultimately requires that all existing parts in the product are represented by a CAD model in the virtual analysis as well as have the same geometrical shape, so that the analysis result is in line with the result of a disassembly based on a physical product.

Analysis in the area of perceived quality includes analysis of what customers perceive through their senses, e.g. the feeling and appearance of materials, width of split lines, finish of painted components and the sound and feeling of movable and fixed components (Wickman et al., 2010). These analyses can be based on CAD models and requires semantic information that supports analysis of e.g. the customers' feeling and appearance of materials.

2.1.5 CAD standard

In order to improve consistency, many organisations create their own formal CAD standard (Middlebrook, 2000). Standards are used to manage the quality and quantity of manual labour output, enabling measurability and expectation setting (Zandin, 2001). Depending on the component, the geometries vary, but the methods creating them can be common (Stroud & Nagy, 2011), which could be referred to as a standard. A typical standard could include: design guidelines, file naming, folder structure and supported software products and versions (Middlebrook, 2000). Middlebrook (2000) continues saying customization to support the CAD standard is imperative, though the customization itself will not guarantee compliance of the CAD standard, hence training is a must. In addition, utility programs are a good way to check compliance, though Middlebrook (2000) points out that these programs can only check parts of the CAD standard, and that there is no straightforward economical way to check compliance. Hence, any enforcement of a CAD standard will only be partially successful, and that a combination of supporting activities and some kind of penalties are recommended to maximize the compliance (Middlebrook, 2000).

2.1.6 CAD format

To enhance operability between CAD software systems, there is a need for an open standard regarding formats (Huber, 2011). Today many producers and consumers rely on ad-hoc formats according to Huber (2011). Compatibility between CAD software systems is an issue, if information is lost in the conversion it might be impossible to retrieve it again (Stroud & Nagy, 2011). Neutral standard data formats are often used, though these formats cannot contain any detailed information such as design history, only the geometry is converted (Hirz, 2013). To be compared with the exchange of CAD data within the same software system, where full detail production information and design history can be preserved (Hirz, 2013).

2.2 Organizational Learning Theory

Since this study investigates errors in CAD deliveries, it is of interest to understand why errors occur, and also why they might not be resolved, hence this chapter will describe one theory for analysing failures in organizations and one regarding decision-making concerning why errors might not be resolved. To resolve errors, motivation is essential, hence this chapter will also describe motivation.

2.2.1 Analysing failures in organizations

When a complex system fails, for instance a nuclear power plant, aircraft, oil platform or railway network, the post-accident investigations often focus on those humans who have the direct interface with the system itself, though the origin for the failure might stem from actions performed long before the emergence of a failure (Reason, 1990). In order to understand why socio-technical systems fail, Reason (1990) presents a distinction between active and latent failures.

Active failures are those who have an immediate adverse effect, often associated with actions performed by train drivers, pilots or air traffic controllers. Meaning those whose actions cause an accident almost immediately. Latent failures on the other hand, are those who lie dormant for a long time, associated with actions or decisions made by designers, managers or maintenance staff (Reason, 1990). Reason (1990) continues describing that these latent failures become present in combination with e.g. active failures or atypical system behaviour. In terms of safety benefits, focusing on latent failures is more efficient than focusing on active failures.

According to Reason (1990), decision makers are the main cause for latent failures, but latent failures are present all over an organization caused by a human condition. Human condition can be stress, ignorance, low motivation, or failure to perceive hazards.

2.2.2 Motivation

Is it possible to design work to get more motivated employees? A model for this was developed by Hackman and Oldham (1976), called the ‘Job characteristic model to identify Motivation through the design of work’. They examined when a job leads to beneficial outcomes by combining job characteristics and individual responses to the work (Hackman & Oldham, 1976). They defined a concept for motivation as well as a method to increase employee effectiveness in a workplace.

Hackman and Oldham's model builds on three psychological states:

1. Experienced meaningfulness of the work
2. Experienced responsibility for the outcomes of the work
3. Knowledge of the results of the work activities

The three psychological states means that motivation lies in being aware (3) that you have performed well (2) on a task that you care about (1). Hackman & Oldham (1976) presents five reasons enabling the psychological states to emerge, in the model called core job dimensions. The core job dimensions are possible to achieve by the workplace design, and when in place can lead to desired personal and work outcomes, described in fig. 2.5.

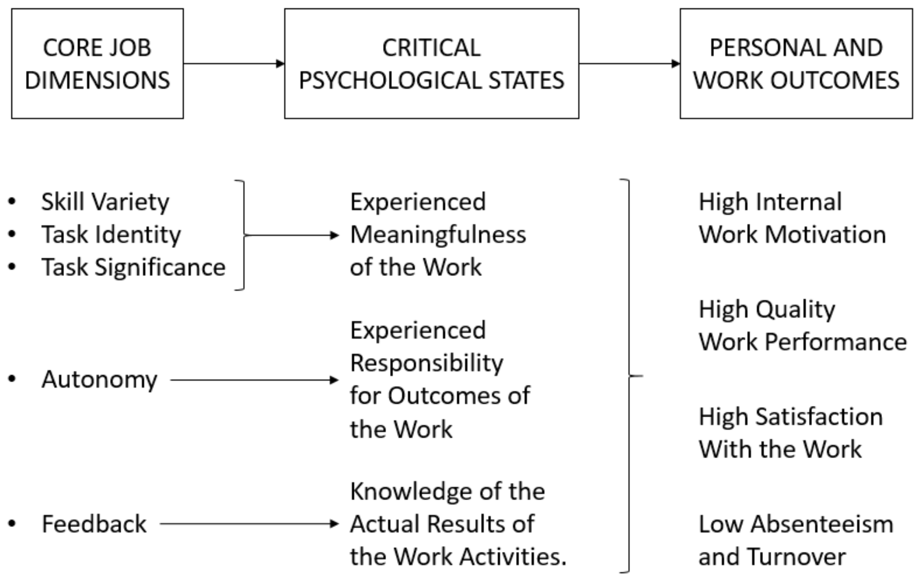

Figure 2.5: The job characteristics model of work motivation adapted from Hackman & Oldham (1976).

Hackman & Oldham (1976) present the core job dimensions in the model to give an understanding of which conditions are important for a job to be motivational, namely the grade of variety, the ability to see the bigger picture in which the task operates, the grade of impact of others, the grade of independency and finally the grade of information regarding how the task is carried out.

2.2.3 Decision making and learning

When making a decision, whatever the outcome of the decision is, a mental map is used to plan, implement and review this decision (Argyris and Schön, 1974 in Anderson, 1994). Though, it is said that when asked about what the reason was for that decision, why it was taken, few people are aware that the maps they used to make the decision are different from what they espoused (Argyris, 1980 in Anderson, 1994). Moreover, when looking at the number of people who actually know the map used for making that decision, that number is even lower (Argyris, 1980 in Anderson, 1994). Meaning there is a difference between why we do something, and what we think is the reason for why we did it, and few people are aware of that distinction, and even fewer are aware of the reason for why they do what they do.

Argyris and Schön (1974 in Anderson,1994) created a model on how people make decisions, described in fig. 2.6.

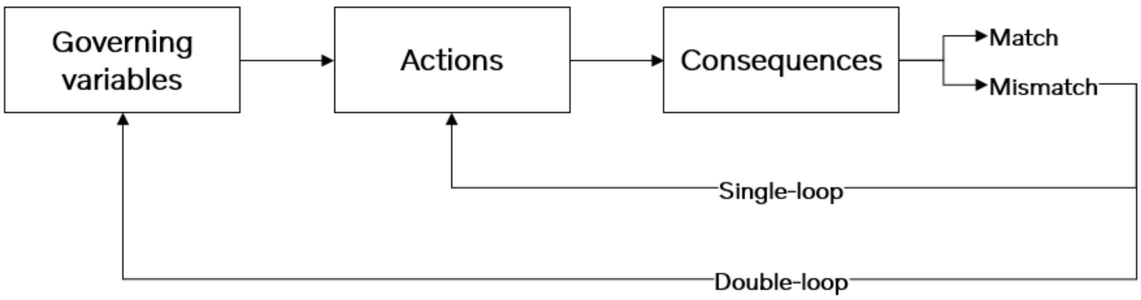

Figure 2.6: Decision making model adapted from Argyris and Schön (1974) in Andersson (1994).

Governing variables are the values or morale people have governing all decision making. The decision making is the actions, what people do depending on their values. The outcomes or consequences of an action can be intended or unintended. A match represents when the consequence and the intention align, whilst a mismatch represents when the consequence is unintended (Argyris and Schön 1974, in Anderson 1994). Argyris and Schön (1974 in Anderson, 1994) assert that a mismatch can have two potential responses, in the model called single-loop and double-loop. Single-loop is when searching for a new action, to see if it will lead to the intended result satisfying the governing variable (Argyris, Putnam & McLain Smith, 1985 in Anderson, 1994). Double-loop on the other hand, is when instead of searching for another action, the person critically looks at the governing variable, maybe changing the variable, substituting it, and then also changing the action (Argyris, Putnam & McLain Smith, 1985 in Anderson, 1994). Double-learning is according to Argyris (1974 in Anderson, 1994) the more efficient way to make informed decisions.

According to Argyris (1980 in Anderson, 1994) there are two different categories of governing variables that can be outlined based on how people act. Category one is the governing variables that inhibits double-loop learning and are characterized by:

- Achieve the purpose as the actor defines it
- Win, do not lose
- Suppress negative feelings
- Emphasise rationality (Argyris, Putnam & McLain Smith, 1985, in Anderson, 1994)

These governing variables express themselves with for example control of oneself or others through treating your own view as absolutely correct, or by omitting important pieces of information to save face. This may result in defensive mechanisms, which could inhibit communication and increase protection of oneself's control (Argyris, 1980, in Anderson, 1994).

Category two is the governing variables that enhance double-loop learning, characterized by:

- Valid information
- Free and informed choice
- Internal commitment (Argyris, Putnam & McLain Smith, 1985, in Anderson, 1994)

In contrast to category one, category two advocates bilateral control with the combination of internal goals and commitment, together with an invitation of others to confront this, minimizing defensive behaviours (Anderson, 1994).

3 METHOD

The following chapter will present the parts that formed the study. Firstly, the methodology approach will be presented, followed by a description of the data collection, data analysis and lastly a chapter about trustworthiness.

3.1 Methodology approach

This study was performed with a qualitative approach. Qualitative research is more focused on generating theories, whilst quantitative research is more focused on testing existing theories (Bryman, 2011). The study was aimed to find concepts and theories explaining why ACME is receiving insufficient CAD deliveries, hence the qualitative approach was chosen as the method for answering the two research questions.

3.2 Research outline

The research design to answer the research questions consisted of the steps described in fig. 3.1 below.

Figure 3.1: The research outline that formed the study.

The method for searching answer to the research questions was divided in two major parts:

- Data collection
- Data analysis

Where the data collection was divided into two major sources of data:

- Literature review
- Interviews

The data collection and data analysis activities were performed in several loops. A loop consisted of collecting, compiling and analysing data, where the analysis gave input where to search for new data. The loops were performed until no new data emerged.

3.2.1 Initiation

The aim with the initiation phase was to:

- Formulate the research questions.
- Decide on the methodology approach.
- Provide a basis of understanding for the data collection activities.

The initiation phase included observations at ACME and research in literature of previous research as well as methodologies and findings within the field. A couple of initial interviews were performed to gain a basic understanding of the organization and the persons involved.

3.2.2 Data Collection: Literature Review

A research in literature was performed to serve the following purposes:

- Provide knowledge in the field and define terms and concepts.
- Provide a basis for analysing and discussing the collected data.

The literature supported the process to understand and explain the possible reasons to why ACME receives insufficient deliveries. In addition, it gave the literature perspective of what sufficient CAD is, how it is defined and how it can be tested.

3.2.3 Data Collection: Interviews

Both research questions sought answers in the context of the organization by conducting interviews. The interviews performed in the initiation phase formed the basis of the interview forms. Three different interview forms were developed, each form containing a mix of specific and open questions, where the open questions encouraged descriptive answers.

The interview sessions were performed semi-structurally. Bryman (2011) describes semi-structurally as a flexible interview method, where interview forms are used, but there is a flexibility in how the sessions are performed. The interviewer may throw the question order and add questions outside the question form, and the interviewees are allowed leeway in how they may reply to the questions (Bryman, 2011).

Both writers were present during all interviews in this study, and both were active asking questions and taking notes. Though interview forms were used, the order in which questions were asked varied depending on the respective interviewee's answer. Moreover, complementary questions were asked in order to encourage the interviewees to elaborate on their answers.

3.2.3.1 Interviewees

The interviews took place at ACME and most commonly with one respondent at a time. A total of 18 interviews were performed, nine with specifiers and receivers at ACME, four with downstream consumers at ACME and five with suppliers to ACME. The quotations in the result were translated from Swedish to English. Table 3.1 below lists the respondent groups and interviewees who were involved in the study.

ACME specifiers/receivers	ACME downstream consumers	Suppliers
Respondent 1	Respondent/department A	Respondent/company alfa
Respondent 2	Respondent/department B	Respondent/company beta
Respondent 3	Respondent/department C	Respondent/company gamma
Respondent 4	Respondent/department D	Respondent/company delta
Respondent 5	-	Respondent/company epsilon
Respondent 6	-	-
Respondent 7	-	-
Respondent 8	-	-
Respondent 9	-	-

Table 3.1: Overview of respondent groups and anonymized interviewees.

The responses of the interviews were handled anonymously in order to not jeopardize any business relationship and to make the respondents feel more comfortable answering the questions. The respondent group referred to as ACME specifiers/receivers covered both interviewees responsible for specifying CAD and interviewees responsible receiving CAD as it varied from case to case if these responsibilities were handled by the same person or by two different persons. In the result they were therefore seen as one respondent group. Department A, B, C and D were all users of CAD data at ACME, but for different purposes and procedures. The supplier respondents were the corresponding senders of the virtual data at companies alpha to epsilon.

3.2.4 Data Analysis

When the data had been gathered through literature review and interviews the two research questions were answered by compiling and analysing the data. The list below shows how the two research questions were answered:

- **RQ1** - In what way is the virtual delivery insufficient and according to whom?
    - Compiling interviews

- **RQ2** - How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?
    - Compiling and sorting interviews

3.2.4.1 RQ1: In what way is the virtual delivery insufficient and according to whom?
To understand what insufficiency is, the literature together with the initial observations at ACME were used. Then to answer RQ1, the interview replies were compiled to locate what kind of insufficiency that was expressed, and who was expressing it.

3.2.4.2 RQ2: How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?
In order to answer RQ2 the interview replies were firstly compiled in a search for patterns. Answers were selected and ultimately included in the result if they were:

- Frequently mentioned in one respondent group.
- Mentioned in several respondent groups.
- Mentioned in one interview but not in others (of interest due the lack of mentioning in other interviews, which implies a variety in focus at the respondents).
- Mentioned and found of interest based on the writers' interpretation and knowledge.

The compilation of answers were afterwards sorted and categorized to what was named as potential delivery inhibitors, in short PDI:s. A total of 7 PDI:s where formulated, representing both internal inhibitors expressed by ACME, and external inhibitors expressed by suppliers to ACME.

3.3 Trustworthiness

Trustworthiness of a research is measured by different criteria concerning reliability and validity (Bryman, 2011). According to Bryman (2011), reliability refers to the degree to which the result is repeatable and possible to replicate. Bryman (2011) further emphasizes that validity refers to whether the findings proves the concept, whether the conclusion represents a causal relationship and whether the findings are applicable in other contexts. Following section will describe how trustworthiness has been acknowledged within this study.

3.3.1 Reliability

There are different aspects of reliability and the terminology is varying among researchers.

External reliability is described by LeCompte and Goetz (1982, in Bryman, 2011) as being the ability to replicate the study. External reliability is also described by Guba and Lincoln (1994, in Bryman 2011) as being the likelihood to which the findings can be applied at other times, though they call it dependability. These criteria are according to Bryman (2011) met by e.g. keeping records of and by describing the context of the study thoroughly. To increase replicability of this study, a thorough description of the data collection and the data analysis approach has been written.

Internal reliability is described by LeCompte and Goetz (1982, in Bryman, 2011) as to which degree the researcher has impacted the result. Internal reliability corresponds to confirmability or objectivity described by Guba and Lincoln (1994, in Bryman 2011) as when the researcher "[...] has not overtly allowed personal values or theoretical inclinations manifestly to sway the conduct of the research and findings deriving from it.". In this study both researchers attended all interviews and were both active in asking questions and taking notes to try to reduce the degree of subjective values affecting the outcome. Though, respondent validation, by sending the result to the respondents before submitting the research, has not been performed due to lack of time.

3.3.2 Validity

Similar to reliability, validity appears in different terms and aspects.

Internal validity is described by LeCompte and Goetz (1982, in Bryman, 2011) as being the level of congruence between concepts and observation. Guba and Lincoln (1994, in Bryman 2011) are instead of internal validity referring to credibility or objectivity when describing how believable the findings of a study are. Bryman (2011) emphasizes using respondent validation and triangulations to ensure a high level of internal validity. Bryman (2011) further describes triangulation as using more than one method or source of data. In this study data collection has included both literature review and interviews, to use several sources of data. Moreover, the interviewees have been from several different departments and roles at ACME as well as from suppliers, to increase the input perspectives. Though, the supplier involvement is mainly limited to suppliers working at ACME office, it is not unreasonable to assume a supplier working outside ACME office might have different views. Apart from interviews, sending out surveys could have served as another source of data.

External validity is described by LeCompte and Goetz (1982, in Bryman, 2011) as to which extent the findings can be generalized to different settings. External validity corresponds to transferability described by Guba and Lincoln (1994, in Bryman 2011) as whether the findings can be applied to other contexts. Bryman (2011) suggests writing a thick description to let readers judge the external validity of the study, in other words if the findings can be generalized to other areas. To enable the reader to determine the degree of generalization of this study to other areas, a chapter called Supplier CAD at ACME has been written to give insight in the concerned context of the study. Though, to fully understand the generalization, the organization itself would maybe have to be revealed, chosen not to in this thesis.

4 SUPPLIER CAD AT ACME

This chapter will present a more in-depth view of ACME's organisation and the process concerning CAD models.

ACME is a production company, developing and manufacturing a product consisting of several parts. The company includes both a product development department and a production department. For some of the parts in the product, ACME procures suppliers to develop, manufacture and deliver their part to ACME. Hence, suppliers need to supply ACME with both virtual models and physical parts.

The process in which ACME's product is developed and manufactured consist of a product development phase and a production phase. Before the product is manufactured in the product production phase, it is developed and tested in the product development phase. The product development phase refines a product concept by testing and retesting to get closer to a final product. At ACME, the development and testing is based on virtual models and as the development phase proceeds physical tests are introduced.

At ACME the CAD is handled by several roles and in different stages of the CAD model lifecycle, from being specified to being used. The different roles will in this paper be called the specifiers, the suppliers, the receivers and the users, see figure 4.1.

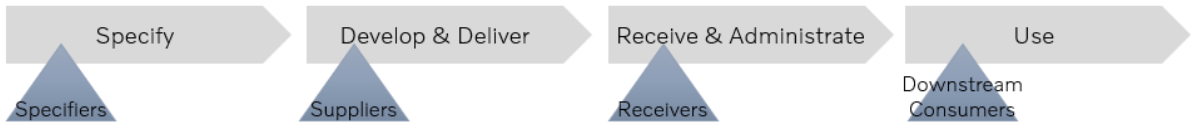

Figure 4.1: During the product development phase a CAD model goes through mainly four steps, namely being specified, developed and delivered, received and administered, and used.

The CAD model is specified by a role called the specifier, who specifies and then communicates the specified requirements to the supplier. The requirements are specified in a document called Engineering Statement of Work (ESOW). Inside the ESOW, amongst others, there is a CAD attachment where ACME specifies what CAD model the supplier should deliver, e.g. what physical product it should represent, and what format it should be delivered in.

Apart from the ESOW document, ACME's CAD standard is central concerning CAD models. The CAD standard governs the allowed formats for the CAD models, and specific CAD design guidelines, whereas in the ESOW the specifier chooses what format and design guidelines the supplier should choose. Depending on format, different design guidelines apply.

The supplier develops the CAD model based on the ESOW and the CAD standard and delivers it to ACME. The one who receives the CAD model from the supplier at ACME is called the receiver.

The receiver verifies whether the received supplier part is according to ACME's CAD standard by using a quality checking tool, different parts of the CAD standard are checked by the tool depending on for instance CAD model format. The receiver also verifies that the part fits together with the other parts in the product and makes the CAD model available for usage by downstream consumers in the organization.

The downstream consumers perform their analysis and simulations based on the CAD model. The downstream consumers aim to reach an optimized product in terms of being able to manufacture, being secure and durable, meeting the customers' needs and desires, being able to repair and being cost and material efficient. The role downstream consumers is divided in four user groups with different requirements: CAE, manufacturing, service and perceived quality.

The CAE departments are calculating and doing FEM analysis, to make sure the product is durable enough, meets safety requirements, meets the customers' expectations of solidity, has a good aerodynamic and doesn't make a lot of squeak and rattle.

The manufacturing departments perform analysis to make the product possible to assemble, plan the assembly in order to make it ergonomic for the assembly workers, make instructions of how to assemble and analyse the capacity and movements of the manufacturing robots.

The service departments prepare for the aftermarket of the product when it has been bought by a customer and needs to be repaired. They analyse to make the product possible to disassemble and repair, make instructions of how to disassemble and replace parts, plan which parts need to be spare parts and which parts must be replaced as a whole system of parts.

The perceived quality departments make sure the customers' expectations of the product are met by analysing surface material, perform light and reflection simulations, verifying spacing between parts and surfaces so that it looks even and are not too big, verifying what other parts are visible in the spacing between parts and make sure they do not disturb the visual expression.

In summary, all described downstream consumer departments at ACME perform analysis and simulations based on CAD models before a physical product exists.

5 RESULTS

This chapter will present the results for research question 1 and research question 2.

5.1 RQ1: In what way is the virtual delivery insufficient and according to whom?

Qualitative interviews have been made to determine what an insufficient delivery is, and according to whom it is insufficient. In the chapter Supplier CAD at ACME, four steps with corresponding roles were mentioned, shown in fig. 5.1.

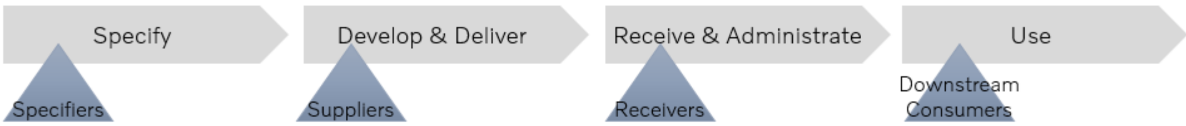

Figure 5.1: The four process steps and corresponding roles at ACME.

To recap, the role that first encounters deliveries from suppliers is the receiver of the CAD model. They are responsible for geometrical analysis and verifying that the delivery is according to ACME's CAD standard. In what way they experience insufficiency is elaborated in the interview responses. The next role to encounter the models are the users, i.e. the downstream consumers CAE, manufacturing, service and perceived quality. Their experience about insufficient deliveries will also be elaborated in the interview responses. In summary, the insufficient CAD models are experienced by the following at ACME:

- Receivers of the CAD models - the geometrical analysts
- Downstream consumers of the CAD models
    - CAE - the durability analysts
    - Manufacturing - the assembly analysts
    - Service - the repair analysts
    - Perceived quality - the visual expression analysts

In the result, the downstream consumers (bullet 1-4 in list above) will be referred to as Department A, B, C and D, the receivers and the specifiers will be referred to as respondent 1-9, and the suppliers will be referred to as alpha, beta, gamma, delta and epsilon.

A sufficient model for department A means a model where "all parts that are physically disassemblable in the real world, should be that virtually" according to respondent A, and in order for all parts to be disassemblable they need to be represented in the CAD model.

Meaning according to Department A, a CAD model needs to have the same form and consist of the same parts. Department B states that there are some issues with the gearbox. Respondent B express: “There is little understanding that the component should be mountable. Screws fit when they are in place but they interfere with the gearbox when being removed.” Moreover, in general each part that is connected to a linkage, needs to be represented in a CAD model as a linkage, in order for department B to analyse the movement of the linkage part. To generalize, department B’s requirement is that a CAD model needs to be able to move as the physical product.

Department C is dependent on material representation in the CAD model, “if no material ID exists it is impossible” according to respondent C, meaning they are unable to perform certain analysis. Material is crucial in order to analyse the behaviour of each CAD model, when running simulations department C needs to be confident the CAD model behaves in the same way as the physical product.

For department D how the part is placed and how it moves, e.g. boundaries that restricts the part, is of great value. Respondent D states: “Restriction volumes are important for all parts”, enabling department D to analyse e.g. sounds (e.g. parts nudging one another), spacing between parts, what is visible between parts (e.g. red cablage), and surface material. In short, department D has a requirement that the CAD model needs to have the same visual expression as the physical product.

The receivers on the other hand experience other issues with the deliveries. Many respondents claimed it was hard to get the CAD models through ACME’s quality checking tool. The quality checking tool, mentioned in the chapter Supplier CAD at ACME, is governed by ACME’s CAD standard. Respondent 6 mentions that the supplier “do not work according to ACME’s standard, assuming it is not required”. Respondent 4 experience the same issue, even though the CAD models “passes ACME’s quality checking tool relatively easy”, adding that the requirements nowadays are higher than before.

Different formats of the CAD models is also a common issue, due to suppliers working in other software than ACME. Respondent 5 says that “the supplier works in other softwares. It is not possible to demand specific formats since ACME wants to keep competition with several suppliers, and if demanding specific formats it would decrease the available selection”. Respondent 3 and 8 refers to the same subject, that it is difficult getting the wanted format from the suppliers, and that “if the suppliers cannot deliver exactly what is specified in the ESOW, it will not overturn the procurement” according to respondent 3. And respondent 8 says that the quality of the CAD models from suppliers differs, and that it “to a big extent depends on the supplier’s software”.

Another common issue is missing material information, since calculation of mass and center of gravity and inertia (MCI) is crucial to be able to understand the behaviour of each part. This is governed by the choice of material ID on each part. Respondent 5 says that they often have to “chase MCI and material data from the suppliers”, and that if MCI is missing at a project deliverable timing they do not prioritize to get that information at that event. Respondent 8 also stresses the importance of MCI, and that department C are in need of this in order to simulate the parts behaviour.

In summary, the result of the first research question regarding in what way is the virtual delivery insufficient, is that the CAD models are insufficient when failing to meet the following sufficiency aspects:

1. Represent the physical product geometrically, e.g. same form and consist of the same parts.
2. Be able to move as the physical product.
3. Include material information, to behave in the same way as the physical product.
4. Have the same visual expression as the physical product.
5. Fulfil ACME CAD standard, e.g. be in the right digital format and CAD design guidelines.

5.2 RQ2: How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?

After the initial interviews and observations of ACME four main roles have been recognized, namely the specifiers of CAD, the receivers of CAD, the downstream consumers of CAD and the suppliers of CAD. Since it varied between our respondents if the receiver was only receiver or specified the ESOW as well, the receiver and specifier were considered as the same respondent group in our interviews. This is also suitable as the specifier and the receiver can be seen as representatives of the same interests regarding their work with CAD models as they are situated at the same department with the same goals. As described in the method the interviews were performed to involve different areas that could possibly affect the sufficiency of the CAD delivery.

In the following section the results of the conducted interviews will be presented. The answers have been compiled and thereafter categorized in seven PDI:s (possible delivery inhibitors) as follows:

- PDI 1 - Investigate requirements
- PDI 2 - Communicate requirements
- PDI 3 - Perception of requirements
- PDI 4 - Fulfilment of requirements
- PDI 5 - Protection of intellectual property
- PDI 6 - Verify fulfilment of requirements
- PDI 7 - Actions performed if unfulfilled requirements

The categories represent different stages where either ACME or the supplier handle the CAD models. Namely, PDI1-2 and PDI6-7 are internal possible delivery inhibitors observed internally at ACME in that very stage. The same applies for PDI3-5, which are external possible delivery inhibitors observed at suppliers.

5.2.1 PDI 1 - Investigate requirements

When resources are limited outsourcing is one alternative, but the aid is of little help if the result of the aid isn't of the same standard as it would be expected to be if developed inhouse. Requirements are formed to represent the result. Forming requirements equals trying to estimate and predict what level of sufficiency that is needed in the future. It is difficult enough as it is, but even more challenging if the development is changing during the process. This is investigated in this PDI.

5.2.1.1 Difficulties in setting requirements at an early stage

The downstream consumers emphasized the complexity in stating their respective requirements in an early stage of the process. Respondent A mentioned the fact that they form requirements on a structure early in the process when in fact the complexity of the structure isn't yet developed or established.

5.2.1.2 Differences in downstream consumers' level of requirements

Respondent B emphasized the fact that they should not set too high general requirements in an early stage, since that might backfire: "it costs more to demand it, and we would get blamed if it shows that we do not actually need it". While respondent C talked about the fact that "it could be so that more than is needed is required, rather than having to fix it afterwards".

5.2.1.3 Downstream consumers perceived ability to influence

Regarding how the downstream consumers perceive their ability to influence the sufficiency of the CAD models, respondent A was discouraged, respondent C was dedicated, while respondent D was very hopeful.

5.2.1.4 Downstream consumers work emphasizing their requirements

Moreover, there is a difference between how the downstream consumers work regarding their respective requirements on the CAD model, and how they reach out with their requirements. Department C uses a document stating their requirements at different stages of the construction, while the other departments call if there is something missing, or they fix the problem themselves without calling.

5.2.1.5 Perception of CAD models usage at ACME

When the CAD receivers were asked what the CAD models are used for at ACME and who uses them, department C was mentioned the most. 1 out of 4 respondents mentioned all of the four downstream consumers, but overall when the respondents elaborated about the downstream consumers they focused on department C. Apart from department C, packing stood out as a clear focus.

5.2.2 PDI 2 - Communicate requirements

Setting requirements raises several issues, for example regarding how to formulate the requirements such that another person understands it and can work according to them. Moreover, how two people interpret the same information may not always be aligned, depending on for example experience and point of reference. This PDI intends to investigate these kinds of issues.

5.2.2.1 Competence to specify

During the interviews with respective downstream consumers both respondent C and D mentioned that competence and experience is the key when formulating requirements to the CAD models. Overall, the downstream consumers expressed that competence and experience is vital when working with the CAD models, and that their respective department should be included in the process to aid the work.

5.2.2.2 Dialogue across departments when formulating specifications

All of the downstream consumers (department A, B, C, D) talked about the fact that there is a need for dialogue between downstream consumers and the person who specifies the CAD models to determine what to specify in the CAD attachment in the contract. Respondent A said that “it should not be possible, they should be forced to make contact” , and respondent B said that “they should talk to department B”, “need to have a dialogue with department D” according to respondent D. Respondent B said that there is a need to “work more in cross-functional teams to solve tasks together”.

5.2.2.3 CAD receivers perceived ability to influence deliveries, when set requirements are low

Overall, the receivers appeared to feel little control over the CAD sufficiency when the contract is written, 3 out of 4 felt that the CAD model was not a prioritized delivery but rather an appendage to the physical product.

Moreover, it seemed as the CAD receivers perceived the suppliers’ ability to deliver sufficient CAD models to be low on the priority scale when ACME decides which supplier to contract. Further respondent 7 expressed that the contract “feels rather bureaucratic, not so high on the priority list, mainly quality history and price”, meaning that the CAD models’ requirement is not what determines the choice of supplier.

Further, they expressed that if the software used by the supplier is different from the one at ACME the ability to set higher requirements decreases which affects the sufficiency of the CAD models.

5.2.2.4 Requirement of using ACME’s virtual standard

Regarding the contract respondent 6 expressed that the supplier (that is involved with respondent 6) doesn´t work according to ACME’s standard, and the respondent assumes that it is not required to work according to it. Respondent 5 perceived ACME’s standard to be “a necessary evil", and that it was not included in the dialogue with the suppliers since the supplier did not bother to use it.

5.2.2.5 Ability to receive more sufficient virtual deliveries

The CAD receivers perceived that they could get more sufficient CAD models from their suppliers if they asked, though it was not clear to which extent this was made. But it was mainly done when they got feedback from downstream consumers concerning insufficient CAD models. In contrast, downstream respondent A expressed that it is "not sustainable in the long run to hunt", meaning that it is too costly to always be forced to chase a more sufficient CAD model.

5.2.2.6 Ability to communicate requirements in relation to length of partnership

Overall, the CAD receivers perceived that the dialogue with their respective suppliers worked well, especially with those whom they collaborated with for many years. It was expressed that if they needed something more regarding the CAD models, they (the CAD receivers) could ask the suppliers for that and then they usually got it.

5.2.3 PDI 3 - Perception of requirements

In an organizational partnership there are at least two parties. They have a collaboration of which the requirements are defined in a contract. It is of interest to review the contracted party's interpretation of the requirements since this interpretation is what is going to lead to an end result. Inhibitors can for example be that the contractee has biases that make them interpret in a different way than the intended, or that the contractor has not been thorough enough. This PDI will investigate these types of inhibitors.

The interviews revealed that the suppliers have more complex models (that they use for manufacturing) than they deliver to ACME, but the cause for this varies.

5.2.3.1 Perception of what ACME is interested in

Respondent beta expressed that ACME "don't want to see everything" and ACME are "not interested in close details" according to respondent epsilon, referring to parts of the CAD models. Moreover, respondent epsilon mentioned that company epsilon keeps the complexity down in the model they deliver to ACME since they can be difficult and time consuming to handle.

Both respondent gamma and delta mentioned that ACME wants "editable models", but respondent gamma expressed that "in some cases ACME don't need editable models, it varies between different departments, depends on how much the contract is specified".

When asked what is specified of the CAD models respondent beta claimed that the expected delivery is to be regarded as “exactly as it looks installed in the end product”, respondent epsilon and gamma emphasized that the specification is general while respondent alfa didn’t know what was specified regarding the CAD model.

5.2.3.2 The ability to assimilate a comprehensive document of requirements
Both respondent delta and epsilon mentioned difficulties with documents. Respondent epsilon expressed that the pile of paper representing the contract consists of documents nearly looking the same from one project to the other, which made it challenging to spot out the changes made. Respondent delta focused on documents which presents what has changed regarding the CAD models. These documents were perceived hard to interpret due to bad colouring and too many details on the same document.

5.2.4 PDI 4 - Fulfilment of requirements

Perception of requirements may as mentioned be an inhibitor for sufficient CAD models, it is connected to the individual and hence challenging to control. In addition to perception, work preferences is another highly individual feature. Work preferences could be a strive to simplify the work performance or make it less time consuming, based on a selected perspective (yourself, your department, the whole world). This PDI intends to investigate what a work preference could be and how it can be an inhibitor.

5.2.4.1 Level of complexity required in the virtual model
Respondent beta mentioned that company beta had to “redo much because of the new requirements”, since ACME requires a higher complexity than before. Company alfa gives ACME CAD models of low complexity. However, the CAD models used at company alfa are of a more complex nature consisting of many parts (called a master model), meaning that the CAD models they deliver could easily be more complex. Another company, epsilon, as well emphasized that the key is to “keep the complexity down”. Respondent epsilon continued with mentioning that it is “less work with the dumb model, it saves time”, meaning that it was less work for ACME with the dumb model.

Further respondent epsilon expressed that it was “difficult to handle the master model”, meaning that the fully detailed model was too complex to handle for ACME. Respondent epsilon also expressed that “boolean is the best way”, and that company epsilon “try to use boolean as much as possible”, which can be seen as a more efficient way of producing the virtual model.

5.2.4.2 Time spent checking sufficiency

Moreover, respondent delta mentioned that it is mandatory to perform checking on all the CAD models separately, which takes a lot of time. Respondent delta also mentioned that it takes time to perform the mandatory checking for all the CAD models and therefore the CAD models are gathered until the checking is performed. The checking referred to, involves verifying whether the model is created according to ACME's CAD standard.

Respondent alpha expressed that company alpha delivers a less complex CAD model to ACME since they otherwise would have had to "redo every part making them a dumb part".

5.2.4.3 Access to support needed to fulfil requirements

All of the suppliers had heard about the supplier portal, but only one of them use it regularly. Respondent delta mentioned having difficulties logging in the recent past. Further respondent epsilon expressed that it was "quite tricky to navigate and find areas" on the supplier portal.

Respondent alfa and gamma argued that it was important that the project leader on ACME communicates any changes, updates and if the time plan changes.

5.2.4.4 Changes in the project

Four of the five interviewed suppliers expressed the fact that ACME makes many changes during projects. Respondent epsilon emphasized that it is "up to ACME in the end, to decide if they will take the cost", since the changes might not be included in the agreed contract.

Respondent gamma mentioned that it is usual with changes because of the fact that testing and analyses are late. Furthermore, respondent alfa expressed that ACME have an ongoing development process during the construction process with the aim to adjust and improve the end product.

5.2.5 PDI 5 - Protection of intellectual property

In a competitive market a cutting edge is vital to be able to challenge for lucrative contracting. Cutting edge could be technical knowledge, called know-how or intellectual property, which the company who owns it value very high and want to keep for themselves. This know-how is likely to be sought-after by other companies fighting for the same contract, and likely in interest by the company that is prepared to contract you. This PDI will investigate the interaction and compromising between the set technical requirements by the contractor and the know-how at the contractee.

Respondent alfa mentioned that company alfa “don’t want to give everything to ACME”, referring to the company know-how, and that there was a perceived risk that ACME, with the know-how in possession, “would go to other companies” to get a more favourable offer than company alfa proposed.

Respondent beta agreed, mentioning that company beta do not wish to show all the details since if they do there is a risk that ACME could learn it by themselves or procure another company, meaning company beta loses their cutting edge.

5.2.5.1 Concern about competitors having access to virtual models in ACME’s system

Moreover, respondent beta and epsilon expressed another cause for not wanting to share their know-how, namely that there are other suppliers working at ACME with insight in the internal data system and thus with access to their respective company’s know-how.

Other issues that were raised during the interviews with the specifiers regarding the ability to specify more and why a specific type of model was specified was that the suppliers “don’t want to show all details”, “want to protect their intellectual property”.

5.2.6 PDI 6 - Verify fulfilment of requirements

Sufficiency assurance is central regardless of what is developed. In a similar way as inhouse development needs verification, either software or human, outsource development is in need of being verified as well. Like requirements are set to increase the probability that the delivered result is what is expected, the verification needs something to verify against. Something that answers to the requirements in the best way possible. Challenges could be that there is still room for human interpretation, and that software only can test a limited number of things. This is investigated in this PDI.

5.2.6.1 Competence to verify fulfilment of requirements

The interviews with the downstream consumers revealed that experience and competence are keys to be able to verify the CAD models. Respondent A said that it is “indeed possible”, but “it is not easy”, and that it requires “great understanding” which refers to whether it is possible to test the CAD models before they are stored in the common database. Respondent B mentioned that “the competence is lower than needed to determine that”, with that referring to sufficient CAD models. Respondent C emphasized that it is “beneficial that the designer sits down with department C and checks if it is okay. Experience is needed to do a comprehensive check”.

5.2.6.2 Methods to verify fulfilment of CAD models

Further, the CAD receivers were asked whether they tested the CAD models in some way before they store them into the common database. Aside from the mandatory sufficiency checking program, the testing was limited. Respondent 5 said that “it is not that thoroughly specified that we can check against the specification”, respondent 6 and 7 emphasized the fact that the checking program is the focus and that modifications are made only to make the CAD models pass through the verification.

The CAD receivers claimed that there was none, or little, dialogue with the downstream consumers to verify the sufficiency of the CAD models. Though it was emphasized that department C got their models that they need.

5.2.6.3 Late changes in the project

The interviews revealed that there are many changes during the process, sometimes late in the process, which makes it difficult for many of the stakeholders since they need to adapt their work to the new changes. Respondent 8 and respondent C emphasized the fact that ACME does many changes during projects.

Moreover, several CAD receivers expressed difficulties regarding how to determine the revision of the received CAD models. The consequence is that the verification of fulfilment of requirements is even more complicated.

5.2.7 PDI 7 - Actions performed if unfulfilled requirements

Verification of inhouse and outsourced development is necessary to guarantee a certain level of sufficiency. The inhouse development uses methods and standards defined by the company, as well as the company set requirements to the outsourced company that corresponds to the methods and standards in house. If the development from outsourced companies isn’t approved by the verification, modification is necessary. Modification that could alter the developed result if precaution isn't taken. In spite of the modification’s potential necessity, recurring delivery insufficiencies is a clear sign that something that lies beyond correction and modification is missing. The person on the receiving end can choose to work in a reactive or proactive manner. This PDI will investigate the process in correcting unfulfilled requirements.

5.2.7.1 Time pressure due to the standardised process

The interviews with the CAD receivers revealed that it is of high importance to release models into ACME’s common database at the project deliverable timings. Other departments are depending on that specific models are in the system at specific times, and models turned in late cause delays as well as irritation according to respondent 9.

5.2.7.2 Modifying by receivers

The interviews revealed that it is not uncommon that the CAD receivers do modify the CAD models. Respondent 6 expressed that a model that doesn't meet the requirements gets modified to get through the sufficiency checking.

Respondent 7 mentioned that every model needs a couple of hours modifying. When asked if there is a risk to alter the model in an improper way, the respondent mentioned that there is a risk that "things disappear" when modifying.

In situations when the pressure of time is palpable (for example facing a gate) and whenever it is perceived to be more efficient, the majority of the CAD receivers mentioned that they rather modify the CAD models themselves than sending them back to the supplier. At the gates it is of higher importance according to the CAD receivers to get the model into the common database, and some parts regarding the CAD model get disregarded. For example, respondent 5 said that "at the gates things get prioritized away" and continued with claiming that it takes "more time to get a model from the supplier, goes much faster at ACME". It "feels more efficient" according to respondent D, to do it inhouse.

5.2.7.3 Feedback

Overall, the CAD receivers give some kind of feedback to their suppliers. The CAD receivers experience that suppliers mostly have a positive attitude to the feedback; they want to deliver what is expected. But respondent 5 emphasized that
"it is not much dialogue around CAD models". Respondent 6 experienced that it felt redundant to send insufficient CAD models back since the suppliers don't have insight in the requirements of the sufficiency checking.

5.2.7.4 Modifying by downstream consumers

Moreover, the interviews with the downstream consumers revealed that all four of them modified the CAD models as well when they perceived it to be more efficient. Respondent D mentioned that department D had to do manual work, "unnecessary extra work", and 60% of the work was preparation work, making the CAD models sufficient. Further, respondent B emphasized that department B have to make estimates and assumptions when they get insufficient CAD models.

5.2.7.5 Modification to meet the downstream consumers requirements

Further, respondent A expressed that over half of the work that is performed on A:s department is used to make the CAD models they receive useful and ready for analysing. Respondent A also mentioned that the result of the work they do to make the CAD models useful very much could be of use for other downstream consumers. Respondent C was on the same track talking about the risk that sub departments of department C were remaking the same CAD models, meaning the same work is done by different people.

5.2.7.6 Dialogue across departments regarding fulfilment of requirements

Though all of the downstream consumers emphasized the need for dialogue with the CAD receiver, there was a difference between how they handled situations where they got insufficient CAD models. Respondent C stated that there was a good dialogue. Respondent A claimed that there exists a dialogue but that the typical response is “we are working with it”, and in the end the result doesn’t show that there never was any ongoing work. The other two respondents said that there was either not enough, or no talk at all.

6 DISCUSSION

In this chapter the two research questions are discussed by comparing and interpreting findings in the result and the theory.

6.1 RQ1: In what way is the virtual delivery insufficient and according to whom?

A two-part question, where the second part delivers a straightforward answer. The issue is experienced by the following user groups at ACME:

- CAE - the durability analysts
- Manufacturing - the assembly analysts
- Service - the repair analysts
- Perceived Quality - the visual expression analysts
- The receivers of the CAD models - the geometrical analysts

One could argue, or perhaps speculate, without knowing anything about CAD, that insufficient CAD deliveries could be due to one or several of the following reasons:

- Lack of global way of creating CAD.
- Limited possibility to quality enforce CAD deliveries.
- Limited possibility to quality check CAD deliveries.
- Differences in sufficiency aspects depending on user group.

Previous research indicates that the usage of CAD has rapidly increased the past decades. This could indicate that the complexity in the deliveries has increased. From being used for geometrical purposes, to include other data, such as material information. The result of research question one, indicates that ACME, to make way for a streamlined CAD usage throughout the company, has developed a CAD standard, to help guide designers, as well as suppliers, how to design CAD according to ACME’s needs. Whether this standard is in line with global standards needs further investigation. Though the fact that ACME has a standard is an advantage in terms of possibility for suppliers to fulfil ACME’s requirements.

Moreover, the standard itself, as researchers claim, is not sufficient enough to guarantee a common design of CAD, enforcers are needed. The CAD standard itself cannot act without enforcement, as Middlebrook (2000) states, evidently ACME has a quality checking tool to verify the fulfilment of the CAD standard. So, ACME has a CAD standard, and ACME has a quality checking tool, still they are not receiving sufficient CAD deliveries from suppliers.

Result indicates that more than half of the CAD receiver respondents, experience issues in terms of the CAD models not passing ACME’s quality checking tool, raising the question whether the suppliers are testing the CAD models or not. CAD receiver respondents claim this is due to lack of correct format. Meaning, if the suppliers are not having the same CAD format as ACME, the possibility to quality assure the models using a quality checking tool is limited next to none. As Stroud & Nagy (2011) state, compatibility between softwares is an issue in terms of conversion deviations, meaning information can be lost and not retrieved back again, missing information means missing quality. The results are inconclusive whether the requirements can be fulfilled to some degree even without the correct format. A common error seems to be lacking material information, though whether this can be enforced when suppliers are having another CAD format needs further investigation. Hirz (2013) states working in other softwares restricts sharing information to only geometry, meaning detailed information as for example material might not be converted.

The result further indicates that there is at least one major difference in how department A through D (downstream consumers), and respondent 1-9 (CAD receivers), experience CAD insufficiency. The receivers focus more on system driven requirements, with the models not passing the quality checking tool or not being in the right format, whilst the downstream consumers focus on how they are limited in their work due to functional requirements not being met, such as a CAD models ability to move and behave in analysis. The explanation for this might be as easy as that the CAD receivers and the downstream consumers have different things they work with, but it raises the interesting question: is it possible that some requirements are not possible to test, unless the models are in the hands of that specific user group?

As the areas where CAD is used throughout the development process have increased, it might be so that some requirements are not possible to enforce with a CAD standard and a quality checking tool, which evidently leads us to the second research question, how do members of ACME and ACME’s suppliers explain why ACME is receiving insufficient virtual deliveries?

6.2 RQ2: How do members of ACME and ACME's suppliers explain why ACME is receiving insufficient virtual deliveries?

The result of the second research question indicated various reasons for why ACME is receiving insufficient CAD models, according to members of ACME. The following reasons were formulated, called possible delivery inhibitors (PDIs):

- PDI 1 - Investigate requirements
- PDI 2 - Communicate requirements
- PDI 3 - Perception of requirements
- PDI 4 - Fulfilment of requirements
- PDI 5 - Protection of intellectual property
- PDI 6 - Verify fulfilment of requirements
- PDI 7 - Actions performed if unfulfilled requirements

A couple of topics will be discussed:
Possible differences in criticality in between PDIs?
What drives motivation in terms of CAD sufficiency? By whom?
Could there be other behaviours inhibiting learning in the organization ACME? What?

6.2.1 Possible differences in criticality in between PDIs?

It is possible to speculate that one PDI is maybe more critical than the other, though how does one determine criticality? Reason offers a theory that gives an idea of what types of inhibitors that might need more focus than the others. Reason (1990) offers a distinction between different types of failure types, namely active and latent failures. Some of the possible delivery inhibitors can be categorized as active failures, while others can be called latent failures, where Reason (1990) indicates the latent failures should be prioritized when seeking to prevent a failure from reoccurring (insufficient CAD deliveries).

Moreover, Reason (1990) mentions that the so-called accident occurs in combination with an active failure. Hence, the accident of insufficient CAD deliveries can stem from a string of latent failures, and on top of that an active failure being the ignition who lights the fire. It will be further elaborated what of the results that do not immediately lead to insufficient CAD deliveries, hence can indicate a latent failure.

For instance, in the result challenges when writing requirements were mentioned, which could indicate latent failures. It is mentioned by the downstream consumers, setting requirements in an early phase is challenging, as all the information is not at hand when it is time to write the agreement. Meaning, agreements are signed with suppliers, though it is not until later on, when deliveries are received the insufficiency is discovered. As the effect of insufficient agreements is not discovered until deliveries are received, this can be seen as a latent failure according to Reason (1990). Whether early phase refers to an extraordinary early phase, or early but in accordance with how ACME in general write specifications, remains unclear. Maybe what is required in terms of specifying is not according to the maturity of the downstream consumers' work at that time. How much of an impact this may have on the deliveries needs further investigation.

Moreover, competence is another topic raised by downstream consumers that could indicate a latent failure. For instance, if uneducated people are put in a position of writing agreements, there is a risk of low quality of the agreement. The consequence is that suppliers develop with insufficient requirements, therefore sending insufficient CAD models, but according to the written agreement.

Given the agreement is sufficient, still the supplier might deliver insufficient CAD models. Another latent failure could be that the receiver of the insufficient CAD models is uneducated, approving the delivery by not sending feedback due to not understanding the supplier is obliged by agreement to deliver sufficient CAD models. Whether competence is the main issue at ACME, needs further investigation.

6.2.2 What drives motivation in terms of CAD sufficiency? By whom?

Could feedback have a positive effect on motivation leading to increased CAD sufficiency? When there is feedback given to the suppliers, the CAD receivers experience that suppliers mostly have a positive attitude to the feedback. In line with the experiences of the suppliers mostly being positive to the feedback, Hackman & Oldham (1976) describes feedback being a vital part in feeling motivated. One could also argue that lack of feedback might lead to the suppliers not being aware of the issues, hence leading to repetitive insufficient CAD deliveries from suppliers. Moreover, the downstream consumers also mentioned they were urged to modify models in order to perform their work, meaning there might be a lack of feedback from the downstream consumers to the CAD receivers as well. The result also indicates there was either not enough, or no talk at all between the downstream consumers and the CAD receivers.

In the interviews the CAD receivers mentioned that they modify the CAD models themselves instead of sending feedback to the supplier. They stated that it was more efficient to redo the CAD models themselves to pass the checking tool. Two reasons mentioned in the result for this were time pressure and that the suppliers did not have enough insight in the checking procedure to be able to correct the models. In addition to these practicalities, to fix the model in time and to pass the checking tool, could it also be a way for the CAD receiver to be in control and to add a sense of autonomy to the task of receiving CAD? As Hackman and Oldham (1976) states, Autonomy is a necessity for feeling responsible for one's task which leads to higher motivation. Whether modifying and not sending feedback is a representative issue at ACME, needs further investigation.

Could increased awareness of the users of CAD have a positive effect on motivation leading to increased CAD sufficiency? According to the result, not all CAD receivers knew about all the downstream users of their CAD models in the system. Knowing that one's work affects others and plays a significant role for someone else is described by Hackman and Oldham (1976) to add motivation. Unawareness of the CAD data users might result in missing to verify that the CAD deliveries meet the requirements of the CAD data users. Though all models are checked with the quality checking tool, could it be that the CAD data users' requirements is not checked by the tool? Whether this is actually the case at ACME, needs further investigation.

6.2.3 Could there be other behaviours inhibiting learning in the organization ACME? What?

As ACME is aware of the issue, how come they have not solved it yet? Is it because they are not learning, and if so, why are they not learning and thus maybe improving deliveries from suppliers? There are according to Argyris behaviours in human beings that inhibit learning, called category one behaviours. The result of research question two indicates reasoning from the respondents that can be associated with category one behaviours, hence then inhibiting double-loop learning (Argyris, 1980, in Anderson, 1994). This will be further elaborated.

The downstream consumers claimed there was a complexity in setting requirements in an early stage towards the specifiers. Downstream consumers state that their demands could cost a lot of money, and if later on in a project it is shown they do not need what is specified, they will be blamed, hence they set low requirements. But on the other hand, it is also stated that they set too high requirements, to avoid getting in a situation where they later on in a project find out they would need more. The downstream consumers' reasoning indicates a defensive relationship, where they take measures, to avoid getting in difficult situations later on in. According to Argyris (1980, in Anderson, 1994) defensive relationships is a consequence of behaviours inhibiting double-loop learning. Moreover, the downstream consumers claim that they need to be more involved when the specifiers are setting requirements, which could indicate that today the communication between the downstream consumers and the specifiers is dysfunctional. For instance, respondent A mentions that the specifiers should be forced to make contact, indicating a defensive relationship where they do not have as much of a say as they perhaps would want to have. Defensive relationships might inhibit double-loop learning according to Argyris (1980, in Anderson, 1994).

The CAD receivers claim that when the contract is written, they experience that they have little control of the quality of the delivery, they experience that it is not a prioritized delivery in the specification and not the main reason for choice of supplier. It was mentioned in the result from downstream consumer respondent A, when asking for an updated CAD model, that it was ongoing, though they never received an update. Actually, the majority of the downstream consumers experienced lack of communication when trying to reach out to the CAD receivers regarding the deliveries. Lack of communication, or withholding information, can be interpreted as a defensive mechanism, indicating that the CAD receivers reasoning can be associated with category one behaviour. Defensive mechanisms might inhibit double-loop learning according to Argyris (1980, in Anderson, 1994).

Downstream consumers also state that they redo a lot by themselves, making the CAD models good enough for their analyses, since they judge that it is more efficient for themselves to redo than to ask for it. The downstream consumers rationalize this redoing as more efficient, even though it is a delivery they should receive from the supplier. Rationalizing their own view is by Argyris (1980, in Anderson, 1994) also mentioned as a category one behaviour, inhibiting learning. The receivers of the CAD models state the same, it felt more efficient to perform the modifications themselves instead of sending feedback to the supplier. In addition, the CAD receivers mention they assume ACME CAD standard is not a requirement, as the supplier deliveries do not fulfil it. This reasoning indicates that the CAD receivers treat this view as the obvious one, which is by Argyris (1980, in Anderson, 1994) also mentioned as a category one behaviour. The results are though inconclusive whether this is a representative scenario for all receivers of CAD at ACME.

7 CONCLUSION

The final chapter presents the conclusion of research question one and two, as well as a recommendation for future research.

The aim of this study was to investigate why ACME receives insufficient CAD models from its suppliers. Two research questions were formulated for this very purpose. The first research question was used to understand in what way the CAD models were insufficient, and according to whom, while the second research question was formulated to understand in what way different stakeholders at ACME explain why this issue exists. Qualitative interviews were used to answer both research questions.

To recap, a CAD model is a virtual representation of a physical part. ACME, a company producing products, performs virtual tests on the CAD models in a development phase instead of testing physical parts, due to the time and cost of producing physical parts. Some parts of the product are developed and manufactured by suppliers. In other words, the tests in the development phase include CAD models developed by suppliers.

The first research question is a two-part question, part one regards in what way the CAD models are insufficient, and part two is according to whom. To answer the first part, we need to understand what a sufficient CAD model is.

First of all, it must represent the physical part in all geometrical aspects, e.g. it must have the same form and content. It also needs to be able to move in the same way as the physical parts, e.g. inertia and degree of freedom. The CAD model also needs to include data describing the behaviour which is representative for the physical part. As an example, metal and plastic do not behave in the same way, therefore the CAD model needs to have information about which material it consists of and how that specific material behaves. The CAD model also needs to have a visual expression representing the physical part. And finally, it needs to be in the right digital format in order to be handled in the tools and systems where it is analysed.

To summarize, the CAD model needs to fulfil following sufficiency aspects:

1. Represent the physical product geometrically, e.g. same form and consist of the same parts.
2. Be able to move as the physical product.
3. Include material information, to behave in the same way as the physical product.
4. Have the same visual expression as the physical product.
5. Fulfil ACME CAD Standard, e.g. be in the right digital format and CAD design guidelines.

The conclusion to part one of the first research question, why the CAD models are insufficient, is that the CAD models to ACME fail in meeting either one or several of the mentioned sufficiency aspects.

The second part of the first research question concerns according to whom at ACME, the CAD models are insufficient. Five user groups have been identified performing virtual tests on the CAD models, they can be summarized to:

A. CAE - the durability analysts
B. Manufacturing - the assembly analysts
C. Service - the repair analysts
D. Perceived quality - the visual expression analysts
E. The receivers of the CAD models - the geometrical analysts

The first user group, A, is the one who makes sure the product is solid, durable and that the product can be used without breaking. User group B is the one who makes sure the product can be assembled in the factory. The third user group, C, makes sure the product can be repaired if it breaks when it is used. User group D aims to make sure the product is visually appealing to the customer. The last user group, E, is the one who receives the CAD model from the supplier. This user group makes sure the received part fits together with all other parts in the product.

The user groups virtual testing is based on the CAD models, meaning if the CAD models are insufficient the user groups cannot do their job.

The second research question was answered using the same method as for research question one, namely qualitative interviews. During the interviews, members of ACME answered the questions on why ACME receives insufficient CAD models. In the compilation of the interview answers, various reasons were singled out and categorized in possible delivery inhibitors, in short PDIs. Meaning, each PDI is to be seen as a container of reasons which all can lead to ACME receiving insufficient CAD models. A reason could be e.g. user group behaviours or working procedures. The PDIs are:

- PDI 1 - Investigate requirements
- PDI 2 - Communicate requirements
- PDI 3 - Perception of requirements
- PDI 4 - Fulfilment of requirements
- PDI 5 - Protection of intellectual property
- PDI 6 - Verify fulfilment of requirements
- PDI 7 - Actions performed if unfulfilled requirements

The conclusion to the second research question is that it could be either of the PDIs, or a combination of the PDIs that leads to ACME receiving insufficient CAD models. This study is unable to answer which PDI or combination of PDIs that are most critical. Further studies are recommended to quantitatively measure the impact of the PDIs to see if critical ones can be singled out.

As the usage of CAD in testing is a fairly new technique compared to the original testing of physical prototypes, the requirements in the ACME organization are not yet fully defined. In addition, the requirements vary between different departments, and seemingly they have yet to agree in some way. Moreover, it is not until the CAD delivery is in the hands of the downstream consumers that their requirements can be confirmed, though they are not the ones who receive the models, which also could contribute to the issue.

The usage of CAD models in virtual development is becoming more and more important, hence our recommendation to ACME and researchers is to continue investigating this field.

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