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Merja Huhtala

PDM SYSTEM FUNCTIONS AND UTILIZATIONS ANALYSIS TO IMPROVE THE EFFICIENCY OF SHEET METAL PRODUCT DESIGN AND MANUFACTURING

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 1382 at Lappeenranta University of Technology, Lappeenranta, Finland on the 27th of June 2014, at noon.

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“If we knew what it was we were doing, it would not be called research, would it?”

– Albert Einstein -

ABSTRACT

Merja Huhtala

PDM system functions and utilizations analysis to improve efficiency of sheet metal product design and manufacturing

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This study will concentrate on Product Data Management (PDM) systems, and sheet metal design features and classification. In this thesis, PDM is seen as an individual system which handles all product-related data and information. The meaning of relevant data is to take the manufacturing process further with fewer errors.

The features of sheet metals are giving more information and value to the designed models. The possibility of implementing PDM and sheet metal features recognition are the core of this study. Their integration should make the design process faster and manufacturing-friendly products easier to design. The triangulation method is the basis for this research. The sections of this triangle are: scientific literature review, interview using the Delphi method and the author’s experience and observations.

The main key findings of this study are: (1) the area of focus in triangle (the triangle of three different point of views: business, information exchange and technical) depends on the person’s background and their role in the company, (2) the classification in the PDM system (and also in the CAD system) should be done using the materials, tools and machines that are in use in the company and (3) the design process has to be more effective because of the increase of industrial production, sheet metal blank production and the designer’s time spent on actual design and (4) because Design For Manufacture (DFM) integration can be done with CAD-programs, DFM integration with the PDM system should also be possible.

Keywords: Product Data Management, product, data, sheet metal design, sheet metal features, DFM, Design for Manufacturing

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I would like to present my thanks to all of the interviewees who took part in this research. Without you this dissertation would not exist.

I'm also really grateful to have had so wonderful workmates around me. The coffee breaks and lunch times are the best with all of you! Special thanks go to Anna-Kaisa Partanen who helped me to organize the practical things involved with this thesis in many different ways. And also the nice chats when I was feeling "not so happy".

There is no certain thing which pushed me to do this dissertation. After I graduated as a Master of Science I started to work in a design company as a design engineer. This time period somehow opened my eyes and made me think about doing the dissertation. I didn't trust my skills and I wasn't sure if I managed to do all this work. But the great colleagues encouraged me to keep going and to chase my dreams. Therefore I'd like to thank you all, especially Mikko Kääpä, the chat breaks with you were awesome!

I also like to thank all of my friends. The past few years I have only talked about my dissertation, but I hope that in the future I will have something else to talk about. Thank you Reetta Kinisjärvi and Kirsi Peltokoski, you have saved my "life" so many times, without you I would be lost.

Of course there are many other friends and colleagues I would like to thank. Thanks to everybody who somehow earn my thanks ☺

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To my brother Mika: I think you are the person who I can blame (there always has to be at least one person to blame). Without you and your studies I would never have figured out what I would like to study. You are also a person whom I can trust and call in the middle of the night. Thank you for being my brother and helping me, love you!

Lopuksi haluan kiittää myös rakkaita vanhempiani Aarnoa ja Marja-Terttua. Te olette tukeneet minua koko opiskeluideni ajan, niin taloudellisesti kuin henkisestikin. Nyt alkaa olla aika päättää virallisesti opiskelut ja todeta, että tulipahan opiskeltua. Olette minulle tärkeitä ja rakkaita, kiitos!

Merja Huhtala

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	two- dimensional
3D	three- dimensional
BOM	Bill Of Materials
CAD	Computer Aided Design
CAx	Computer Aided Technologies
CCC	Cost Competitive Countries
DFM	Design For Manufacturing
DFM(A)	Design For Manufacturing and Assembly
ECR	Engineering Change Request
ERP	Enterprise Resource Planning
FEM	Finite Element Method
GDSP	Global Disk Storage per Person [MB/p]
IT	Information Technology
NC	Numerical Control
PDM	Product Data Management
PFS	Principal Flat Surface
PLM	Product Lifecycle Management
SME	Small Medium Enterprises
STEP	International standard for product data exchange

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1 INTRODUCTION

The current trend in industry seems to be the decentralization of design and manufacturing work. This automatically puts pressure for companies to manage all the information that is created during the design and manufacturing processes. This thesis will concentrate on sheet metal design aspects and Product Data Management (PDM) at the parts level; bigger assemblies are out of the scope of this study.

1.1 Introduction to Product Data Management (PDM)

When talking about the most important software that today's industry should have, Product Data Management (PDM) is one that keeps resurfacing. The system was created in the early 1980s and since then, it has grown and developed, especially in manufacturing companies. Over all these years, the principle of the system is still the same: managing the data inside the company during product design and manufacturing. (Kumar & Midha, 2001, p. 126; Mesihovic, Malmqvist & Pikosz, 2007, p. 394.)

During design and manufacturing processes, a significant amount of information is created and there has to be a place to store it for later use. PDM is not just a place for storing information; the information can be found from the system and then modified and exchanged during the design and manufacturing process. PDM itself is not a design tool; it has to be linked to other design software (e.g. different types of CAD), such as SolidWorks. (Kumar & Midha, 2001, p. 126; Kropsu-Vehkapera, Haapasalo & Harkonen, 2009, p. 759.)

As written in Huhtala, Lohtander and Varis (2012):

> *…also important feature of PDM is to share information among the users who are working with the manufacturing process (such as subcontractors, manufacturers and purchasers). At the same time, the system helps to organize and utilize the data in such a way that products are ready just on time.*

In this thesis, the PDM system is seen as an individual system. Integrated PDM systems, which can be found in different CAx (Computer Aided Technologies), are not included in this research. Also the points of view of products, parts and data life cycles are outlined in this dissertation.

1.2 Challenges of Sheet Metal Design

In sheet metal design, the main problem is to find the correct parameters so that the product can made correctly the first time. Usually, the main problem is to select the correct parameters, such as bending radius, according to the sheet metal’s thickness and material. The used tools and machines also affect the final quality of the part.

In this thesis, the sheet metal being studied has a thickness of up to 3 mm. Also, this thesis is only concerned with the uncoated sheet; it should also be known that different kinds of lubrication chemicals (e.g. which help the sheet metal storage) are included in coating materials. These are not included the research because of their properties affecting the formability of the sheet metal.

1.3 Research Problem

Globalization is a current trend and it seems that more and more design work, and also manufacturing, is done in a foreign country. When the ‘gates’ opened to India, China and Russia, at the end of the 1990s, globalization grew rapidly. Furthermore, the help of computers and even faster networks helped to have co-operation with so-called cost competitive countries (CCC). (Koren, 2010, pp. 12-14.) In this context, the term globalization means that the actual company is manufacturing and designing their products in a foreign country. In fact, the design of these products may be happening all over the world. The main advantage in globalization is that the products are now easily available in the whole world within a short time period.

Although globalization is common, there are still many challenges and unsolved problems, such as how to keep costs low, quality high and production fast. (Koren, 2010, pp. 227-229.) Subcontractors are easy to find but filling all the quality demands is harder. The most time consuming aspect is to settle the basics; making contracts and making sure that all is going to work smoothly. The way things work in one’s own country may not be so in the other culture. However, when the proper subcontractor has been found, the co-operation may last several years, which is the ideal situation when considering the design engineers: the information about available tools and machines can be easily accessed.

Designers use different computer-assisted design (CAD) systems to create their designs. Normally, after or during the design process, the design is saved to the PDM system. With help of PDM, the drawing is transferred to the manufacturing plant. And at the same time it is also made available to other parts of company for viewing information and the drawings of the product. If manufacturers need to change something in to the drawing, they will send the drawing back to the designer via PDM. Thus, PDM is actually communication tool between the manufacturing and design units.

As mentioned in Huhtala, Lohtander and Varis (2013a) the PDM "includes several inside operations; some of these are already in use, some of them are unknown to the user". One operation is the sheet metal function. It includes an add-on, whose main idea is to help the designer to choose the correct parameters for sheet metal design. It can be considered a guideline reminder; designers still have to have the basic knowledge of sheet metal designing.

Because of the complex design requirements of many products, designers really have to know how to design product in a way that it is easy and even possible to manufacture. With the abundant help of computers and different programs, designers too often rely on the automatic features that the programs are offering. *The key research problem is that designers cannot be sure that these features (for example bending angels) are correct for their designs. By using the pre-set parameters of the design program, it may be possible that the part cannot be manufactured in the first try without any changes. In sheet metal designing, the design and manufacturing features are critical and the design software's library models are not more often than not suitable to use in designs. PDM systems are already widely in use in companies and finding the sheet metal function from the system is challenging. After the finding of this function the PDM system's effectiveness to sheet metal design and manufacturing has to be defined.*

1.4 Framework, Scope of Thesis and Research Questions

The scope of this thesis can be seen from Figure 1. Figure 1 illustrates the designing process of a sheet metal product. The actual design process starts in the middle of the circle, where designers start to draw sketches and determine the features and requirements of the part (and also the assembly). When the actual design process starts, it may be that the main assembly will be divided into smaller subassemblies. After this, the work process can be decentralized to subcontractors, globally or not. The red cut line illustrates the process where the design and manufacturing processes are decentralized to different subcontractors. At this point, it is critical to handle the data in such a way that the final product can be manufactured; all the subassemblies have to come together. The connection between all these is the red PDM line; this system is linking all the information together so the information can be there where it is needed and where something is happening. PDM is also making sure that all the necessary information is linked to the product.

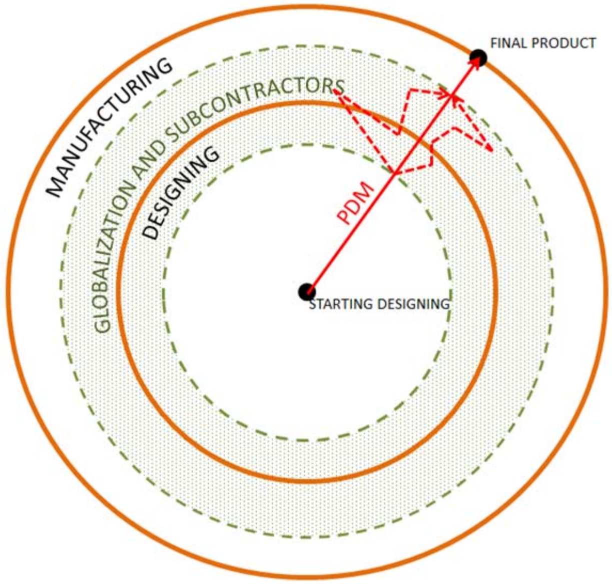


Figure 1. The scope of the thesis starts from the point where the designing is starting and ends to point where the designed product will be ready.

The theoretical framework concentrates on mechanical engineering, and more specifically on sheet metal designing. This study presents the information which should be taken into concentration when doing sheet metal design and when the goal is to make a manufacturing-friendly product. PDM is the helping tool to handle the design and manufacturing information during the process. The main point is not just in the design process but also in the manufacturing. Manufacturers also need to have enough information about the product and its features when the manufacturing process is starting. The product should be able to be manufactured without error, even without knowing which tools and machines are to be used (which is of course the challenge). To reach this point, the co-operation between design engineers and the manufacturing unit has to be seamless. Mathematic models, system programming, and business-oriented calculations and investments are left out from this thesis: the information exchange and business point of view are taking concern in general way. The framework can be seen from Figure 2.

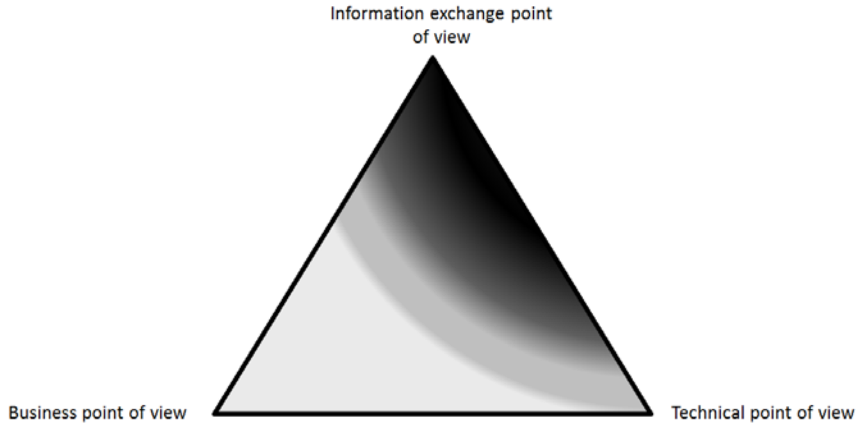


Figure 2. The framework of the thesis is shown in dark in the triangle.

The thesis concentrates on technical and information exchange points of view. The technical point of view in this thesis means the ‘melting pot’ for the created drawings. The PDM system assures that the drawings are transferred to a general form to assure that everybody who needs the information can read the documents from the system. This basically means that the viewers do not have to have a certain program which has been used to create the drawing or document in the first place. The information exchange point of view means that the PDM system is a tool which shares the designer’s information with the manufacturing unit and vice versa. In the middle of these points of view is a place where the actual designing happens and where help is needed from the PDM system.

The main research question concerns *the parameters in sheet metal design which affect manufacturability in such a way that the product can be designed without errors in production. Can the PDM system be the helping tool to determine these parameters? Are, in sheet metal designing, all the design features in software’s library suitable to every design? Moreover, would it be possible to add a function to the PDM system that helps the designers to choose the correct parameters for their sheet metal designs? How and to what extent would the potential PDM sheet metal function affect the manufacturability of the product, the number of defected parts in the manufacturing process and the time needed for the actual design process?*

The hypothesis is that it can be assumed that more tasks can be carried out in an industrial environment with PDM systems than currently are. There are already functions in PDM systems which have not been utilized.

1.5 Statement of the Study

In this study, the PDM system and sheet metal design process move together hand-in-hand. Designs are stored in the system and designers can retrieve drawings and information from the system. However, PDM itself is not just a storage place for the product information; it can be more. The key element to handle the information in the company is a tailor-made PDM system, but all its benefits are not really utilized. The first PDM system was created in the middle of 1980s by engineers who needed help with their documentation management (Kumar & Midha, 2001, p. 126). At the beginning of the 1990's researchers started paying attention to this system and started their research on the topic, which has continued to this day (Moorthy & Vivekanad, 2007, s. 94).

Sheet metal parts normally have different kinds of shapes/features and every shape has its own parameters. Parameters and manufacturing-friendly shapes depend mainly on the material and the thickness of the sheet. It is almost impossible to remember all the necessary and important parameters when designing. Today's CAD programs already give hints for some parameters and the program's own library includes several different 'ready to draw' features. These features and ready models may not be possible to manufacture with the tools and machines that are existing in company's machine shop.

The claim of this research is that the already existing PDM system in the company can actually do more than is known; all of its benefits are not fully utilized. It can support the sheet metal design process by giving design guidelines after the sheet metal part has been saved into the system and the category for the item has been chosen. When all of the company's tools and machines are updated, not only in CAD systems but in the PDM system as well, the design will be easier to manufacture because the recognition of appropriate/required parameters and the establishment of their magnitudes will be done correctly the first time. This means that the role of PDM systems is slightly changing from passive databases towards analyzing tools to support designers' work.

Currently, the PDM system is mainly used as a vault for drawings, models and data sheets, and also to manage the revisions of the drawings. In cases where the manufacturing unit is located inside the company (no manufacturing subcontractors), the drawings should be transformed to the machine shop via the PDM system. Companies with tailor-made products also use this system as a project tool: the product is handled as a project and product-related information is stored in one place. However, the PDM system can also include features that are hardly in use or unknown to the users:

- Handle feedback. From customers and the manufacturing unit to design unit and vice versa.
- Transfer of drawings. Not only inside the company, but with the help of a 'light' license (limited access) version, the drawings can be transferred to subcontractors.
- Efficiency measurement. The approximate time used for the design process can be measured.
- Material (mass) consumption calculations. The system can calculate the mass of the product according to the 3D model. This will also help to determine the final mass of the product.
- Problem reports or in other words, Engineering Change Requests (ECR). The system can track the changes made and inform the designers about ECR's.
- Workflow. The workflow can be tracked by the state of the designed part (in use, released, accepted).
- Unknown area. The PDM system has a capacity that is unknown. With the help of add-ons, the software is protean and it corresponds to company's needs.

In Figure 3, the approximated bar graph concerning the PDM systems unused and already used potential, as well as their relation (the size of the bar's boxes) is shown. When adding more add-ons to the system, it should be more efficient to use. For example the integration of DFM(A) into PDM, design guideline pop-ups and sheet metal recognition are key add-ons to improve the capacity of a PDM system.

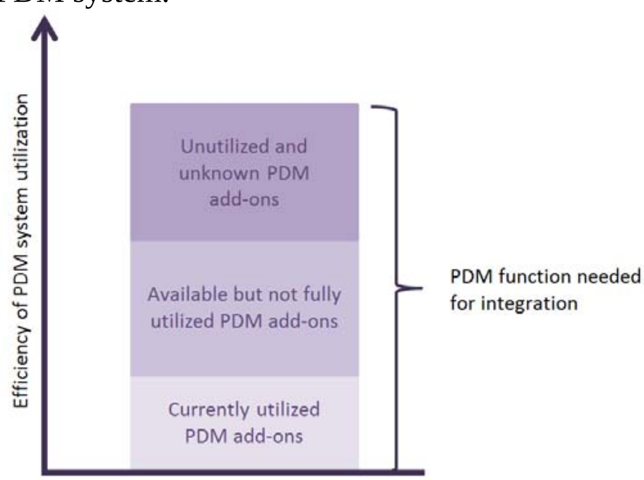


Figure 3. Efficiency of PDM system utilization should increase when more PDM add-ons are known and implemented to use.

1.6 Motivation

This thesis is motivated by the following:

1. Globalization.
2. The author's own experience in an engineering office and the use of CAx and PDM systems.
3. Costs: material, labor, processes, et cetera.
4. Time consumption in design processes.

Today, design and manufacturing are done all over the world. Designers quite often are situated in a different place than where the actual manufacturing is happening. In this situation, it is really important that the designs are correct, even if the designers do not exactly know what kind of machines and tools are in use. Iterations take time and resources, and sometimes there is no extra time for corrections: the product has to be manufactured in a certain time period. If the period is exceeded, it may cause additional costs to the company (penalty). In these cases, designers have to rely on standard tools and shapes.

With the help of PDM, the information is available to all who have been granted access to the system. Also, all the system benefits should be in use so the design process is faster and fewer errors occur in manufacturing. However, not all PDM features are supposed to make the design process faster: properties such as faster spare part purchase (parts are easy to find) do not directly affect the design process. All of this starts from the design and if the designers do not have enough information to complete their designs correctly, there will be errors in manufacturing.

The key motivation element for the author was her own experience in an engineering office. Many different CAD software were in use and the PDM system linked all of this software together. The PDM was just a storage place for all the information created, and there was a lack of knowledge about how to optimize all the benefits of the system. The system was becoming too large, nobody actually knew how to find the necessary information from the system and every designer saved their design in the system however they wanted. The company was thinking about buying a newer, better system but in the author's opinion, the reasons were wrong ones: the old system could do much more, but it was unclear as to how much. This experience led to a situation where the author wanted to know more about why all of the possibilities/benefits of PDM systems were not in use properly; and whether the system can be used in the way that the author thought.

The market trend in the field of standard steel products has increased almost every year. Furthermore, the material costs have increased as it can see from Figure 4. There, the development of hot-rolled coil and cold-rolled coil spot prices euros per ton is shown. The chosen courtiers' are USA, Germany, Russian and China, the world's leaders in standard steel products. (The Federation of Finnish Technology Industries, 2013a.) When the material cost increases, it automatically means that the cost of production (by using materials) also increases. This puts pressure on engineering departments to save in material costs, and also to save on the time spent on the design process (the total savings). Indeed, time is money: the design process consumes 70% of the total product cost. Mainly, the costs come from changes that have to be made to the product when the manufacturing process has already started: in most of the cases, the reason is the lack of information on how things are done in the manufacturing unit and how the manufacturing process actually works. (Boothroyd, Dewhurst & Knight, 2002, pp. 5-7.)

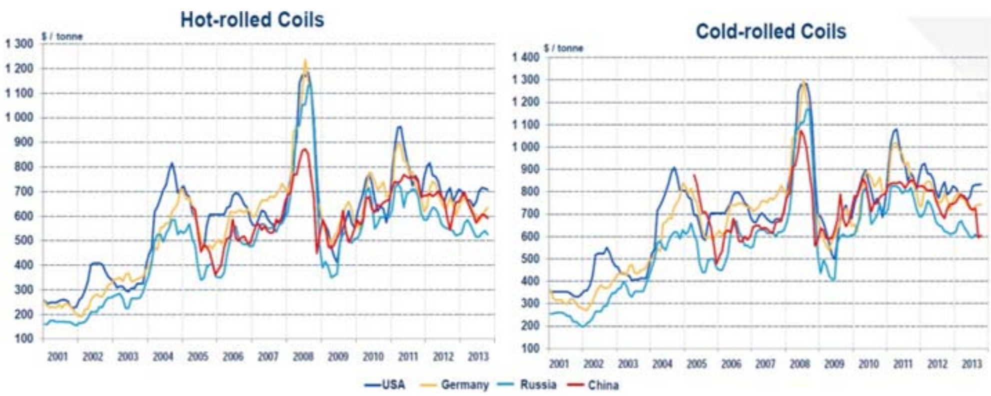


Figure 4. The spot price development of hot and cold-rolled coils in the USA, Germany, Russia and China (modified from: The Federation of Finnish Technology Industries, 2013a).

In addition, the trend in production development is increasing, especially in China. More and more companies are trying to reduce costs by moving design processes and/or manufacturing to cost competitive countries (CCC). Although the production in China has snowballed, the production in Finland (for example) has not decreased with relation to China. The development of industrial production can be seen from Figure 5. (The Federation of Finnish Technology Industries, 2013b.)

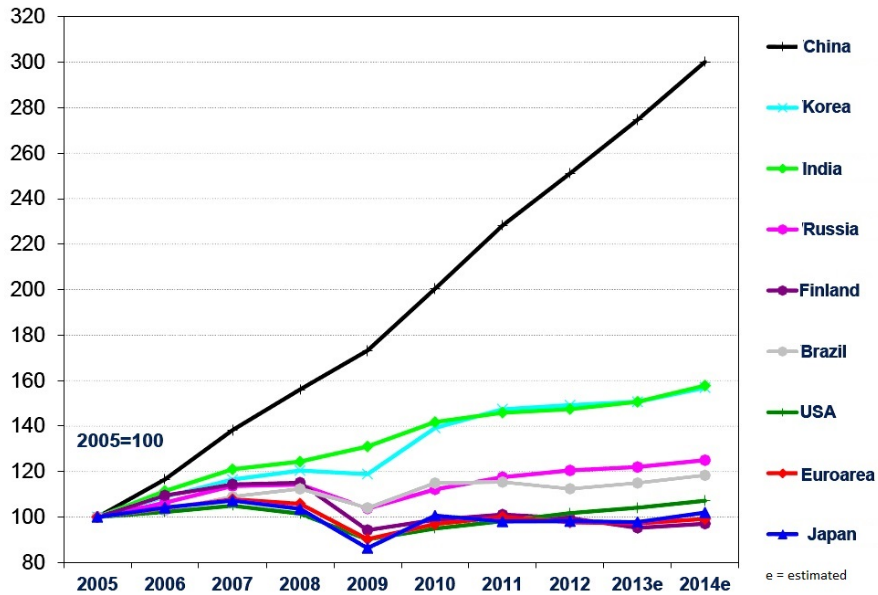


Figure 5. The development of industrial production (modified from: The Federation of Finnish Technology Industries, 2013a).

Robinson (2012) has researched design engineering working time and how that time is divided. He has also compared his result to earlier studies in the same field and noticed that still, after 20 years, the time is divided in approximately the same way. Of course, some new technical devices are in use, such as e-mail, but in general almost the same amount of time is spent for example on technical work. In Figure 6 the work time fracture is shown. Of the time that engineers are spending on problem solving (included in the solo technical work section) 20.25% of that was spent on understanding the problem. After that, it took 18.41% of the time to solve the actual problem. (Robinson, 2012, pp. 412-415.)

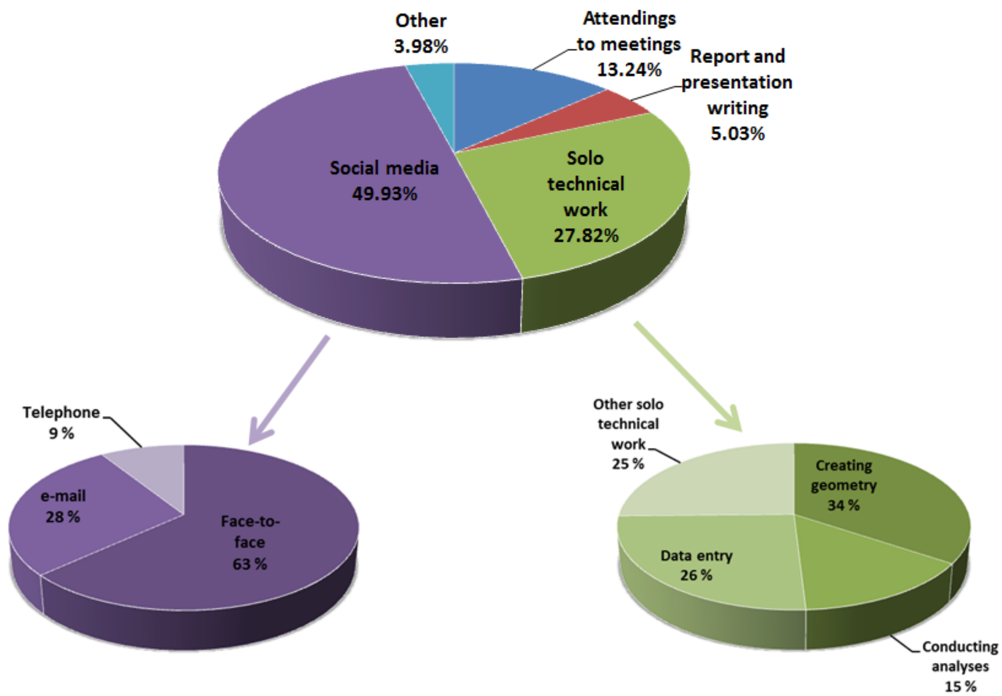


Figure 6. Engineers time use allocation (Robinson, 2012, pp. 412-415).

All of the things mentioned in motivation section (section 1.6) have increased the author's motivation to do this dissertation. By saving on costs and time, more production may be convinced to stay in Finland. If the design processes are still moved to CCC countries, the quality of the product data will still be at a high level and the co-operation between different countries will be easier. The main key is to handle the data correctly and share it inside the company. Companies invest more money every year in data management systems to take care their data. As can be seen from Figure 7, it is estimated than in 2016, more money is going to be spent on PDM systems. Figure 7 shows the grown of the product lifecycle management (PLM) system, but because PDM is the core of PLM, the statistics can be used here. (CIMdata, 2012.)

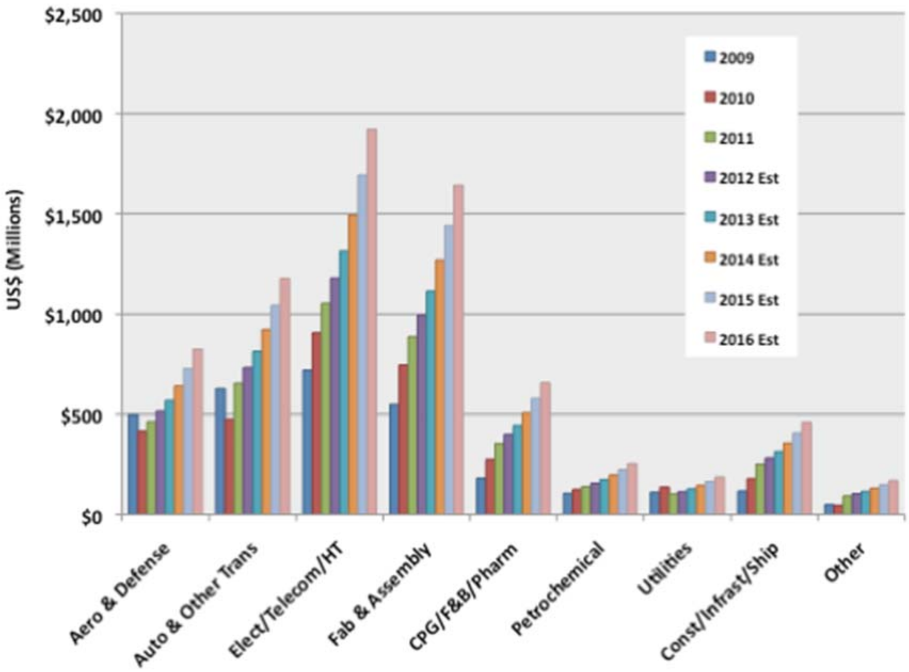


Figure 7. The forecast of PLM markets in different industry field (CIMdata, 2012).

1.7 Contribution of the Thesis

The contribution of this thesis is to provide a basis for understanding all of the benefits that PDM systems can offer to sheet metal design and manufacturing. Also, it should be clarified what kind of features the sheet metals can actually include and what are the main parameters that should be known during the design process.

The author has experience from one kind of PDM system, which was in use in a middle-sized manufacturing company, where the design processes were outsourced. Moreover, as Ahmed and Gerhard (2007), Borrmann et al. (2009, pp. 359-360), Gascoigne (1995, p. 38), Gott (1995, p. 18) and Stark (2005, pp. 233-235) have mentioned, the PDM system is a known system among designers. With the help of literature and the experience of use, the PDM system can be development to respond more effectively to designers' needs. (Abramovici, Gerhard & Langenberg, 1997; Cao & Folan, 2012, pp. 641-642; Stark, 2005, pp. 233-235.)

The research focus area is on the PDM system and its relation to DFM(A) and CAD systems. Today, the interaction between the Design For Manufacturing and Assembly (DFM(A)), CAD and PDM is seen as separate (as in Figure 8) and the design intent is only one big complex. According to Stum (2002, p. 1182), the design intent can be defined as:

> *"…written documentation of the functional requirements of the facility and the expectations of how it will be used and operated. They include project and design goals, budgets, limitations, schedules, owner directives and supporting information. They include necessary information for all disciplines to properly plan, design, construct, operate, and maintain systems and assemblies."*

The design intent can be divided into different sections and one of these sections is sheet metal design features. If a designer wanted to design a manufacturing-friendly product they have to take the special aspects of sheet metals into account and with the help of DFM(A) methodology, the design can be done. When integrating DFM(A) and sheet metal features into the PDM system, the designer can easily find all the necessary information. This should lead to the situation where the design process is faster and fewer mistakes occur. The future interaction between these areas can be seen in Figure 8.

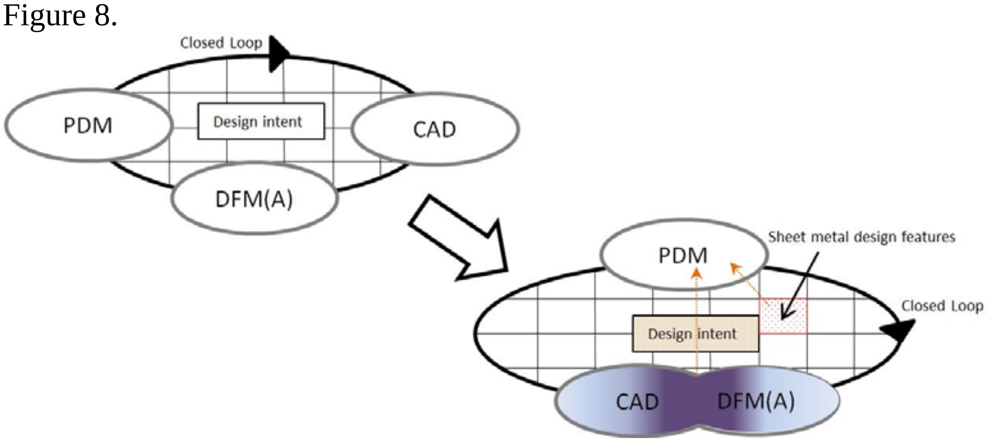


Figure 8. The current interaction between CAD, DFM(A) and PDM (above), and the interaction from a future standpoint (below).

Elements that should be included in the PDM system when designing sheet metal parts are:

- design guidelines for different sheet metal features;
- different material properties, which will affect the design when selecting the parameters and
- in the case where the company uses many different subcontractors, the list of tools and machines that are used by each subcontractor should be known. And, of course, when the machines and tools are known, their properties should also be taken into account: the

parameters of tools (dimensions, tool types, et cetera) and machines (what materials can be machined, the maximum thickness, et cetera).

The PDM system is mostly in use in the design process, but the benefits that PDM can actually provide is not well known or then there is an unwillingness to modify the system to fit it to an exactly purpose. Some research was done in 1997, when Bilgic and Rock (1997, pp. 1-2) stated that the PDM system should, by their function and structure, classify parts that are saved into the system. Classification is one basic feature of PDM but all its benefits are hardly in use.

Earlier studies of the author comprise sheet metal designing and PDM. Below is the list of the author's earlier studies related to this thesis.

- Huhtala, M., Lohtander, M. and Varis, J. (2013a): *Product Data Management and Sheet Metal Features – sheet metal part recognition for an easier design process producing manufacture-friendly products.* This paper was presented at IEEE2013 (the International Conference on Industrial Engineering and Engineering Management) and the main content was to point out the lack of standards according to sheet metal feature classification. With an imaginary example part, the challenge of designing sheet metal products was pointed out.

- Huhtala, M., Lohtander, M. and Varis, J. (2013b): *Manufacturability of sheet metal design with the help of Product Data Management (PDM).* This ADM2013 (5th International Conference on Advanced Design and Manufacture) conference paper briefly illustrates sheet metal features which are important when designing a sheet metal part. The paper also raises the question about whether PDM is useful when designing sheet metal products. This paper was also published in Key Engineering Materials (Advanced Design and Manufacture V, Volume 572, 2014).

- Huhtala, M., Lohtander, M. and Varis, J. (2013c): *Sheet metal design with the aid of Product Data Management systems (PDM).* This paper was presented at the ISAM2013 (International Symposium on Assembly and Manufacturing) conference. The paper ruled out DFM(A) aspects which should be taken into account when designing sheet metal products. The paper also comments on the knowledge of the designers and how the PDM system should help them to save their knowledge into the system.

- Huhtala, M., Lohtander, M. and Varis, J. (2013d): *The role of Product Data Management (PDM) in engineering design and the key differences between PDM and Product Lifecycle Management (PLM).* This conference article delineates the point where the PDM starts to act as PLM. The article also showed the key differences of these two systems and why these two systems should not be mixed together.

- Huhtala, M. and Eskelinen, H. (2013): *Proceedings of the PDM2013 conference, LUT 24.-25.4.2013.* This publication brings together all the papers that were presented in the 1st PDM forum for Finland-Russia collaboration. The publication includes different points of view on PDM and PLM, and how these can be applied in industry.

- Huhtala, M., Lohtander, M. and Varis, J. (2012): *Confusing of terms PDM and PLM: examining issues from the PDM point of view.* This conference article presents the basic information about PDM and why currently this PDM term is often mixed with Product Lifecycle Management (PLM). The terminology's direction seems to be increasingly misleading, which also makes the correct and exact information more often hard to find.

- Huhtala, M., Räsänen, A-N., Lohtander, M., Eskelinen, H. and Varis, J. (2011): *DFMA-Aspects of Sheet Metal Product in Case of Lowcost Strategy.* This conference article is based on one real sheet metal product. The aim was to inspect its manufacturability and design, and to develop a new method to produce and redesign the part. During the research, it was noted that the PDM system (Aton) was able to help neither the design nor the manufacturing processes.

1.8 Thesis Outline

After the introduction, the research methods are presented. Chapters 3, 4 and 5 concentrate on the background and the framework of the thesis claim. The literature review (chapter 3) is mainly based on the articles concerning the topic of the thesis. Chapter 4 will show the results of the interview using the Delphi method. The chapter 5 showcasing the author's experience and observations will concentrate on expressing the author's work experience from industry and the gathered knowledge from there.

Chapters 3, 4 and 5 will create the base outlines for the triangulation. Chapter 6 will gather together information from the previous three chapters and illustrate the results for the triangulation method. The result will be the support for the claim from three different points of view. At the end, the discussion and summary will be presented. The thesis outline is shown in Figure 9.

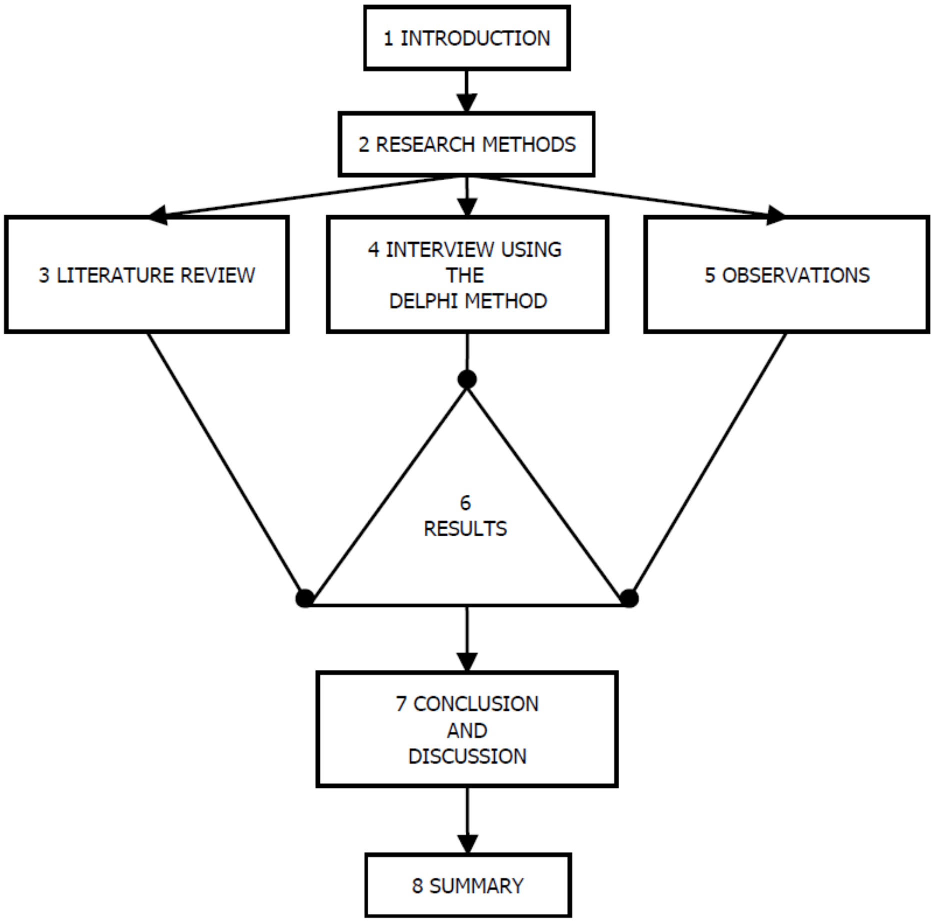


Figure 9. The outline of the thesis.

2 RESEARCH METHODS

The research methodology used in this research is based on the triangulation process, which consists of the following three independent knowledge sources:

1. Literature (based on 63 references)
2. Interview using the Delphi method (10 experts from industry were interviewed)
3. Author's experience and observations (gathered from industrial work during the years 2007-2012 and made visible by seven scientific and peer-reviewed articles written by the author of this thesis)

2.1 The Literature Data Search

In the beginning of the thesis, a preliminary literature review was done. The search was based on the following words and their combinations:

- Product Data Management (PDM)
- Product Lifecycle Management (PLM)
- Sheet metal parts
- Sheet metal features
- Managing product changes
- Choosing of PDM
- Manufacturing friendly production
- Design For Manufacturing and Assembly (DFM(A))

The search was done using Lappeenranta University of Technology's library's databases. In the first stage, there were no limitations on the articles (e.g. age limit, impact factor). When the first stage was completed, the author started to consider important words that should somehow describe the content of this thesis. The guideline of the thesis was clear so the articles were put in the table and analyzed using the following words:

- Introduction to PDM
- Different point of view of PDM
- Integration and relationships (to other design programs)
- Bill of Materials (BOM) / product structure (how this can be seen from the PDM system)
- Managing changes
- PDM software vendors
- Product development process
- Typical problems (when using the system and implementing it to different software)

- Configurations
- Choosing of PDM
- Advantages of PDM
- Execution
- PDM/ Enterprise Resource Planning (ERP)
- Lifecycle
- Sheet Metal Features
- DFM(A)

The feature recognition was also included in the search criteria, albeit that the research in that field mostly concerns mathematic models. The reason why this field was included in this thesis was that the features were classified and defined strictly in the papers.

After the first analysis, the second analysis was done. In the first stage there were 16 different criteria (see list above) and over 200 different articles and books. The next step was to reduce the number of the criteria to five (5), after which 115 articles and books were left. The last five categories were:

- BOM / product structure (how this can be seen from the PDM system)
- Product development process
- Advantages of PDM
- Sheet Metal Features
- DFM(A)

2.2 Interview Method

The interview was conducted using the Delphi method. The name Delphi comes from Greek mythology; the oracle Delphi helped people by giving political instructions. The main purpose of the method was to make decisions before a major course of action. The method was launched in the 1950's and early 1960's by Kaplan, who thought that the method should be published. After publishing, the method came into wide use in medicine and sociology, and later on it became popular in other fields. (Franklin & Hart, 2007, pp. 237-238; Iñaki, Landín & Fa, 2006, pp. 813-816; Loo, 2002, pp. 762; Steurer, 2011, pp. 959-960.)

The Delphi method can be divided into three different sub-methods by Franklin and Hart (2007, p. 238): classical Delphi is based on facts from a specific situation or topic; decision-making Delphi, as the name implies, is a method for making collaborative decisions; and policy Delphi is based on experts. First, the topic of the problem is created and then opinions are asked from the experts. After this, the collected information is analyzed and summarized and the feedback is given to each person who took part in the interview. The main purpose is to collect opinions and make sure that the interviewer has understood the answers correctly. (Franklin & Hart, 2007, pp. 238-239.)

Although the classical Delphi method is mainly used to handle technical issues and topics, policy Delphi was chosen for this thesis. This sub-method seems to give significantly opposing views related to the issued topic. The first difference to other sub-methods is that the participants do not have to be the best experts in the chosen field; they can be people who are familiar with the topic. The second difference is that the researcher will concentrate on the analysis of the issue, not on the mechanism of how the decisions are made. Mostly, policy Delphi deals with statements, comments and discussion; therefore, it is important to organize a meeting where the participants can talk freely around the research problem. Still, there have to be certain questions to which the researcher wants specific answers. (Turoff, 2002, pp. 80-83.)

The method follows always a certain route (Iñaki et al., 2006, pp. 814-816; Loo, 2002, pp. 764-768; Steurer, 2011, pp. 959-960). First, the researcher defines the problem to be investigated (Steurer, 2011, p. 960). When the problem is established, the researcher prepares questions which are, of course, related to the main topic; the researcher determines what kind of information they would like to have. The questions should be simple and clear so the respondent can easily answer them; normally, the questions are open-ended questions and no right answer exists. (Iñaki et al., 2006, pp. 814-815; Loo, 2002, p. 765-766.)

Secondly, an expert panel is selected, which is a requirement for the Delphi method. It is crucial to select qualified experts; if the researcher does not know enough experts, the experts who have been invited to the panel can suggest other suitable candidates. This can lead to the situation where the panel consists of experts that are connected to each other somehow or another (for example colleagues and friends). This may be a problem in case if the answers of the panelists are affecting to each other's. (Steurer, 2011, p. 960.) In addition, the important thing is that the panelists remain the same through the whole study; all the panelists participate anonymously and the issues discussed are confidential (Loo, 2002, p. 766; Steurer, 2011, p. 960). Also, the selection criteria are freely chosen: criteria can be based on, for example, personal experience or the selection can be done randomly (Iñaki et al., 2006, p. 814; Steurer, 2011, p. 960).

The number of the panelists is not specified; the Delphi method is only based on the gathered research information (Loo, 2002, p. 765; Iñaki et al., 2006, p. 814). When choosing the panel size, the research problem should be clear because this clarifies the number of panelists (Loo, 2002, p. 764). Depending on the topic to be discussed, the panel's size may vary from one member to thirty members and because of the careful choice of panelists; the results can still be reliable (Iñaki et al., 2006, pp. 814-816). The main thing is to collect opinions, beliefs and judgments; and also to give opportunity for anonymous individual responses (Steurer, 2011, pp. 959-960).

After the previous steps are done, the actual Delphi method takes place as a questionnaire. The goals of the researcher's study have to be clear and the literature review should be done, as these are the tools for generating reasonable and effective questions for the panel (Loo, 2002, pp. 764-765; Steurer, 2011, p. 960). The questionnaire can be performed as a face-to-face interview, through mail/e-mail or on the Web (Loo, 2002, pp. 766).

When the researchers have the responses, the actual analyzing of the results begins (Iñaki et al., 2006, p. 815). The results may be listed in a graph or as calculated medians: this depends on the main question which was set in the beginning of the survey. (Steurer, 2011, p. 960.)

In the second round of the questionnaire, the analyzed answers from the previous round are shown to the participants At this point, the participants can check the answers and make corrections or additions. (Iñaki et al., 2006, p. 815; Loo, 2002, p. 766; Steurer, 2011, p. 960.) If the researcher feels more information is needed, a new questionnaire may be set and a third round begins. In most cases, the final analysis is done according to the results from the first and second rounds. (Steurer, 2011, p. 960.)

As with other methods, the Delphi method also has critical properties. It is true that the answers to the questions are based on the respondent's personal beliefs and opinions but this can also be the strength of the method, depending on the main research question. When choosing different panels with different experts, the answers will lead to different results. (Steurer, 2011, p. 960.) However, as Steurer (2011, p. 960) wrote: "In general, the Delphi method is used only when scientific evidence is either absent or contradictory, and judgmental information is necessary". (Loo, 2002, pp. 767-768; Steurer, 2011, pp. 959-960.)

The greatest benefit is that the Delphi method is based on the researcher's questions. The conversation is focused on a certain problem and the discussion stays on the right tracks. Still, because it is not a quantitative method, it gets considerable criticism from academia. Nevertheless, the benefits of this method outweigh this criticism (Franklin et al., 2007, pp. 241-242; Iñaki et al., 2006, p. 816):

1. The members in the panel are the experts and they will mutually complement each other.
2. Members' opinions can be compared with other opinions.
3. Each comment in the research comes from an expert and expresses their point of view.
4. All the information collected during the panels is anonymous, so the participants are free to share their opinions or beliefs. As Steurer (2011, p. 960) stated, the anonymous aspect will protect the participants; they can say their real opinion and they will not lose face.

2.3 Author's Experience and observations

The author started her industrial experience as a senior design engineer in a mid-sized design office. Soon the target was to start design machines for mining, metallurgical and chemical industries. The helping tool to manage the drawings and projects inside the company was one type of PDM system.

Mainly, the designing was concentrating on other structures than sheet metals. However, in some cases, knowledge of sheet metal designing was also needed. The author noticed that if the designers only do sheet metals design one or two times per month, the specific information needed during sheet metal design is forgotten. The designers trust the parameters which are in the design program's library, although they know that in most cases those parameters are wrong. The trust in manufacturing personnel is significant: if a designer designs a sheet metal part, they know that the people in the manufacturing unit can manufacture it according to its final requirements, no matter what kind of parameters were chosen. Rarely did any feedback come back from the manufacturing unit, so no changes were made to the drawings to correct them.

After a couple of years, when the author's knowledge about the PDM system had grown, the working duty concentrated on Engineering Change Requests (ECR). This task was based on finding information from the PDM and to find missing data sheets for items that were already in the system. Another responsibility was to remove duplicates from the system.

Soon it was clear that managing the information was not easy and the PDM system did not work as it was supposed to. Although the rules on how the information should be saved in the systems were clear, still some information was saved incorrectly. In many cases, the description of the item was not what it was supposed to be and some needed parameters were missed. In the author's opinion, the main reason was that the tasks were able to be carried out in several different ways, all according the rules. The system was rigid and it was not fully tailored for the use of the company. One of the main problems was that the upper (capitals) case and lower case letters had their own meaning: the search from the system could not be done without the exactly correct writing.

The author also has experience from companies that were managing their documentation by folder-system in a network server. When comparing the folder-system and PDM together, the benefit of how easy and fast the information could be found is considerable.

The observations and author's experience is reflected with the results of literature research and Delphi interviews by analyzing the contribution of each scientific paper written by the author on this topic. Further below in section 5 a detailed table (Table 6, starting on page 95) with key observations.

Although the Delphi method is not commonly in use in the field of technical sciences, especially when researching DFM(A) aspects, in this thesis there are justifiable reasons for using this method. For the research, it is important to obtain a general view from experts in different fields (information technology, business and mechanical engineering) and reach a consensus between the different viewpoints, but also highlight possible conflicting or limited viewpoints between the different groups of respondents. Also the results have to be in proportion to the prevailing situation in the industry. The Delphi method is cyclic, which will improve the reliability of the collected information: the author's own readings from the interviews are checked by every expert. Due the triangulation, the Delphi method is a more suitable choice than a traditional interview study.

3 LITERATURE REVIEW

With the literature review, the goal was to find answers to the following questions:

(1) What are the definitions for product, data, product data and Product Data Management?
(2) Which sheet metal parameters affect manufacturability in the way that the product can be designed without errors in production?
(3) Are all the design features in software's library suitable to every sheet metal designs?
(4) Can the PDM be the helping tool to determine these parameters?
(5) Would it be possible to add a function (add-on) to the PDM system which helps the designers to choose the correct parameters for their sheet metal designs to design manufacturing-friendly products in less time?

In addition, the background of the PDM system was examined; why this tool was invented, what the main goals of it are and how companies see the system today.

After the preliminary literature research, the articles were ranked based on the used sources, how they covered the research area, and their viewpoints. After this, the sources were tabulated. The ranking was based on the following methods:

- Bibliometric analysis
    - The citation analysis (numbers of citations) was done by using Harzing's Publish or Peris tool, and the results were added to Table 1 (page 41) and Table 2 (page 42).
    - The Impact Factors for different journals were sought by using the Impact Factor Search Tool (http://www.impactfactorsearch.com/) and the results were added to Table 1 and Table 2.
    - If the numbers of citations or/and impact factor were not found, it was indicated in the table with N/A (not available). At the end of the tables, the average value is calculated only from the sources where all of the information was available.
- Reference analysis
    - The main idea was to find the original source; if an article systematically referred to another article, this latter was sought and the former was excluded However, if the first found article included research study and results it was now ranked out.

    - Articles with indefinable sources (such as Google or Wikipedia) were excluded.
- References in the text
    - If an article included specific information without any reference, the article was excluded. However, if the article's information was based on research, the article was seen as valid.
- Abstract versus text content.
    - In some cases, the main content corresponds to the abstract. These articles were excluded.

Every subtopic got its own table. In Table 1 (page 41) the most relevant articles in the field of PDM are shown. The main target was to find relevant information for the term definitions and the history review. The standards SFS-ISO 16792 (2010), SFS-EN ISO 11442 (2006) and SFS-EN ISO 10303-210:en (2003) has been left out of the table because one of the targets of these standards is to determine the terms to be defined. Even though the standards have been left out, they play an important role in the further definition of the terms and will be used later on in the text for this purpose.

It can be seen from Table 1 that research in the area of PDM has mostly been carried out after 2000. Although the PDM system was created in the middle of 1980s, the reason why research was done mainly after 1990s is because that is when companies realized the importance of the system. After 2000, researchers woke up to the field of Product Lifecycle Management, which has also revealed the impertinences of Product Data Management.

Table 2 (page 42) was created with the same method as Table 1. The target was to find out relevant information about sheet metal features and DFM(A). Also, the purpose was to find articles from different years in order to determine if the definition has changed. The sources in Table 1 and Table 2 which are marked with orange are sources which are included in the author's own articles but not in the triangulation process. However these sources support the verification of author's own publications and also the literature review.

When triangulation was used, it was made sure that the sources which were used in the author's own articles were not included in the triangulation process. In this way, the author ensured the reliability of the method through the independence of the sources. This independence check is shown in Table 1 and Table 2. All the sources mentioned in the tables can be used as supporting material in the literature review and the sources are used more widely than in the author's own articles.

Table 1. The most relevant articles in the research area of Product Data Management.

Year	Author	BOM / product structure	Managing changes	Product development	Advantages	Citations	Journals' impact factor
1995	Gascoigne					27	N/A
	Gott					1	N/A
1996	McKay, Bloor, de Pennington					65	1,892
	Philpotts					69	1,674
1997	Abramovici, Gerhard, Langenberg					16	N/A
	Bilgic, Rock					37	N/A
1998	Wang, Lee, Pipino, Strong					288	N/A
2000	Fan					13	0,08
2001	Liu, Xu					224	1,709
	Storga, Pavlic, Marjanovic					9	N/A
	Svensson, Malmqvist					24	N/A
2002	Helms					49	N/A
2003	Burden					15	N/A
	Weber, Werner, Deubel					55	1,066
2004	Amann					7	N/A
2005	Stark					4	N/A
	Saaksvuori, Immonen					437	N/A
	The Aberdeen Group					N/A	N/A
2006	Bergsjö, Malmqvist, Ström					15	N/A
	Rueckel, Koch, Feldmann, Meerkamm					4	N/A
2007	Ahmed, Gerhard					5	N/A
	Cavarero, Chiabert					N/A	N/A
	Chan, Yu					25	1,709
	Moorthy, Vivekanand					4	N/A
2008	Gielingh					38	1,264
	Lanz, Kallela, Järvenpää, Tuokko					3	N/A
	Sendler, Waver					1	N/A
	Xie, Ching, Du					1	N/A
2009	Borrmann, Schorr, Obergriesser, Ji, Wu, Günthner, Euringer, Rank					2	N/A
	Kropsu-Vehkaperä					N/A	N/A
	Könst, la Fontaine, Hoogeboom					3	N/A
	Loshin					3	N/A
2011	Do, Chae					12	1,709
	Kemppainen, Kropsu-Vehkaperä, Haapasalo					N/A	N/A
	Otto					N/A	N/A
2012	Cao, Folan					8	0,6
	Kropsu-Vehkaperä					N/A	N/A
2013	Horváth, Rudas					1	N/A
				AVERAGE		46	1,300

Table 2. The most relevant articles on the research area of Sheet Metal Features and DFM(A).

Year	Author	BOM / product structure	Product development process	Advantages	Sheet metal features	DFM(A)	Citations	Journals' impact factor
1991	Nnaji, Kang, Yeh, Chen						41	1,46
	Wierda						59	1,066
1993	Salomons, van Houten, Kals						257	1,07
1994	Gupta, Regli, Nau						40	0,542
1995	Shah, Mäntylä						1008	N/A
1996	McKay, Bloor, de Pennington						65	1,892
	Radhakrishnan, Amsalu, Kamran, Nnjai						16	1,07
1997	Wang						36	N/A
2002	Dereli, Filiz						9	1,066
2003	Weber, Werner, Deubel						55	1,066
2004	Cross						359	1,545
	Ding, Yue						30	1,709
	Liu						8	N/A
	Liu, Li, Wang, Li, Xiao						17	N/A
	Ramana, Rao						17	1,46
	Tang, Eversheim, Schuh						12	0,944
2005	Amaitik, Kilic						4	1,46
	Ramana, Rao						17	1,278
	Zhao, Shah						36	1,264
2006	Kumar, Singh, Sekhon						22	1,674
2007	Ming, Yan, Lu, Ma, Song						16	1
	Rao, Huang, Li, Shao, Yu						14	1,278
2008	Lanz, Kallela, Järvenpää, Tuokko						3	N/A
2009	Kannan, Shunmugam						14	1,46
	Selvaraj, Radhakrishnan, Adithan						35	1,205
2010	Banabic						N/A	N/A
2012	Emmatty, sarmah						2	1,066
	Wang, Yan, Lei, Zhang						2	0,438
						AVERAGE	81	1,228

3.1 Definition of Terms

The definition of the terms *product*, *data*, *product data*, *product data management*, *sheet metal* and *sheet metal feature* depends on the source and the year it was written. In this case, it is crucial to define the term before they are actually used. The definition depends on the point of view of the researcher. Some take a simpler approach and some apply deeper analysis. For example, Andreasen (2011) defines the term product through deeper analysis. A product can be defined based on its properties, which can be divided into four different classes: function, eigen properties, relational properties and allocated properties (Andreasen, 2011, pp. 306, 309).

This thesis frequently mentions the word *system*. According to Buede (1995, p. 597), a system can be defined as “a set of components (subsystems, segments) acting together to achieve a set of common objectives via the accomplishment of a set of tasks.”

3.1.1 Defining Product

The definition by McKay, Bloor and de Pennington (1996) can be seen from Figure 10. In the figure, the line with a ball at the end describes the terms in relation to each other. An already manufactured object, or object which will soon be manufactured, is called a part. The object which is going to be or has already been sold is called a product. In some cases, the part can be called a product; these two may be identical, but the related data to them may be different. Basically, this means that the assembly or a component can also be called a part and the part itself can also be called an assembly or a component (the part cannot be a component and assembly at the same time). The assembly consists of at least two different parts and the component also includes several parts but a component is always non-decomposable object. (McKay et al., 1996.) However, according to SFS-EN ISO 10303-210:en (2003, p. 10) the definition for part is: “a product with operational functionality that is expected to be used as a component of one or more assembled products”. Therefore, from this point in the thesis, the product and part cannot officially be the same thing.

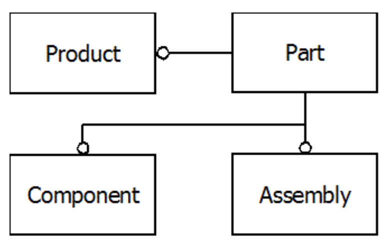


Figure 10. One kind of definition of the terms *product* and *part* (modified from McKay et al., 1996, p. 828).

Different departments inside a company see the product differently, so the exact definition of product is hard to give. It all depends on the viewer and on the use of the product. This situation is described in Figure 11. (Kemppainen, Kropsu-Vehkaperä & Haapasalo, 2011, pp. 40-41.)

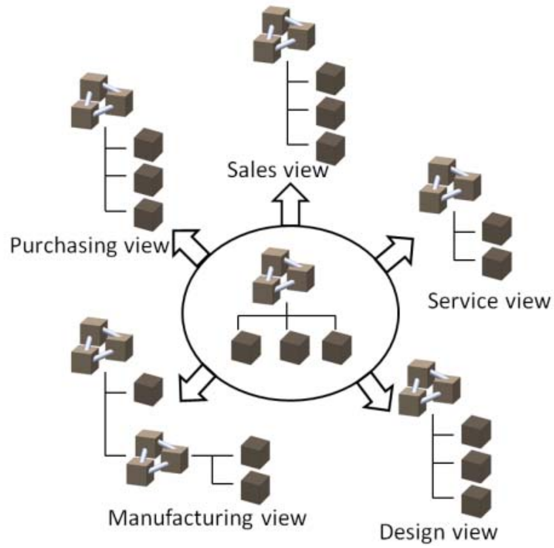


Figure 11. The different points of view of the product (modified from Kemppainen et al., 2011, p. 41).

Stark (2005, p. 20) defines product with the help of Product Lifecycle Management (PLM). He wrote that the product (Stark, 2005, p. 20) “may be a successor or derivative of another product”. The words part and assembly are also related to the word product. The product may consist of several different assemblies (and vice versa) or parts. The stage of the product depends on where it belongs at a certain time in the lifecycle: whether it is in the stage of developing, manufacturing or delivery. Product can also be a physical object (such as a produced article) or it can be immaterial (such as software) but when thinking about the definition from the PLM (PLM system) point of view, all of the articles in the system can be called as a product. (Stark, 2005, p. 20.)

According to Horváth and Rudas (2013, pp. 106-109) the product can be defined by term ‘model space’. Model space includes the actual product, and under this product are features, parameters, relationships and constraints. All these four different terms are related to each other and if one of them is missing, the product is not perfect: features need parameters, relationships define the parameters related to features, and relationships are defined by different rules, reactions and equations (constraints). (Horváth & Rudas, 2013, pp. 106-109.)

According to Rueckel et al. (2006, pp. 616-617), the product can be described in an electronic folder with different divisions created by specific software. These divisions can be seen from Figure 12 (where the most common divisions are listed). Not every product includes all the divisions, but every product has to have some kind of information to describe the product. (Rueckel et al., 2006, pp. 616-617.)

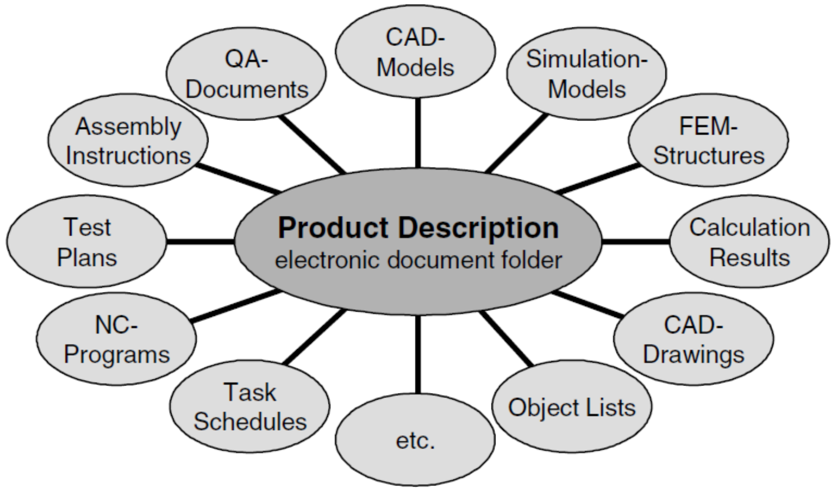


Figure 12. Description of product with the help of different divisions (Rueckel et al., 2006, p. 617).

In this thesis, the starting point for the definition of the term product is partially based on Stark's (2005) definition. The term product covers all the parts, assemblies, products, sub-assemblies that the company needs to produce a finished or semi-finished article for the market/customers, and all these necessary articles are inside the PDM system. Product can consist of different parts and each of these parts includes information. This information defines the part so that it can be manufactured.

Because the term product is confusing, the correct term for the products in the PDM system should be item. Item includes all the parts, products, materials, assemblies which are imported into the company's' PDM system. According to Crnkovic, Asklund and Persson Dahlqvist (2003, p. 31), an item can be seen as a business item or a data item. A business item includes the representation of parts, assemblies and documents and it, as Crnkovic et al. (2003, p. 31) mentions, "contains attributes and metadata, which define the properties of the item." A data item describes the database: a business item's attributes include values, and these values (one or more) are data. Figure 13 shows the difference between a business item and data item. (Crnkovic et al., 2003, p. 31.)

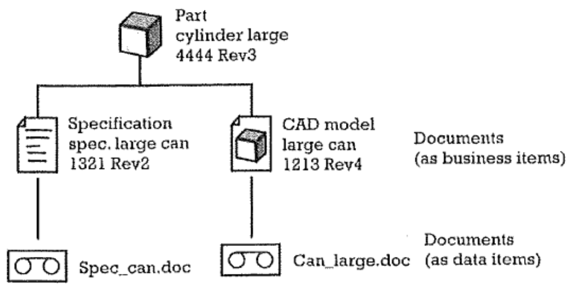


Figure 13. The differences between a business item and data item (Crnkovic et al., 2003, p. 31).

3.1.2 Defining the Data

SFS-ISO 16792 (2010, p. 3) defines data as follow: “information represented in a formal manner suitable for communication, interpretation or processing by human beings or computers”. Sometimes, data is also called a document, the official definition for which (according to SFS-EN ISO 11442:en (2006, p. 2)) is a “fixed and structured amount of information that can be managed and interchanged as a unit between users and systems”.

According to Saaksvuori and Immonen (2005, pp. 7-8) the data of the product can be divided into three different sections, which are related to the actual product:

1. Data that defines the product by its properties, which can be physical and functional properties. This data is special and with the help of these properties, the product can be defined by the product’s fit, form and function. Normally, this data is specific information about the product; the data is described by images and characteristics of the actual product.
2. Lifecycle data, which is included with the product from the starting point of the designing to the end point where the product will be recycled. All the data between these two points, user information and maintenance, are included.
3. Meta data describes the product data; the meta data will tell the users the location of the data, and who has made the data.

According to Loshin (2009, pp. 5-8) data can be called master data. It is the information the company needs to operate: data includes the information about company’s products (materials, functionality, et cetera), suppliers and vendors, among others. The data always include value for the customer (who is going to buy/use the product) or for the manufacturing company. Without the different types of data, the company cannot operate. (Loshin, 2009, pp. 5-8.)

Data is information about the product. As the product is important for the companies, so is the data; therefore (according to Wang et al., (1998, pp. 95-96)) the data should be treated like a product. Companies are producing products for consumer needs, in the same way the data is produced for some person's needs. This person may be the manufacturing engineers, sales staff or consumers. Without the right data, the product may be difficult to manufacture and if it is possible to manufacture, the quality may be poor. (Wang et al., 1998, pp. 99-101.)

The definition of data may also change during its lifecycle. As Stark (2005, p. 241) wrote: "The definition of the product does not have to be identical at all stages, but it does have to be consistent." In this case, Stark is talking about data as a product. He also mentioned that there is no standard definition for the word data which can be associated to a certain product or part. The word data means different things to different persons inside the company: even the different programs (e.g. different types of CADs, stress analysis program) understand and handle data in different ways. Data is seen from different points of view and the users only see data that they want to see; their requirements are different. A good example of this 'data can be seen in different way' is Stark's (2005, p. 242) example "For one system, 05-06-07 may mean 5 June 2007, for another it may mean 6 May 2007, or 7 June 2005, or 6 July 2005. And 5 June 2007 may be acceptable to one system, but not June 5 2007. On what date does the customer want delivery?" Normally, these kinds of problems occur when transferring the data from one program to another or from person to person. (Stark, 2005, pp. 241-242.)

The problem defining the word data occurs when various types of data exist. The data can be in four different ways, according to Stark (2005, p. 237)

- *Text data* which includes different types of manuals, schedules, specifications and so on.
- *Numeric data* which includes for example different kinds of calculations and computer programs.
- *Graphics data* which includes drawings, photographs and sketches.
- *Voice data*.

Products and processes both need data, so the different data types can be linked to both of these or only one of these. In order to optimally handle the data, the usage of the data must be taken into consideration, and also the amount of product data necessary is dependent on the processes. (Stark, 2005, pp. 237-238.) Stark (2005) also mentions that the definition of the word data depends on the user (see Figure 11, page 44). Every user may have a different point of view and definition: this may actually lead to a situation where time can be wasted, errors may occur and money can be lost. Moreover, the data definition changes during the lifecycle of the product; the amount of data increases to the point where the product is in use. Often the details of data change when the customers start to use the product. Users normally do not need so much detailed data as the manufacturers or designers. (Stark, 2005, pp. 245-247.)

According to Burden (2003, p. 2) “the data includes information from engineering, purchasing, manufacturing, field services, cost accounting, sales and marketing, quality assurance, and even from vendors and customers.” All this information should be included with the data, which is located in the PDM system. (Burden, 2003, p. 2.)

In this thesis, the data is handled as a product; without the correct information, the product cannot be manufactured. In addition, companies’ should consider the data as important as the final product. This observation does not take into account the department of the company in which a person is working. If the data is valid from a designing perspective and the data fully describes the product, the data should also be valid to everybody else.

3.1.3 Defining the Product Data

After defining the terms product and data, it is crucial to define the term product data. In Kropsu-Vehkaperä’s (2009, p. 147) conference paper, the product data is defined as data related to product. Product data is not just one thing; it can be divided into three different categories: the description of the product, lifecycle data and metadata (Kropsu-Vehkaperä, 2009, p. 147; Saaksvuori & Immonen, 2005, p. 7). These categories are also somehow related to each other. Without the product description, there cannot be lifecycle data. (Kropsu-Vehkaperä, 2009, pp. 147-149.)

The SFS-EN ISO 10303-210:en standard (2003, p. 3747) describes the product data as follow: “all data that is used to describe aspects of a product.” Stark (2005, p. 82) believes that the definition should be: “The term ‘product data’ includes all data related both to a product and to the processes that are used to design it, to produce it, to use it and to support it.” Therefore, not all product data is created by design engineers; the data may be created for example by production engineers. The main ‘idea’ is that the product-related data can come in many different forms, such as numerical or graphical. (Stark, 2005, pp. 82-83.)

Product data depends on the manufacturing (or designing) stage of the product. McKay et al. (1996, pp. 828-829) have created a diagram (Figure

14), which explains what kind of specific information a product, part, component and assembly should include. These three stages can also be thought of as stages in the product lifecycle, and they are explained in more detail below.

- Every product has its own *specification* and with the help of specification(s) the requirement is set. When the product has its requirement, it has to be satisfied. Also every specification is related to its own aspect and from this relationship the aspect-specification relation is created.
- The *definition* comes from the aspect definition; there are many ways to describe the aspect. Definition includes data, such as the geometry process planning data and/or material and this data relates to the aspect. The definition also helps to understand the specifications.
- The *actual* entity describes the physical object, which has been made according to specification and together with definition. The actual entity may include measurements and the date it was inspected, which is the final data that the product needs to be released from the manufacturing company.

(McKay et al., 1996, pp. 828-829.)

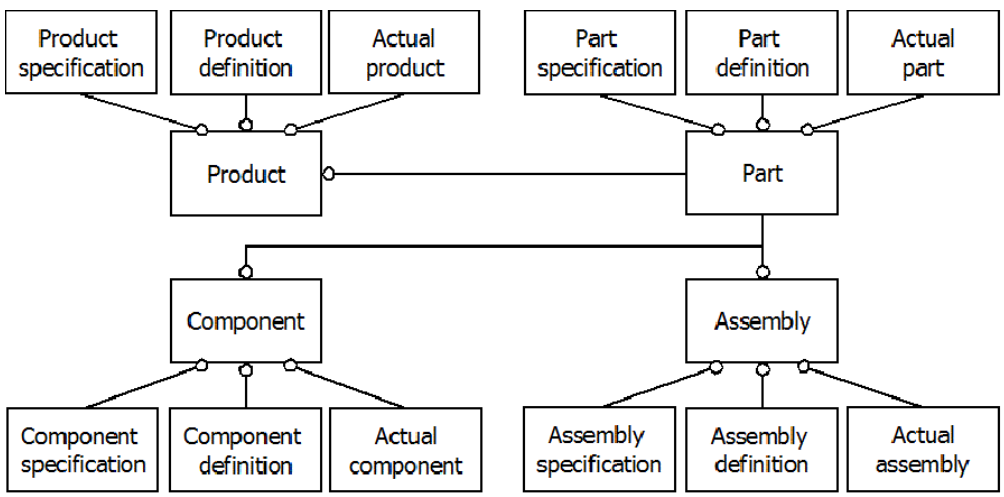


Figure 14. Data information diagram of a product, part, component and assembly (modified from McKay et al., 1996, p. 829).

According to Lanz et al. (2008, p. 204), to fully define the term product data, the product data model is needed. The specific data of the product describes what kind of product is in question. The actual model will include the specific information of the product and in this way, defines its form and content. The actual product then includes different parts and sub-assemblies. (Lanz et al., 2008, p. 204.)

In this thesis, the term product data has the same kind of meaning as the McKay et al. (1996, p. 825) have described: every part has its own specifications, definitions and actual product which describes the physical object. The product data is data for the product which gives it specific value.

3.1.4 Defining Product Data Management – PDM

As Burden (2003, p. 1) wrote: “PDM is often defined differently by different industries and consequently it can be a rather difficult and illusive entity to grasp, implement, and measure.” From this, it can be concluded that the definition is not easy to make. He goes on to define the PDM as a system which manages product-related data in homogenous way (Burden, 2003, pp. 17-18). According to Helms (2002, p. 13), PDM can be known by different names (Technical Information Management, Engineering Document Management, Engineering Data Management) but still the main point is to concentrate on managing the data.

Abramovic1 et al. (1997, pp. 17-19) define the PDM as a tool which supports the Product Lifecycle Management (PLM) system. On the other hand, the authors also recognize that identifying and creating the definition is not easy. They handle the PDM as a small part of a bigger complex, PLM, which works everywhere in this bigger system. (Abramovici et al., 1997, pp. 17-22.) Amann (2004) comes to same conclusion, but with a slight difference: over the years the PDM grows to be PLM.

In addition, Cao and Folan (2012, pp. 641-642) are on the same track: they handle PDM as PLM but they recognize that the system has changed over the decades and in some cases, it can be seen that PDM is a part inside PLM. In contrast, Moorthy and Vivekanand (2007, pp. 94-95) think that when the PDM system was growing, it was developed and improved, after which it became PLM. Saaksvuori and Immonen’s (2005, p. 1) arguments run in the same vein. Könst, la Fontaine and Hoogeboom (2009, p. 4) define the PDM as “a business wide methodology and strategy which makes the appropriate product-related and process-related information accessible to the appropriate people at the appropriate stage in the product lifecycle.”

Storga, Pavlic and Marjanovic (2001) also think that PDM is a part of PLM. They hold the strong opinion that PDM is the backbone for PLM. The PDM system has to be effective, otherwise PLM does not work effectively. The main function of PDM is to control the created data, reuse it and make the retrieval process possible. This is shown in Figure 15. (Storga et al., 2001.)

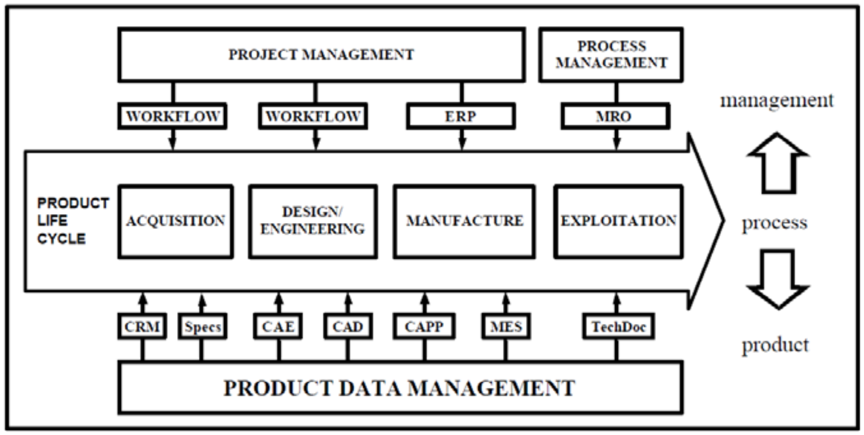


Figure 15. PDM – part of the PLM (Storga et al., 2001).

Ahmed and Gerhard (2007), Borrmann et al. (2009, pp. 364-366), and Gascoigne (1995, pp. 38-40) see that PDM is a tool which manages the information that is produced during the design process. The main advantage, according to Ahmed and Gerhard (2007), is that the system reduces general designing costs. They also see that PDM is a tool inside the PLM system. Gascoigne (1995, p. 40) also wrote that the system helps manufactures to accelerate the time-to-market.

In contrast, Bergsjö, Malmqvist and Ström (2006, pp. 1065-1067) see that the PDM system is an individual system and mainly used only by mechanical engineers. The system serves only as storage for documents and it actually does not support the engineers at all. Bilgic and Rock (1997, pp. 1-2) wrote that PDM helps the actual design process by managing documents among others things but it cannot check what is enclosed in the actual documents. However, Chan and Yu (2007, pp. 823) think that PDM is its own individual system, but this system actually helps the co-operation between manufacturing processes and engineering design. They state that PDM ensures the available data's integrity and accuracy.

Do and Chae (2011, p. 855) and Gott (1995, p. 18) believe that the PDM system is the key element when designing mechanical products. PDM is a tool for managing the information, handling the product structure/classification and sharing it between various applications and with users. Finally, PDM integrates design tools together, so the created information can be available to all who may need it. (Do & Chae, 2011, p. 855, 862.) Also Fan (2000, pp. 224-228) has drawn the same conclusion.

Kropsu-Vehkaperä (2012, pp. 34-35) claims that PDM manages and integrates data between different systems, users and media. The PDM system helps to share the data and control it; the system actually connects the data to products. Still, PDM is seen as a part of PLM. (Kropsu-Vehkaperä, 2012, p. 35; Kropsu-Vehkapera, 2009, pp. 147-149.) Actually, how PDM is seen as the part of PLM can be seen from Figure 16.

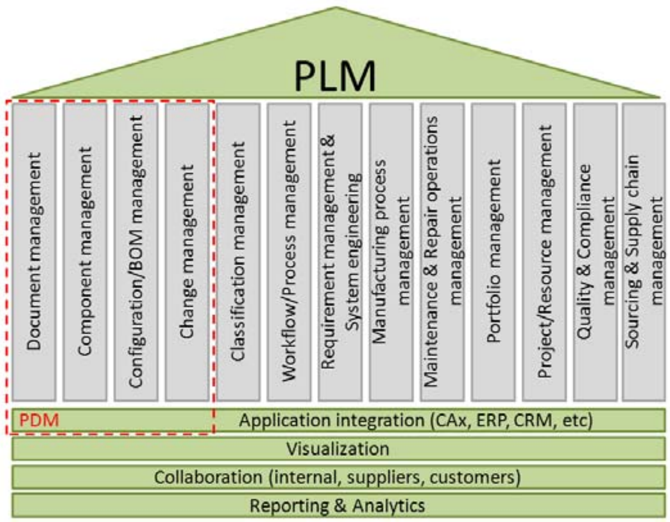


Figure 16. Relationship between PDM and PLM according to Kemppainen et al. (2011, p. 33, modified).

Stark (2005, pp. 233-234) wrote that PDM is the most important component of PLM. Therefore, PDM is part of PLM, but it is its own application, although PLM will not work properly without PDM. The main meaning of existence of PDM is to manage all the activities during the product lifecycle: the design process, data sharing with other users, and product configuration control to name a few. The main purpose of the PDM system is to improve the productivity and manage the product data: the system controls the workflow inside the company. (Stark, 2005, pp. 233-234.)

Rueckel et al. (2006, p. 617) has condensed Stark’s (2005, pp. 233-234) idea about the PDM system’s purpose: PDM is an integration of different CAx-systems. All CAx systems inside the company are integrated with PDM and the PDM collects, stores and administers the created data. Rueckel et al. (2006, p. 618) also called the PDM system middleware: it catches all the information in the same place, where the data is easy to access and find.

Otto (2011, p. 275) wrote that PDM should not be seen as a tool oriented towards designers but rather that it should be used everywhere inside the organization as a general information handling system. The system should handle the information from the starting point of the designing all the way to the delivery; it should handle different management processes. The system should called, as Otto (2011, p. 275) mentioned, a “golden record” of product data. (Otto, 2011, p. 275.)

According to Philpotts (1996), the PDM is an integrated solution of different management systems that can be found inside the company: engineering, product information and technical data/information. All electronic documents are saved into the system: PDM manages Bill of Materials (BOM), the classification of the existing data and projects; and it is a communication and notification tool for its users. (Philpotts, 1996, pp. 11-15.)

Svensson and Malmqvist (2001, pp. 1-2) see that the system is a tool which traditionally manages the product-related information. In Figure 17, a simplified product structure and its related components are shown. This is the complex of information that PDM handles. (Svensson & Malmqvist, 2001, pp. 1-2.)

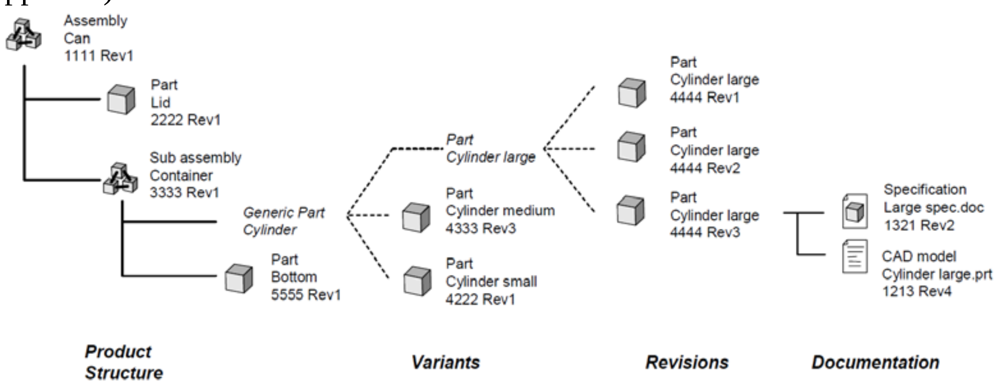


Figure 17. The fishbone from the product structure and its components handled by the PDM system (Svensson & Malmqvist, 2001, p. 2).

The PDM system can be defined in many different ways, as can be seen above in this chapter. The system can be seen as product lifecycle tool, data sharing tool and/or process management tool. In this thesis, PDM is seen as an individual system, which includes inside operations, also called add-ons (see Figure 3, page 23). Some of these operations are already in use, such as data vault, document sharing and project management. In addition, some operations are still unknown to users. The system should not only be a storage place or documentation sharing system; the PDM system is supposed to be seen, in this thesis, as an assistant tool for designers who (in this case) design sheet metal parts.

3.1.5 Defining the Sheet Metal Part

According to Wang (1997, p. 35) “a sheet metal part is a set of planar faces connected by bend lines.” At the engineering stage, the 3D model describes the sheet metal part, where the shapes of the part can be outlined. When all the necessary information is designed into a 3D model, the actual manufacturing drawing (2D) is created. Only with the manufacturing drawing can the manufacturing process planning start. (Wang, 1997, p. 36.)

In this thesis, the sheet metal part is thought of as a modified part from the sheet metal blank (uncoated, no lubrication chemicals), whose thickness is a maximum of 3 mm. At least one forming has to be done, otherwise, the piece of sheet metal is just thought of as a blank.

3.1.6 Defining the Sheet Metal Feature

The features add more information to the product data. According to Lanz et al. (2008, p. 203) features can be geometrical (e.g., holes, pads, edges) or non-geometrical (e.g., tolerances, material and color). These features, geometric and non-geometric, will define the sheet metal production costs. Therefore, by understanding the meaning of the features, the result may reduce the design time and make the designs more manufacturing-friendly. (Wang et al., 2012, pp. 453-454.)

As Tang, Eversheim and Schuh (2004, p. 397) wrote, the official definition for the term feature is missing. However, this depends on the point of view being considered: manufacturing or engineering. They also mentioned that the definition is not the most important point; the actual understanding is. According to Tang et al. (2004, p. 397), a feature can be seen as a tiny element carrying the information of the part.

Kannan and Shunmugam (2009) and Liu (2004) have based their feature definition on an article by Salomons, van Houten and Kals (1993, p. 115): “a specific geometric configuration formed on the surface, edge or corner of the workpiece.” This definition appeared in 1981, and after that, the definition has been somewhat updated. When talking about feature from the process point of view, the meaning comes from the shape; the shapes will determine the process which to be used in manufacturing. However, when talking about features, the first thing is to determine what the consequences of the used feature term are: does it affect the manufacturing, the design or something else. (Salomons et al., 1993, pp. 115-116) When a designer chooses a feature (actually, the designer thinks of it as a shape) for his design, it will automatically affect the manufacturing process to be chosen, so in this case, it can be handles as a design and manufacturing feature.

Amaitik and Kiliç (2005, pp. 3087-3092) mentioned that feature technology will give more information to the part; each part has more information than just its geometry and topology. The feature can be described as a shape that is going to be manufactured to the part. Another perspective is offered by Shah and Mäntylä (1995, p. 8), who define the term feature as: “the generic shapes or characteristics of a product with which engineers can associate certain attributes and knowledge useful for reasoning about that product.” When talking about the product’s shapes they are seen as features: how the product can be seen and defined. (Shah & Mäntylä, 1995, p. 89.)

According to Nnaji et al. (1991, pp. 1867-1868) features define the part that it actually is and what it includes (this is also the definition by Dereli and Filiz (2002, p. 141)). With the help of CAD software, the part is designed and the information is added to the model. The information at this point is the core of the term feature and these features have to be classified in some way to understand them. (Nnaji et al., 1991, pp. 1867-1868.) Wierda (1991, p. 3) had a similar definition: every part has its own properties which have different meanings in different fields of design and manufacturing. The properties will, for example, determine what kind of manufacturing methods are going to be used to manufacture the part. In Figure 18 shows the kinds of features a part can have according to Wierda (1991, p. 5). These features are called design features because the part also needs other information, such as material and dimensions. If only the features are shown in the part, the part cannot be manufactured; the manufacturing drawing is also needed. (Wierda, 1991, pp. 3-6.)

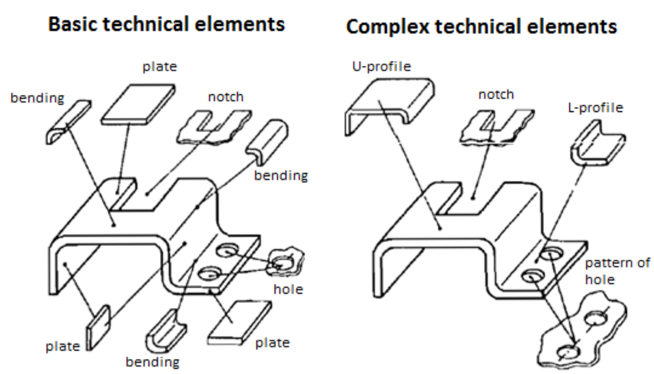


Figure 18. Sheet metal design features by Wierda (1991, p. 5, modified).

The one kind of definition of the feature is set by McKay et al. (1996, p. 828). Feature is a geometrical shape which defines the part. The feature is data which support manufacturing; without this information, the product cannot be manufactured or the manufacturing may suffer errors. In the beginning of the design process, the designer will first (in most cases) create a 3D model. The designer will draw the geometrical features which are based on functional requirements. A sheet metal part's features can be divided into three different features (see Figure 19): management features, material features and shape features. (Rao et al., 2007, p. 438.)

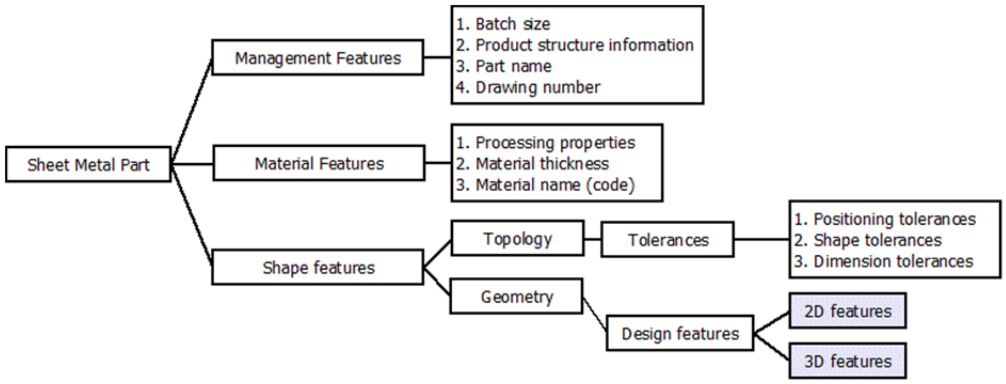


Figure 19. Sheet metal features and their contents (modified from Kannan & Shunmugam, 2009, p. 945; Rao et al., 2007, p. 438; Ming et al., 2007, p. 190; Ramana & Rao, 2004, p. 612).

The three main features in Figure 19 describe the actual sheet metal part and how it should be manufactured. It also describes the information model of the part. To manage the sheet metal part, the important thing to know is the drawing number, and after that, the name of the part. Without the proper management, the actual part cannot be found from the PDM system. The material features describe the sheet metal part according to the material (e.g., thickness and nature) and process properties. With the shape features, the topology and geometry are described according to geometric model. (Rao et al., 2007, p. 438, 441.) The actual design features are part of the geometry and this way, a part of the shape features. The design features can be divided into 3D and 2D features. The 2D features can be further divided into peripheral features and to surface features: the content of these features can be seen from Figure 20. (Ramana & Rao, 2004, p. 612.) A 2D pattern is needed to create manufacturing drawings, to plan the manufacturing process and to do the nesting. (Rao et al., 2007, p. 438.)

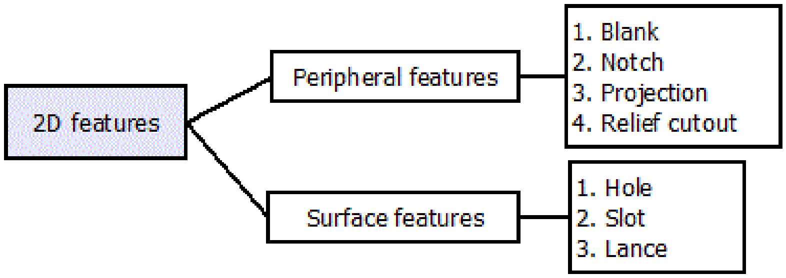


Figure 20. The 2D features of a sheet metal part (modified from Ramana and Rao, 2004, p. 612).

Different features can also be found from the 3D model, which is normally the basis for the 2D drawings. The features that can be found from 3D are peripheral features, surface features and features between surfaces (see Figure 21). The machines to be used in the manufacture of the product are determined by these features so the included information has to be correct to ensure a manufacturing-friendly product. This information mainly comprises different kinds of parameters that affect each other. However, the main factors to consider for the parameters are the material and material thickness. After these, the effective factors are the tools and machines used. (Liu et al., 2004, pp. 1458-1459) In the article by Liu et al. (2004, pp. 148-1459), the authors give two definitions for sheet metal feature:

1. The feature has to include two types of information:
    a. Engineering information, which defines the manufacturing process. This information depends on the used feature, for example the hole has its own typical information (diameter) and bridging needs another type of information (e.g., highness and length of the bridge), and
    b. Geometric information of the shapes.
2. The sheet metal features can be divided into two groups: composites and cellular features. Composites are, as the name says, features that join two or more cellular features together. Cellular features can then be divided into three different groups: primitives, add-ons and connects. Their main is to form the sheet metal blank.

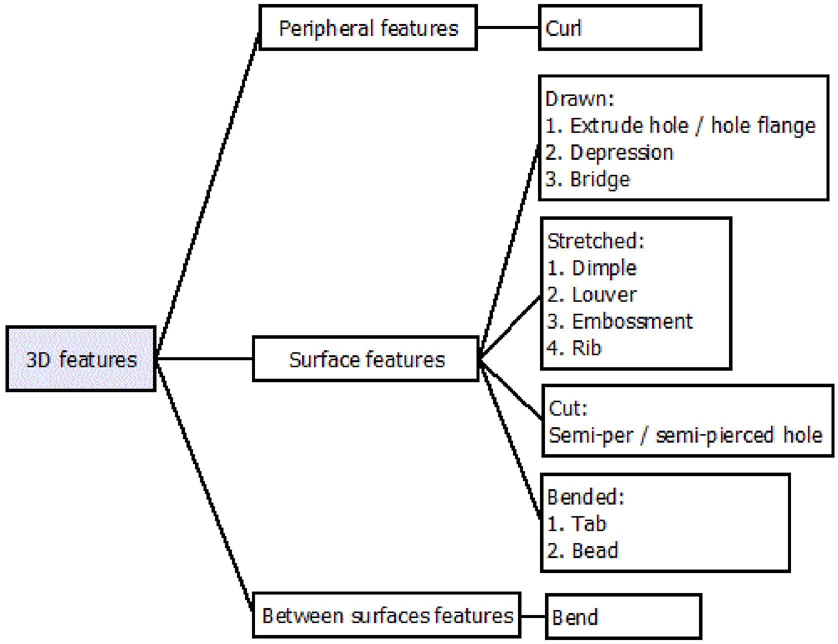
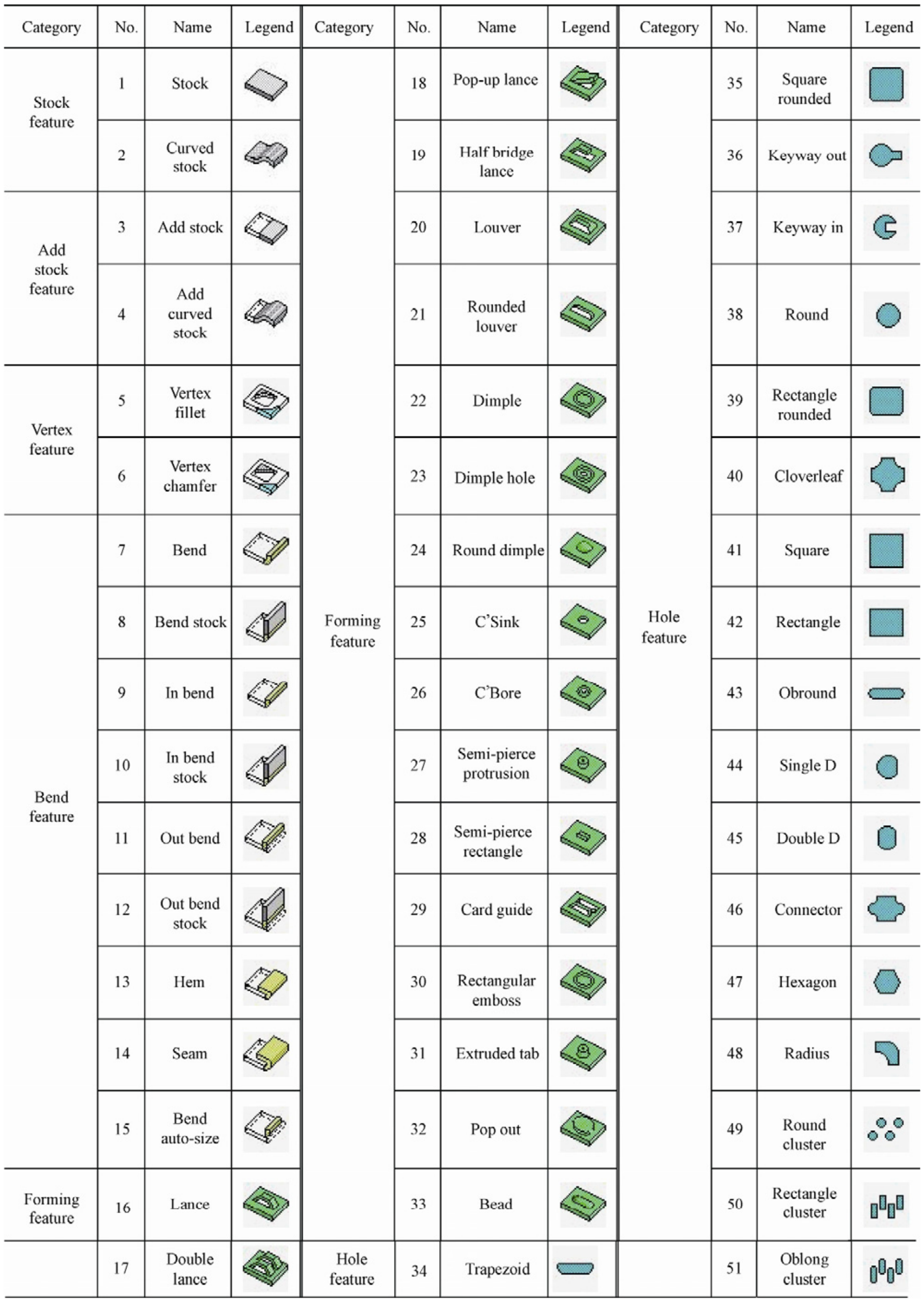


Figure 21. One type of classification of sheet metals' 3D features (modified from Kannan & Shunmugam, 2009; Ming et al., 2007; Ramana & Rao, 2004; Rao et al., 2007).

The official standard for sheet metal features and classification is still missing, although the Standard for the Exchange of Product Model Data (STEP has classified the features. However, there is still the problem of overlapping classification and some definitions are inaccurate. (Ding & Yue, 2004, p. 201.) This has been noticed already in 1995 by Shah and Mäntylä (1995, p. 141), when they wrote that no universal classification exists and the classification depends on the part and the used process.

Features can be understood in different ways, which will lead to a situation where classifications are different. A broader type of classification can be seen from Figure 22, made by Wang et al. (2012, p. 457). Simplified classification can be found from Figure 23, by Selvaraj, Radhakrishnan and Adithan (2009, p. 16). Figure 23 shows the sheet metal part's features on the left side and on the right side, the classification of these features. The abbreviation PFS is the principal flat surface, which is a surface that stays unformed during the sheet metal formation process.



Category	No.	Name	Legend	Category	No.	Name	Legend	Category	No.	Name	Legend
Stock feature	1	Stock		Forming feature	18	Pop-up lance		Hole feature	35	Square rounded	
	2	Curved stock			19	Half bridge lance			36	Keyway out	
Add stock feature	3	Add stock			20	Louver			37	Keyway in	
	4	Add curved stock			21	Rounded louver			38	Round	
Vertex feature	5	Vertex fillet			22	Dimple			39	Rectangle rounded	
	6	Vertex chamfer			23	Dimple hole			40	Cloverleaf	
Bend feature	7	Bend			24	Round dimple			41	Square	
	8	Bend stock			25	C'Sink			42	Rectangle	
	9	In bend			26	C'Bore			43	Obround	
	10	In bend stock			27	Semi-pierce protrusion			44	Single D	
	11	Out bend			28	Semi-pierce rectangle			45	Double D	
	12	Out bend stock			29	Card guide			46	Connector	
	13	Hem			30	Rectangular emboss			47	Hexagon	
	14	Seam			31	Extruded tab			48	Radius	
	15	Bend auto-size			32	Pop out			49	Round cluster	
Forming feature	16	Lance			33	Bead			50	Rectangle cluster	
	17	Double lance		Hole feature	34	Trapezoid			51	Oblong cluster	

Figure 22. Classified sheet metal features by Wang et al. (2012, p. 457).

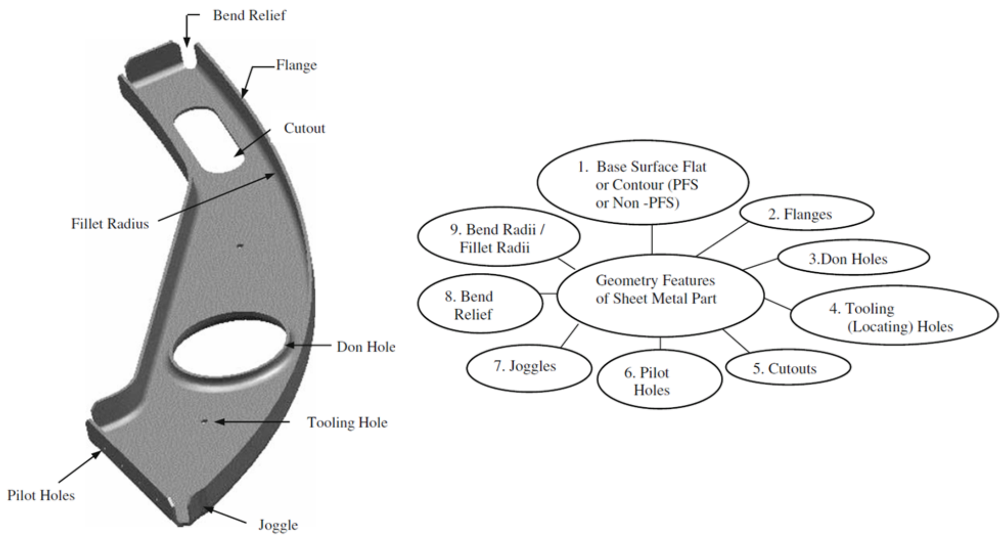


Figure 23. One type of definition of sheet metal geometric features and classification by Selvaraj et al. (2009, p. 16, modified).

In this thesis, the features are geometric features and more over design features. In partial it is also mentioned geometric features which are manufacturing features. The design features include both 2D and 3D features. With these features, the used tools and machines are determined. To help understand the features, Figure 22 (features classifications by Wang et al. (2012, p. 457),) provides a clear classification of features.

3.2 Product Data Management - From History to Today

The first PDM systems were created in the early 1980s. The marketing of these systems was based on usability: systems should help to manage engineering data and activities. Furthermore, according to this marketing, the system could reduce engineering costs. (Ahmed & Gerhard, 2007.) The wakeup call for companies happened in the beginning of 1990s when they recognized the lack of data handling. IT solutions were raising their head and PDM became a really important tool for storing and managing engineering data. (Borrmann et al., 2009, p. 359.)

One of the benefits of the PDM system was to replace all the paper documents with electronic versions. In 1984, the first standard of the electronic exchange was created and it was published in the middle of 1990s. The main meaning of the standard ISO 10303 (also called STEP) was to create a format which helps to share the data from user to user and convert the data from one software to another. The standard was to make sure that in the conversion from a certain software format to a so-called neutral format, (e.g., pdf) no information would be lost. When converting the information, there is always a possibility to lose data, semantics or precision. The fact is that if the information is created in a certain program the files, according to Stark (2005, p. 239): “files “belong” to the programs that wrote them.” (Gielingh, 2008, p. 750-754; SFS-EN ISO 10303-210:en, 2003, pp. xix-3.)

The PDM system was developed to help documentation during the design and manufacturing processes. The Aberdeen Group (2005, p. 6) has carried out research about which stage the documentation starts when designing. The research shows (see Figure 24) that the most common stage for documentation to begin occurs at the beginning of the design process. It can be seen that the companies understand the meaning of documentation; without it, designs may disappear and the designing time may be longer. Also, the iterations during the design processes have to take into account; rarely is the design ready after the first attempt. (The Aberdeen Group, 2005, pp. 7-10.) When companies are considering a PDM system, the main reasons for buying are in business: the company’s targets are to improve productivity and keep the whole documentation system as flexible as possible. Flexibility in this case means the better management of workflow and product data. (Stark, 2005, p. 234.)

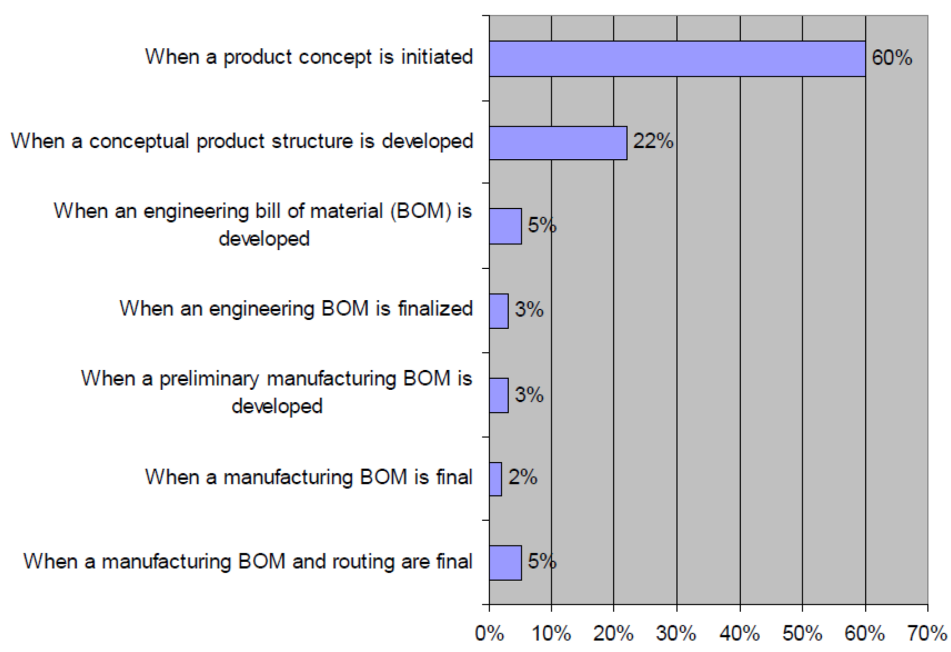


Figure 24. Starting point of the documentation (The Aberdeen Group, 2005, p. 7).

In the beginning of the 1990's, PDM was a great tool for handling product information, change control and handling/creating product structures. The system had broken through the engineering field and after this, the business sector recognized the possible benefits. The co-operation between business administrators and engineering led to a situation where the PDM system burgeoned; the system came more user-friendly and it started to support different platforms than just UNIX. The main idea was to gain business benefits from the system. In the new millennium, the system was still growing and it started to support the product lifecycle. (Moorthy & Vivekanand, 2007, pp. 93-95.)

Already in 1995 (Gott, 1995, p. 18), 600 manufacturing companies thought that the PDM system was at the top in computer technology investment. The reason why they hesitated to do that investment was the challenge of integrating the system with other, already existing systems and the potential change in working practices. (Gott, 1995, pp. 18-19) In fact, the same problems still exist in 2014.

Gascoigne (1995, pp. 39-40) wrote that the use of a PDM system should boost the engineering productivity. There has been research on engineers' working time: approximately only one day per week is actual designing time. The rest of the time is spent finding information and documents, and verifying the information found. The function of the PDM system, according to Gascoigne, can be seen in Figure 25. (Gascoigne, 1995, pp. 39-41.)

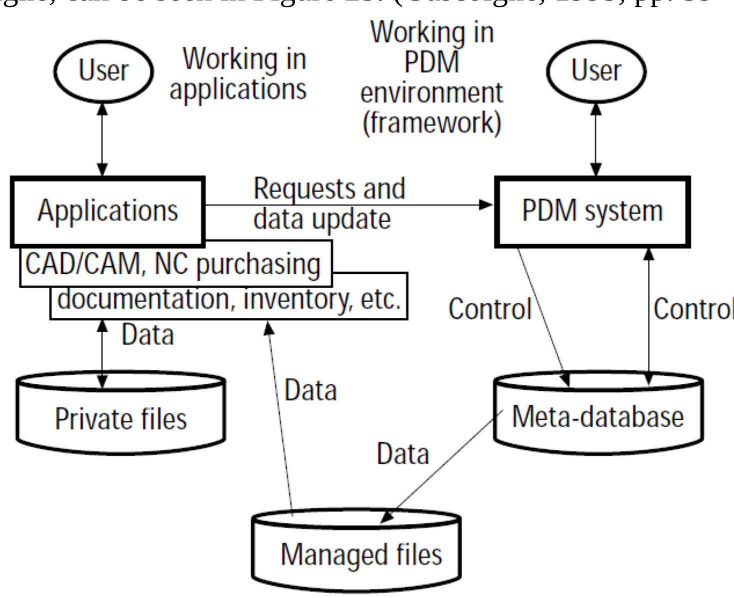


Figure 25. Functional view of PDM system by Gasgoigne (1995, p. 40).

Cavarero and Chiabert (2007, pp. 108-109) have also researched the importance of the different tools that are in used in small to medium-sized enterprises (SME). Their main purpose is to faster product development processes. It can be seen from Figure 26 that the companies' three most important tools are program management, project collaboration and product cost management. Although in the diagram there is also the Lifecycle Management, it can be said that, in the author's opinion, some of these fields can be integrated into the PDM system if the system is tailored to the company.

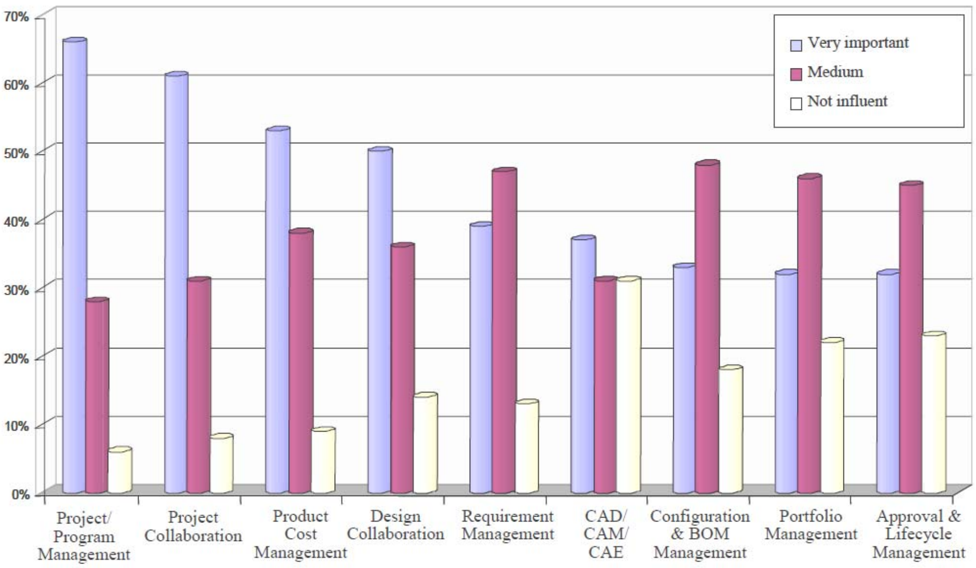


Figure 26. The different tools in SME companies and their importance for fostering the product development process (Cavarero & Chiabert, 2007, p. 109).

According to Liu and Xu (2001, pp. 252-255), the main idea of a PDM system is to coordinate product-related information. This information is everything from 3D designs to 2D drawings, from machine tool programs to product specifications. However, it does not control the manufacturing; the system can be integrated with systems controlling the actual manufacturing (for example, Enterprise Resource Planning - ERP). The PDM system itself is located on the server; the user has access to the server and through the server, all users (if they have rights) have access to the database (Figure 27). Several people participate in design and manufacturing: firstly, designers are carrying out the design process, and secondly, the manufacturing engineers are planning how to manufacture the required parts/products, and in the meanwhile, the purchasing department is working to find the needed materials. These are the main PDM users. (Liu & Xu, 2001, pp. 252-253; Stark, 2005, p. 236.)

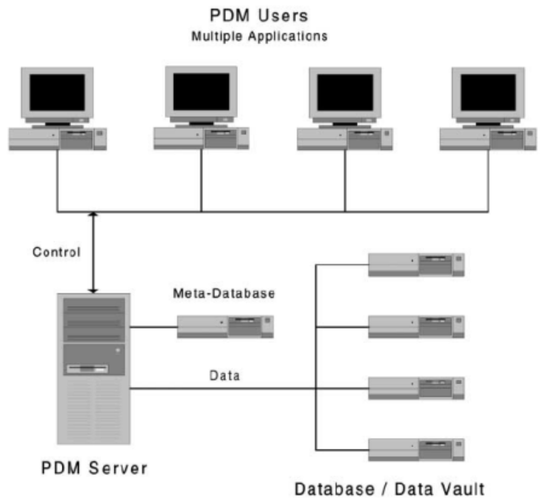


Figure 27. Basic functionality of PDM system (Liu & Xu, 2001, p. 253).

The amount of product data has grown in past years, as well as the type of production. Some years ago, it was really common to produce just a couple of different variants from the product but today, for example in the car industry, there are large amounts of different variants available. Different variants, versions and changes to the product are made faster than in previous decades and this puts pressure on companies to manage products and their data. Additionally, the spare parts are more important to companies. Another advantage is that PDM also ensures that the all product information is still available after 20 years. (Stark, 2005, pp. 243-244.) From Figure 28, it can be seen how much storage capacity has grown over the years. The measurement unit is global disk storage per person (GDSP) and it roughly shows its growth. (Könst et al., 2009, p. 12.)

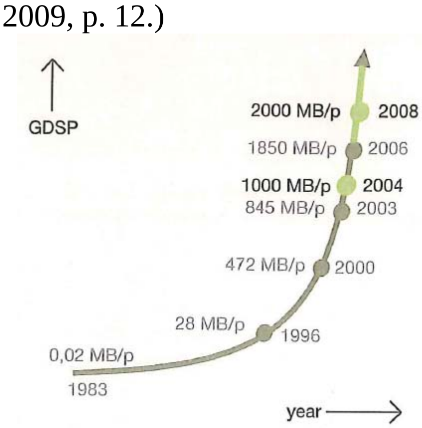


Figure 28. GDSP growth during the years (Könst et al., 2009, p. 12).

If the PDM system works as it should, the following potential advantages to the company are (Burden, 2003, p. 13; Stark, 2005, pp. 234-235; Liu & Xu, 2001, p. 524; Sendler & Waver, 2008, pp. 62-63; Storga et al., 2001):

(1) There is a better control of the created data. The reuse of data is simpler and the access to the data is easy. Because of this, the actual cost, coming from design activities may be reduced. Stark (2005, p. 234) wrote that 75% of the total product costs are exactly coming from this activity. Sendler and Waver (2008, p. 63) claim that the reuse of the part can actually save 700-5000 €. This is based on time savings - designers do not have to design a part again and the maintenance of the product will not have to be planned again.

(2) Change management is easy to control. PDM takes care that the latest versions and revisions are available in the system. Also, the old data can be easily reused as a base for a new part, and the lifecycle management is improved.

(3) The data is in the one safety place where user access can be limited if wanted.

(4) Employees who need the information have access to the system and this will make the interdisciplinary collaboration possible globally. From the system, workers can see at which stage the product is in real time. Designing status is always available to the product development managers and manufacturing information (i.e., how parts have been made earlier) are available to manufacturing engineers.

These advantages can also be called the key functions of the system; these are shown in Figure 29.

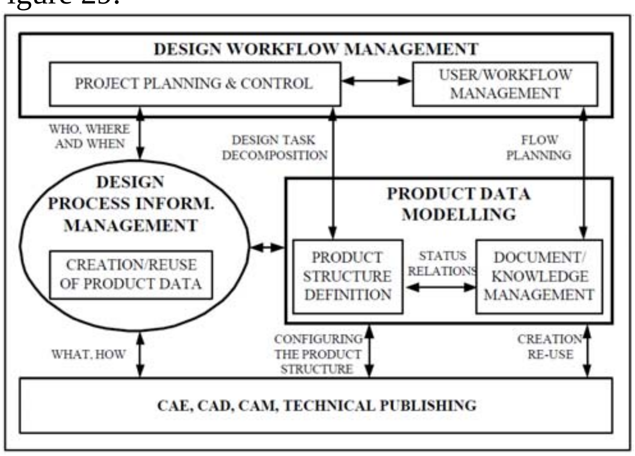


Figure 29. Advantages that can be reached with a proper PDM system (Storga et al., 2001).

To make the PDM system work in the company, it has to be taken as a part of the company's business strategy, and top managers have to be made aware of the system, its existence and its potential. One reason for implementing the PDM system is to secure and protect data. Protection is different in the different stages of lifecycle. At the beginning of the design process, data is protected in such a way that it can still be modified without particular permission. At the end, when the product is in the manufacturing stages, changes are no longer possible to do without the permission of prime designer and the revision of the drawing. (Stark, 2005, p. 23, 239.)

3.3 Sheet Metal Features and PDM - Recognition

The knowledge that sheet metal designing needs is considerable, and the knowledge of formability is also important, even to the designers, not just for manufacturers. Material properties, such as chemical compositions, hardening and density affect the geometric feature parameters. Manufacturing knowledge demands slightly more: material knowledge, process parameters knowledge and strain bounding criteria knowledge. (Banabic, 2010, p. 145.) According to Zhao and Shah (2005, p. 893) the knowledge of sheet metal manufacturing includes:

- The actual part of the sheet metal: tolerances, batch sizes, material, design and manufacturing features.
- Different kinds of design rules, for example where to place the hole according to bend, what is the minimum flange high, what are the minimum distances between two holes.
- The costs: where all the costs are coming and what are the variable and fixed costs of the product.
- The time it takes for the part to be manufactured and the cost for this manufacturing time.
- The kind of machines and tools to be used and which of those already exist in the machine shop.

There are many types of feature recognition models invented. This thesis will concentrate on the classification of the features, which the PDM system will recognize (after adding the part in to the system) according to systems classifications. According to this 'recognition', the PDM system can give hints to the designer about its manufacturing-friendly aspects and parameters.

Nevertheless, a universal standard is still missing for the sheet metal features. Each CAD program has its own classification and parameters for the features. The extent of the program's library also depends on the popularity of the program. Well known programs (e.g., SolidWorks) have a wide library of design features, but the features are based on vendor knowledge. These features can be managed by DFM (Design Form Manufacturing) and this way, it can be ensured that any possible problems are solved in the early stages of design. (Dereli & Filiz, 2002, p. 142.) To actually design manufacturing-friendly products, the company has to verify that the design software's library is updated to correspond and be compatible with the company's tools and machines. This also requires co-operation between the design and manufacturing units.

In Appendix I, the typical sheet metal features and the guidelines that have to be taken into account when designing parts/products are shown. It can be seen that the amount of design information is broad, and the appendix only describes hole, slot, notch, projection, relief cut-out and bend.

3.4 Sheet Metal Designing Methodology and Guidelines

Every designing product/part includes certain characteristics and properties. The shape, structure and material of the product are described with characteristics, and the behavior of the product comes from the material's properties. Designers can choose characteristic features but then the properties depend on this choice. In some cases, before starting the actual design process, properties are set and designers have to follow the set decisions. Therefore, characteristics and properties are always related to each other. In Figure 30 different kinds of characteristics and properties and their main relations are shown. (Weber, Werner & Deubel, 2003, pp. 448-449.) Könst et al. (2009, p. 4) stated that parameters, characteristics, attributes and properties are all mean the same thing.

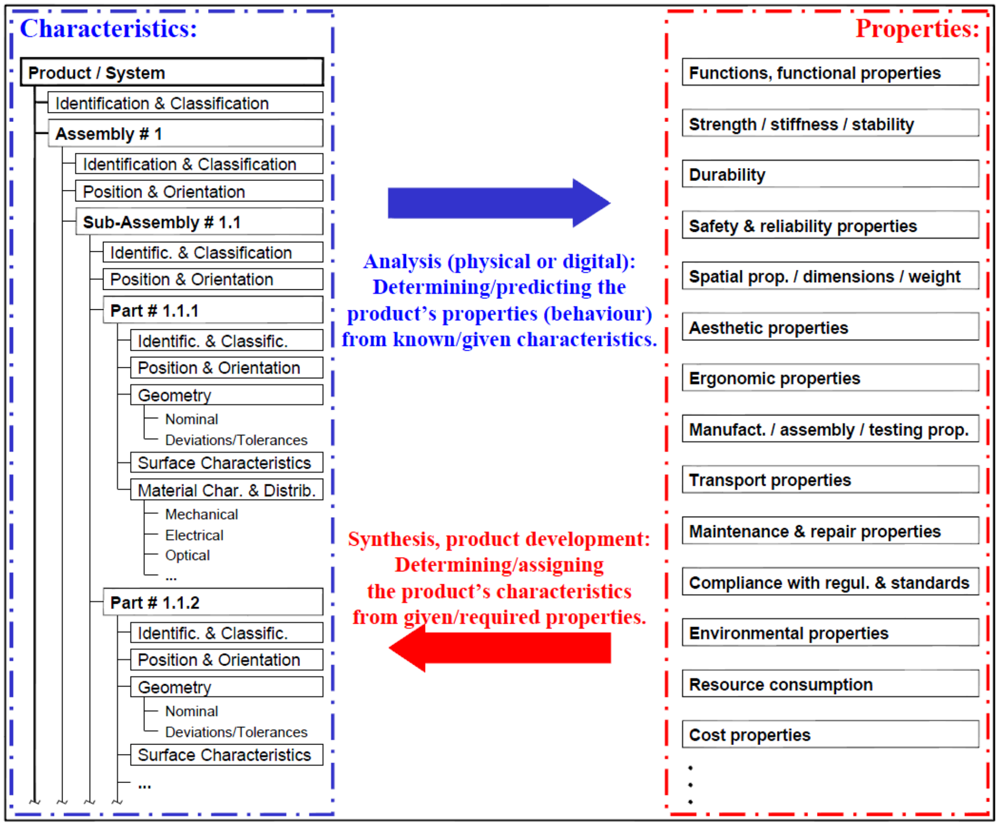


Figure 30. Different kinds of characteristics and properties of the product, and the main relation between them (Weber et al., 2003, p. 449).

One of PDM's key purposes is to manage the information in it. PDM should confirm that only one designer can modify the item at a time; in this way, the system is ensures that the information in the drawings is valid and no duplicates occur in the system. The control mechanism sounds simple, but actually it a more challenging process, as can be seen from Figure 31. (Xie, Ching & Du, 2008, p. 34.)

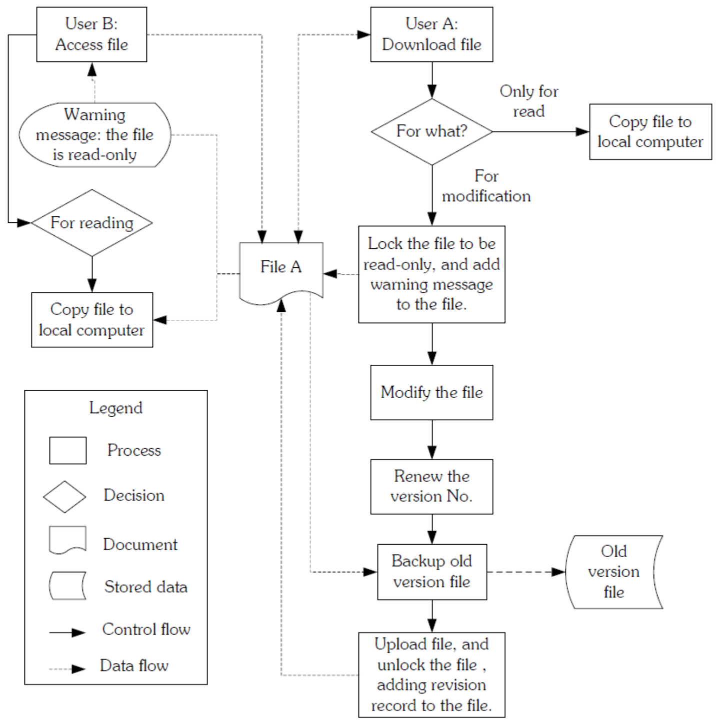


Figure 31. The version control in a PDM system (Xie et al., p. 34).

When talking about DFM, the basic hypothesis is that the designer knows the machines and tools which are in use. Currently, this is difficult in practice because of globalization: design processes may be done in a different country than the manufacturing or the machine shop being used changes now and then because of the manufacturing price. Against all odds, designers can still use so-called rules-of-thumb, which should help the design process. As Emmatty and Sarmah (2012, p. 699) wrote, these rules-of-thumb are mainly based on earlier industrial experience, and rules do not guarantee a manufacturing-friendly product. Rules will just give approximate values for designers; the correct values always come from the practice test. (Emmatty & Sarmah, 2012, p. 699; Radhakrishnan et al., 1996, pp. 182-184.)

Sheet metal formability depends on factors shown in Figure 32. Some of the figures' information about properties lies on the manufacturing engineers' shoulders; the design engineer has to know at least the material properties. The material properties may vary slightly according to different batch size of the material, and this will affect the material behavior. (Banabic, 2010, pp. 142-145.)

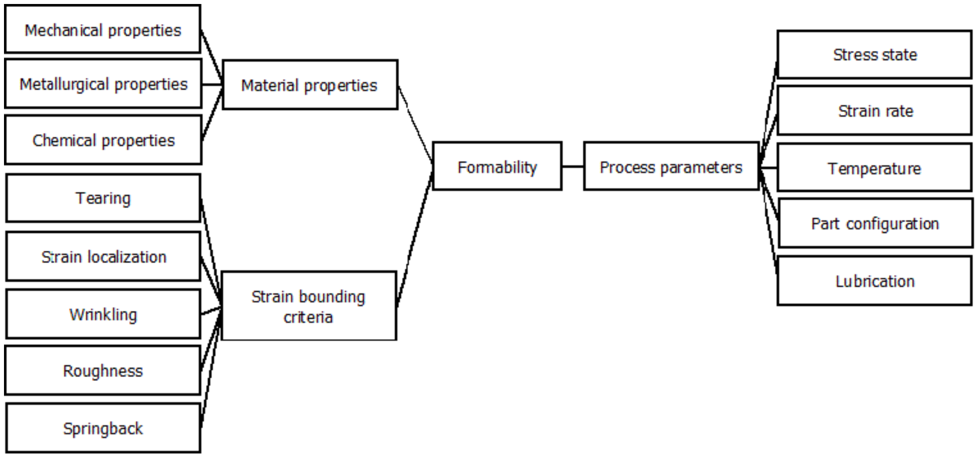


Figure 32. The factors affecting sheet metal formability (Banabic, 2010, p. 145).

By integrating DFM(A) methodology and CAD systems together (future goal in Figure 8, page 29), it would be possible to eliminate manufacturing errors in the early stages of the design process. Research has already been carried out in the area where the CAD programs and DFM(A) have been integrated. DFM can be added as a module to the CAD system to ensure that design features are taken into account and used. (Dereli & Filiz, 2002, pp. 142-143; Gupta, Regli & Nau, 1994.) Because the main purpose of PDM was to manage the data at the designing stage (Do & Chae, 2011, p. 855; Gott, 1995, p. 18), it will mean that when integrating the PDM system and CAD software, the DFM(A) will also be automatically integrated into PDM (compare to Figure 8, page 29).

The main idea of DFM is to integrate design and manufacturing units. The integration has to concern the product and its production: there should not be any design changes during the manufacturing process. All the changes have to happen in the early stages of designing. By knowing the principles of DFM(A), the manufacturing costs will reduce. (Dereli & Filiz, 2002, pp. 143-144.) The manufacturability check is easier to carry out with the help of computers; if engineers are needed, it will take more time, and require experience and knowledge of sheet metal behavior. (Kumar, Singh & Sekhon, 2006, p. 64.)

It is important to understand that manufacturing characteristics depend on the method to be used. If some part is easy to manufacture, it does not automatically mean that the same part is easy to assemble. (Gupta et al., 1994.) Because the total costs of the product are determined in the design stage (Ramana & Rao, 2005, p. 3889), the manufacturing costs may decrease. To make this integration possible, it will require software which can analyze the design (Gupta et al., 1994).

To fully implement DFM in a company, it needs investigation (how the system works, how to get full profit out from the system, how system can be integrated to other systems in company et cetera) and training of the designers. Knowledge mainly comes together with experience. (Dereli & Filiz, 2002, p. 145.) Cross (2004) has done research about experts in design. The main difference between the novice designer and expert designer is the way they solve problems. Novices struggle with the whole problem content but the expert has experience to divide the problem into smaller parts and from that point of view, solving the problem is easier. Also, because of that experience, the time spent solving the problem is shorter than the time that the novices would spend on the same problem. (Cross, 2004, p. 429, pp. 439-440.)

3.5 Conclusion from Literature Review

The definition for product depends on the point of view: researchers seem to have different opinions. Furthermore, inside the company the designers will define the product differently than, for example, in the purchasing unit. The common point is that everybody is trying to define the product in such a way that it will help their duties and keep the workflow going. The word product has a vernacular meaning of assembly and/or part (Stark, 2005), but when taking a closer look at the standard SFS-EN ISO 10303-210:en (2003), the part and product are not the same thing. Therefore, defining a product in a way that everybody inside the company can understand it is important.

A product will always include information or data of how it can be manufactured. The official term for this information is data. The data inside the product includes material information, its shapes and features. Product has to have data inside of it, that it can be manufacture. Different standards, such as SFS-EN ISO 11442:en (2006) and SFS-ISO 16792 (2010), define the term data in official way but to fully define the term using standards will need a closer look and the comparison of many different standards. Now the definitions, even in these standards, are not equal.

However, data is not just one concrete term; it can be divided into different parts, as Saaksvuori and Immonen (2005) have done. Different types of data exist, such as calculations, drawings, and graphics, just to mention a few.

What is common between all of these possibilities is that the data is always related to some kind of product or part: data defines what the product actually is. The same problem occurs with the definition of the product; the content of the data can be seen differently by different people. Not only do people interpret the data differently but the used software can also interpret the information in different ways (see Stark's (2005) example in chapter 3.1.2). Nevertheless, the data is as important as the product to the company and the information handling should be at the same level as documentation management.

Product data is not just used to connect the terms product and data. The product and the data have to have contents, and data has to be related to the product and vice versa. As for the separate terms, product data also have an official definition in the standard SFS-EN ISO 10303-210:en (2003). Product data is specific to the product but can also be seen in a different way: it depends if the product is self-made or purchased. A self-made part needs more specific information to make it possible to manufacture but in purchased parts (e.g., bolts and nuts), just two dimensions (diameter and length) and the standard may be enough. As Lanz et al. (2008) mentioned, the product data needs the actual product model where the information of the product can be situated. This model also makes it possible to create a manufacturing drawing and from this point make the product (in the most cases) possible to manufacture. However, in some cases the self-made part may come to resemble a standard part. This happens when the part has evolved sufficiently in the company.

As in other definitions, feature definition also depends on the source and the point of view. No universal standard exists and that is the reason why the definition varies from source to source. Feature classification has the same issues: the classification depends on sources. Researchers have made classifications: simple ones (see Figure 23, page 60) or complicated ones (see Figure 22, page 59).

The actual part has three different features: management features, material features and shape features (Rao et al., 2007). Shape features include the actual design features which can be imagined as non-geometric or geometric features (Ramana & Rao, 2004). From the vernacular point of view, features are often called shapes. The main purpose of the feature is to determine what the part actually is: it will also determine what tools or machines are going to be used when the part is manufactured (Salomos et al., 1993). The feature can be a shape on the sheet metal blank where the material is removed from the blank or it can be shape where the sheet metal blank is deformed.

The features are concretely seen in the 3D model (and also in 2D drawing). The feature has information inside and the CAD software add this information to every model. The information included can be the material information, material thickness and dimensions for example.

When it comes to the definition of Product Data Management the system can be seen as an individual system, part of a larger system and/or the core function of another system. The last two normally concern a Product Lifecycle Management system and this is normally the main reason why the terms PDM and PLM are often confused with each other.

The main function of PDM is to manage and handle data and to make it available to those who have been granted access to the system. The system is mainly integrated with design software and the transfer to the system is done manually by data creators (designers). The main focus group is design engineers but as Otto (2011) and Stark (2005) mentioned, the system should be included in the company's strategy and not only be the storage vault for the product data. The PDM is a 'melting pot' for different formats of files: it can automatically transfer the formats to a general readable form, such as PDF files. The system itself can be called a dummy system; it does not check the documents, and the classifications in the system are based on company's own grouping. The users define the classes in documents when transferring the documents into the system.

As the concept, the PDM system is over 30 years old, originally created to help the design engineers' workload. The main benefit target was to have one safe place for storing the designs where they were easy to find. In the same time period, CAD programs became common: digital design replaced paper design. Still, it took almost 10 years before the system made the breakthrough: different CAD files required a program capable of reading the various CAD formats and producing drawings from them that could be read by anyone who needed to do so. Therefore, a general format was needed and PDM made that possible.

Currently, PDM is still used as a storage system for documents but the system also manages drawings by making sure that the latest version is available. Programs other than design programs are added to PDM to make the system more efficient. Furthermore, PDM makes it possible to give different roles to users to ensure that the data is safe and only certain users can modify the information. However, the main benefits the company could have depend on the customization of the system; the system should correspond to company's needs.

Features can currently be recognized by CAD programs (Dereli & Filiz, 2002; Gupta et al., 1994) but actual research on how PDM could recognize features has not been done. PDM can recognize the part, but only after the user transfers the product into the system and has classified it. Furthermore, the classification inside PDM is created by the system user's company. One problem is the classification of the features; CAD software have different kinds of features, but those are based on the vendor's definitions. Mainly, the features do not correspond to the manufacturing unit of the company.

The reason why the design guidelines were considered in this literature review was because they affect features from that point all the way to manufacturability. The goal in designing should always be to design manufacturing-friendly products and the main responsibility is on the design engineer's shoulders. Also, some of the responsibility lies on the manufacturing unit: the co-operation between design and manufacturing is crucial. The information in the CAD programs, and also in the PDM system, does not correspond to the real situation without co-operation (e.g., information on what kinds of tools are used, what are the used material and machines). The design guidelines come from the production. General rules-of-thumb are also available, but they may not guarantee manufacturability. The formability of sheet metals depends on material properties, strain bounding criteria and process parameters (Banabic, 2010).

The literature review gave answers to the question of how to define the following key words: product, data, product data and PDM. Also, information about the system's creation, its main goals and its background was found. In addition, the definitions for sheet metal features and design guideline were found as well. Although answers to part of the research questions were found, some questions still remain open.

Based on the results of the literature review, the following research questions are still open:

- Can PDM be the helping tool to determine sheet metal parameters?
- Are, in sheet metal design, all the design features in the software's library suitable to every design?
- How and to what extent would the 'potentially found' PDM sheet metal function affect the product's manufacturability, the number of defective parts in the manufacturing process and the time needed for the actual design process?

The sources selected for the literature review all considered the main topic of the thesis, but still no straight answers were found for the determined research questions. The sources mainly specified sheet metal features, examined PDM properties and defined the terms inside the system, as well as determined the sheet metal design guideline with the help of DFM(A). The connection between the PDM system and the helping add-on to sheet metal designing was not found. For this reason, the interview was generated.

During the literature review, the author also noticed that the terminology in different sources varied: for example the above-mentioned ‘tiny element’ (section 3.1.6) in its original context meant the smallest possible element which has an explicit meaning. This was the reason why the author defined every term in the end of each section.

In the next chapter, will be discussed the interview process in more detail. However, it is important to note here that the question pattern for the interview was based on the open research questions driving the literature review. The main idea was to create questions that were not too leading but still specific enough to gain the missing information.

4 INTERVIEW USING THE DELPHI METHOD

In this thesis, the policy Delphi method was chosen as the interview method because the author wanted to have different opinions on PDM from different fields and from the sheet metal designing industry. The research problems concerned the use of PDM and how the system can help sheet metal designers. An additional question queried what PDM actually does and how different people see the system. By utilizing the Delphi method, the author is able to collect an exhaustive set of observations from ten experts, whose expertise covers the most important areas of PDM system development, utilization and improvements in the industrial environment.

As mentioned earlier in section 2.2 (page 34) “the number of the panelists is not specified; the Delphi method is only based on the gathered research information”. The main purpose was to find experts who had years of experience of sheet metal design, the manufacturing of sheet metal products and PDM systems. This was the reason why interviewees were selected from the following fields:

1. PDM system vendor
2. Design software vendor
3. Sheet metal designers who use PDM
4. Company design and manufacturing sheet metal products (henceforth called Company X + where necessary the person’s title)
5. PC support who has experience installing design programs
6. Academic expert who is familiar with PDM systems

The selected fields and number of participants are shown in Table 3.

Table 3. The participants in the policy Delphi method.

Occupation	Number of participants
PDM system vendor	3
Design software vendor	1
Sheet metal designers who use PDM	2
Company design and manufacturing sheet metal products	2
PC support who has experience installing design programs	1
Academic expert who is familiar with PDM systems	1
Total	10

The panelists in the PDM system vendor group were a business development manager, product manager and PLM specialist. The product manager and product design manager were included in the panel from the Company X, which designed and manufactured sheet metal products. The academic person has extensive experience of engineering knowledge management, systems engineering and agent-based/holonic manufacturing systems.

When the panelists were chosen, the questionnaire was planned. The basic idea was to create the same questions for the different groups. Of course, the questions in some expert fields are different because of the charting of the background information. The lists of questions are shown in Appendix II. The question pattern was followed but in some cases, more specific information was asked if the interviewee’s answer was unclear or if an interesting point of view was brought forward.

During the interview, some of the groups were shown one picture of a sheet metal part and one triangle about how the PDM can be seen. The triangle (see Figure 33) was shown to PDM system vendors, a design software vendor, sheet metal designers who use PDM, a PC support, Company X, and to an academic person who is familiar with PDM systems. The idea was to put a cross in the triangle, but not in the middle, which describe the best way of using PDM at that specific moment. The points of view in the triangle are:

- *Information exchange.* The PDM system is seen as a designer’s extended hand towards the manufacturing unit. The system helps to share the manufacturing documents (and other needed documents) via the system to manufacturing unit.
- *Technical point.* The PDM system is seen as a melting point of different CAD files. It makes it possible for users to see the different CAD drawings without having the actual native design software. Drawings and models are shown in so-called generic form, such as PDF files.
- *Business point.* With the help of the PDM system, the different benefits can be measured with different units (statistical information, i.e. time spent on design work) and values (i.e. the investment was € x and the profit was € x+y). Customers and subcontractors can give feedback and the feedback can be measured with numbers.

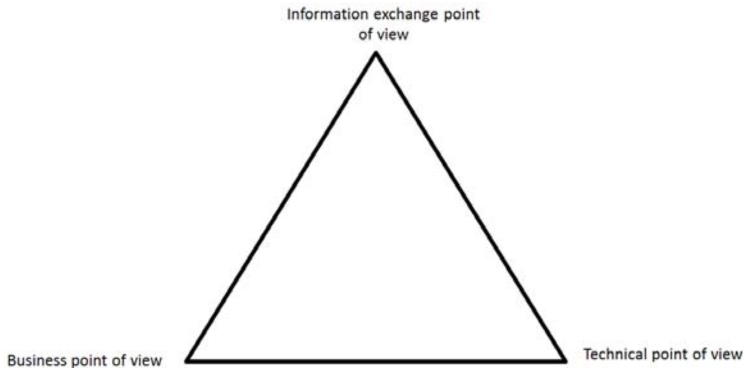


Figure 33. The triangle of PDM from different points of views.

The other picture (Figure 34) was shown to sheet metal designers who use PDM and to the interviewee from the Company X. The point of this was to gather information about the aspects of sheet metal and the knowledge needed in the manufacture of the product: which one is going to be manufactured first, the hole or the bend. It was also asked what kind of information is needed when designing a bended sheet metal part.

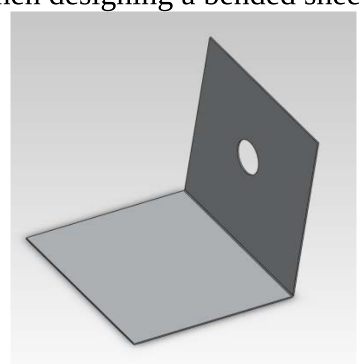


Figure 34. The simple sheet metal example part with a 90º bend and a round hole.

After the questionnaire, the interviews were done. Most of the interviews were done face-to-face, but two of the interviews were done via Adobe Acrobat Connect Pro- Global Connection. All of the interviews were recorded and afterwards lettered and analyzed. After the analysis, the report was sent back to the interviewees and feedback was requested. In Table 4 an example from the analysis report is shown. All of the information was treated anonymously and in confidence.

Table 4. An example from the analyzed questionnaire.

QUESTIONS	ANSWER	RESEAR-CHER'S VIEW	RESEAR-CHER'S READING	INTERVIE-WEE'S NOTES
If we make the sheet metal part (shown in Figure 34) and let's think that the material is aluminum. We choose the material straight from the design software's library. Do you have any idea who has put the material information in that library?	I guess the design software's vendor.	Ready parameters come with the program when the program is bought.	When using the software's own material library (coming with the program), the designer cannot be sure that all the parameters are exactly correct. However designers count on these parameters and they think that they are suitable in every design they make.	This is really important! If manufacturing has problems manufacturing the part, the first thing that comes to mind is not that the problem may be in the design program.

The Delphi method enables a second questionnaire round if the results are not as anticipated. It is also possible to add more interviewees and send the first questionnaire to the new participants to obtain more information. In this thesis, the author realized that after the first questionnaire, enough information was gathered and there was no need for more participants or a new questionnaire (second round).

4.1 Results from the Interview

Below, the results from the interview have been categorized into 10 different groups to make the analysis more effective. The Delphi method utilized in this section is based on the theory described earlier in connection with the interview method (section 2.2. page 34). The following steps were taken to of apply the method and find the connection between the source material and conclusion (an example can be seen from Table 5):

1. The questions and answers were written into an Excel table.
2. The author stated her point after each interviewee's answer in the Excel table.
3. The author interpreted the answer and wrote what could result from the interviewee's answer.
4. The Excel table was sent to each interviewee and comments were requested.
5. If an interviewee commented on the table, the comments were analyzed and corrections made as needed.

The classifications of questions and the number of answers are shown in Table 5. The questions are shown in Appendix II. Table 5 takes into account the number of interviewees: the number of answers may be higher than the number of questions.

Table 5. Interview implementation: the number of answers and questions.

	PDM system vendors (three interviewee)	Design software vendor (one interviewee)	Sheet metal designers (two interviewees)	Company X (two interviewees)	PC support (one interviewee)	Academic person (one interviewee)	Total answers / number of questions
Users	**3/1**	**3/3**	**8/8**	**10/5**	**4/4**	**-**	**28/21**
Requirements	**10/4**	**4/4**	**4/2**	**4/2**	**-**	**2/2**	**24/14**
Facilities	**4/3**	**-**	**4/2**	**7/4**	**1/1**	**1/1**	**17/11**
Capacity	**8/3**	**-**	**4/2**	**8/4**	**1/1**	**-**	**21/10**
Reliability	**12/6**	**7/7**	**12/6**	**7/5**	**4/4**	**1/1**	**45/29**
Cost efficiency	**5/2**	**1/1**	**2/1**	**2/1**	**-**	**3/3**	**13/8**

4.1.1 Implementation and Defining the Requirements

When starting to plan the implementation of the PDM system, the company has to, by themselves, iron out what the needs and requirements are from and for the system. The PDM vendor does not help with this issue; of course they are trying to help companies to make the right choices, but the vendors do not know the basic requirements and the needs of the company. Without a good background information search, the company may buy a system that is not suitable for them. The one problem is that it is likely that the company has carried out its processes and procedures in the same way for several years, so they may not know what kind of solutions are available for their problems and whether their problems can be solved. According to design software vendor the companies normally wake up for the need of PDM when they have already huge amount of non-classified drawings saved in their server.

Not only do the requirements of the needed software have to be plotted, but also the necessary IT equipment (mainly hardware) has to be checked. It has to be known what kind of computer requirements are needed when starting the installation of new design software and/or a PDM system. Normally, for the PDM system, one server is enough to operate it and to store the information. The system does not need to be installed on individual users' computers; the system can be used through a network.

The academic person on the panel stated that the requirements should start from the point where the problem has been plotted. The way should be from the bottom-up, not from the top-down. Firstly, operations issues need to be solved and then it needs to be determined what kinds of operations need support from the PDM system. Therefore, when planning to invest in the system, the investment should be seen as purchase where the repayment period will improve the current situation and in this case, the requirements come from the user or from the process. In the decision process, the opinion of the design engineers plays a key role: they should know what they want from the system and what kind of system properties are essential. If there are many different requirements, the periodization has to be done according to what is the most important thing that the design process needs in order to continue. The point of view of the managers and IT unit are secondary; the design engineers are making the designs and the money for the company.

The investments coming from the implementation of the systems are mostly based on the research work before the actual PDM system is installed. Time and money are spent on determining the needs and problems to be solved. After this, the tailoring will drain money, and of course time. Also, one important and most expensive cost is training the users to use the system properly. The smaller part of the investments is actually the yearly license costs, which depend on the amount of users and the type of user rights. If the company wants to tailor the system later on, it is possible to ask for help from the vendor but in some cases the PDM system is based on Java. If the company has a person who is familiar with Java, the tailoring can be done inside the company. This way, the money can be saved or rather invested internally. This person could also work as a PDM support person and as the main user of the system.

The total costs of the PDM system depend on its size. Different kinds of modules for the PDM system are available to solve different kind of problems, but every module will increase its final cost. On the other hand, if the company needs a certain module only a couple of times per year, it may not be wise to invest in that kind of module.

One sheet metal designer had experience in how a PDM system is implemented. The selection committee consisted of the company's management, IT persons and two design engineers. The first choice criterion was how the system could be integrated into the already existing programs and how the system can be handled and coordinated. The design engineers' opinions were not taken into account, even though the questions of what the design engineers needed and wanted were asked. Eventually, the design engineers were present in the meetings 1-2% of the total time and at the end of the process, no announcement of the selected system was even made. When the Company X, according to the product and product design managers, made its decision, it was based on the design software which was in use (the easiness of the integration to PDM), on money and that operations support was close and easy to reach. The actual properties of each system being considered were not compared.

According to PDM system vendors, the main responsibility of the PDM system after implementation is with the users and the system should have at least one main user controlling the whole system. The users can have different user rights depending on their status in the company: whether they are designers, manufacturers or purchasers for example. The rights have to be determined to make sure that the information in the system is kept safe and that people who have no right to modify documents cannot modify them. In addition, the users have to know what the valid information is to enter and how to classify that information in the system. Every user has to have their own user name and according to this user name and the help of the PDM system for example, change reports can be sent straight to the right people. The PDM system vendors and design software vendor both think in the same way: the controls of the system have to be checked before the actual use of the systems. As the design software vendor mentioned the PDM system should be the guide 'how to work in company' and the information management inside the company should be systemic.

4.1.2 Installation and Updates

Currently, PDM installation is fast, because many installations can be done through the network. However, if something goes wrong during the network installation, it may take time to solve the problem. In many cases, the problem can be found from the computer: there is not enough space or the operating system is not suitable for a certain program. Big companies have their own IT unit that handles all of the installations and purchases the needed programs/software.

Normally, updates are available once a year and if the vendor finds some major problems, smaller updates are released as needed. The PC support did not know if the material library is updated at the same time as other aspects of the software. However, when updating software, it must be made sure that backups are available if something goes wrong. Generally, the reliability of data does not suffer during the updating. After updating, the PC support can only check that the program is starting and the license is available. There is no possibility to check the actual program; ordinarily, PC support does not have any experience with the design programs, and they are just helping with installation and updating processes. The same kind of updating method is in use in the PDM system; once a year, a bigger package is ready for installation and smaller packages are available whenever the system's vendor noticed a need. A large annual update package seems to be common among vendors.

4.1.3 The Typical Use of the PDM System

The main use of the PDM system, according to system vendors, is still focused on the document storage system. The system can actually do more. With the help of the system, design and manufacturing structures can also be created. Furthermore, it is possible to transfer the drawing in electronic form to a subcontractor, who just has to have a user account to the system. The PDM vendors also mentioned that the only reason why different properties are not in use is that the companies do not know about them. The design software vendor shared the same point of view during the interview. Nevertheless, this is not always done. The design engineers claimed that in some cases, the drawings were transferred to subcontractors by e-mail or by mail (printed copies) just to make sure that the information stayed safe. Also, in some cases, the manufacturers inside the company did not know how to use the PDM system so printed drawings were needed.

Company X uses the PDM system to transfer the drawings to the manufacturing unit and to manufacturing machines. The PDM system is integrated with the server where the turret punch press's files are located. The transfer happens automatically when the drawing is accepted in the PDM system. According to Company X's product manager, manufacturing engineers can find the files from the server and make the production plan. Because of the electronic versions of the drawings, the designers do not have to mark every single dimension on to the drawing. Material selection comes from the PDM: every time, designers link their designs to a certain material and material thickness. PDM is a transfer and storage system tool for Company X, although the product and product design managers think that the system can do more. They would like to link more of their programs to the system so the currently twice done work would disappear.

According to the academic person the PDM system is mostly seen as a storage place for documents because of the substance. The substance is thin as is the data content in the system and the engineers are needed to understand the model. The machines do not understand the models as humans; more features should be added to model to make it possible to be machine readable. However, in this case the PDM system should be called a data system not a data management system. It is possible to develop the system to be more intelligent, but this needs time and more research.

Sheet metal design engineers thought that something else should also be able to be done with the PDM system. They recognize that in many cases, the company is stuck in old habits and the company's managers do not know what to do.

4.1.4 Integration with Company's Other Programs/Software

The PDM system can be integrated with different types of systems that companies already have, such as e-mail(s), design software, and documentation software. To make sure that all the information is saved in one place, the PDM system, as many programs as possible should be integrated to that system. It can also convert different format to general formats so everybody can at least look at or read the documents. According to the academic person, this general format will destroy all the feature information from the model. In order to have this information, the user has to have the same program in which the model was created. Of course, the general format is readable, but the features cannot be exploited.

4.1.5 Sheet Metal Designing

Design software is developed with incorporated intelligence. When designing sheet metal parts and adding geometric shapes to them, the software may warn the designer for impossible shapes. These impossible shapes are shapes that are not possible to manufacture. The warning is based on the way the shape has been modeled. However, it is possible to redesign the same shape with a different tool to avoid the warning message. This is only possible if the designer knows the design program and has experience in its use. This may lead to a situation where the designed part is not possible to manufacture. The design program vendor also mentioned that in the end, the responsibilities of the designs lie on the design engineer. Design engineers responded that sometimes, the program errors are systems errors and this error is treated as invisible. Designers will take calculated risks, but they still trust their professional skills. This type of error type recognition requires experience. It may be that some cases, the system error is actually a designing error and repairing the design is needed. Every error is analyzed before it is approved, and in this way designers try to eliminate the possibility of a designing error.

The design engineers had the basic knowledge about design guidelines when the simple sheet metal design with the bend and a hole (Figure 34, page 79) was shown. However, they also mentioned that the relevance of information depends on the designer's experience: one designer's relevant information is not relevant to another. The lack of experience may lead to a situation where the relevant information may be missed. Company X's product design manager also trusted the experience of the designers: the designers should know the basic design guidelines, for example where the hole should be according to the bend. At least the problem (if for example the hole is too close to the bend) will be seen in the turret punch press: if the nesting cannot be done, designers have to make corrections to the drawings.

According to design engineers, some drawings are not checked at all; the designers rely on the feedback coming from the manufacturing unit, and in some cases, it does not even come. Normally, the designs can be manufactured, and the feedback mainly concerns the manufacturability: for example, some things are hard to reach. The main reason why the corrections to the drawings are not done is bureaucracy: first one must fill a form about what is wrong and why it has to be corrected, and then the design manager checks the report and asks help from others if needed. In the end, the managers give permission to the design engineers to make the corrections. If the designs need to be checked, the checking normally happens by the same designer who has designed it in the first place.

Design engineers could not define what the relevant information in the PDM system and in the sheet metal designs could be. One engineer thought that manufacturing method(s) should be mentioned in the drawing and the other one felt that the manufacturing method is irrelevant information. The information about the material and dimensions was, in both opinions, relevant information. They also agreed that the requirements for the parts come from the product's use, so designers have to know where the final product is going to be used. The tolerances are chosen by the designers - no general rules appear: also in this case, the designers trust their professional skills. However, sometimes the tolerances are too tight, which leads to problems in manufacturing. In most cases, no feedback comes from manufacturing; they just try to produce the part as well as they can and determine which changes can be made. On the other hand, the manufacturing unit should follow the drawings and they should not make any corrections by themselves. This, on the other hand, has led to the situation where designers try to put as much information as possible into the drawings just to make sure that no "bad" feedback is given. Moreover, additional information has to be added because some of the parts are manufactured outside of Finland and for example in China there are no ‘good machining shop rules’ that Finland has. In some cases, even basic design rules are broken, such as double measurements in the drawings, to make it simpler for manufacturers to check the dimensions.

Company X’s product and product design managers think that the design engineers should know what information the manufacturing unit needs. If the part is going to be manufactured somewhere else than in its own factory, the purchasing units confirm from the designers that the drawings are correct. However, generally speaking, Company X just orders sheet metal dimensional blanks from subcontractors; bending and punching is done in its own manufacturing unit. The reason is that, in this way, Company X (according to the product manager) makes sure that the products are what were wanted.

4.1.6 Software’s Library Properties

According to the PC support, the design program’s library’s material properties and design features come from the program’s vendor. In contrast, the PDM system vendors’ opinion was that the responsibility of properties of the material libraries is in company’s main user’s hands. The number of materials and features are considerable and even the PC support thought that it was too large for the company’s needs. There are several materials inside the systems that are not in use inside the company, but the designers can still choose them. Library updates rely on the user and their knowledge of what, if any, changes have been made. When the user knows what needs to be updated, permission for making these changes has to be request from the IT unit or from the PDM system’s main user. If the user wants to have information that has been updated, the designer has to be aware of the shake-ups. On the other hand, this requires time to solve what new (for example materials) have been invented.

According to the design program vendor, the material library’s numerical values are only guidelines. It is the designer’s responsibility to ensure that the numerical values are correct. One way of doing this is by asking the material supplier for the material’s properties. The designer has the possibility to change the values and the most common place to take the information is from the Internet. A page such as matweb.com offers material packages which can be installed straight to the design programs. However, where these material properties come from is not known by the design software vendor. The designers, on the other hand, think that the numerical data in the libraries are based on general material properties information. Designers also assume that the program vendor will update the library’s information if some material properties have changed. What is more, is that if it is possible to update the material in the library inside the company, the person who has right to make these changes may not be known. The designers thought that if the right person (who can do the updates) is not easy to find, the updating may not happen. Also, they thought that the updating person will get the information from the Internet. Thus the reliability of the numeric data may not be correct and this may lead to errors in manufacturing.

According to Company X's product design manager, their material library has been updated to correspond to their manufacturing; no extra material is in the library, but in cases when new material is needed it can be added to library. Furthermore, tables are available for the bending angels and k-factors, and introductions for general design principles. Mainly, the sheet metal parts are simply formed (with bends and holes) and no special tools are needed. Company X's product manager mentioned that the company also follows production and inspects the products: if a dimensional error occurs, the changes will be updated on the drawings and into all the necessary tables. In this way, Company X makes sure that production errors are maintained at a minimal level. Company X designs and manufactures the sheet metal products themselves, so the designers are mainly focused on sheet metal design, and they have experience in this field. In addition, Company X is mid-sized company and the material gamut is relatively narrow: all the material parameters in the company are based on practical tests. A problem that normally occurs in manufacturing is compatibility errors: the holes in the assemblies do not match.

For the most part, the interviewed designers use the parameters available from the design program's library. In this company, the library has not been updated to correspond with the tools, machines or materials which are in use in production. One reason for this is that the company uses many subcontractors and they change once in a while. By using the library's parameters, the designers trust that the parameters are correct and suitable for their products. In some cases, when not using the 3D software, the designers have to calculate the necessary parameters and in these cases the experience plays an important role.

4.1.7 Different Points of View on PDM – the Triangle

In Figure 35, a triangle expressing the different points of view on how the PDM system can be seen is shown. The numbers in parentheses below are the reference numbers given to each interviewee in the figure. The PDM vendors (1) seem to weight the economic point of view. The answer depends on the extension of the system: when examining the PDM system widely, and adding the PLM point of view to this examination, the system is seen as shown in Figure 35 (from three different points of views). In this point of view, the system will give the full business benefit to the company. The design software vendor (2) sees the system from a business point of view. He thinks that in every case when an investment has been made, the basic idea is to get some kind of benefit which can be measured with money: ‘when we invest here X amount of money we will get back Y amount of money, which is more than X’. When asked how the PC support (5) sees the PDM system, the answer was based on a technical point of view. The PC support’s opinion was that today’s design engineers are intimidated by technical systems in their work. PC support does not see the systems business point of view and information exchange point of view mainly concerns IT persons.

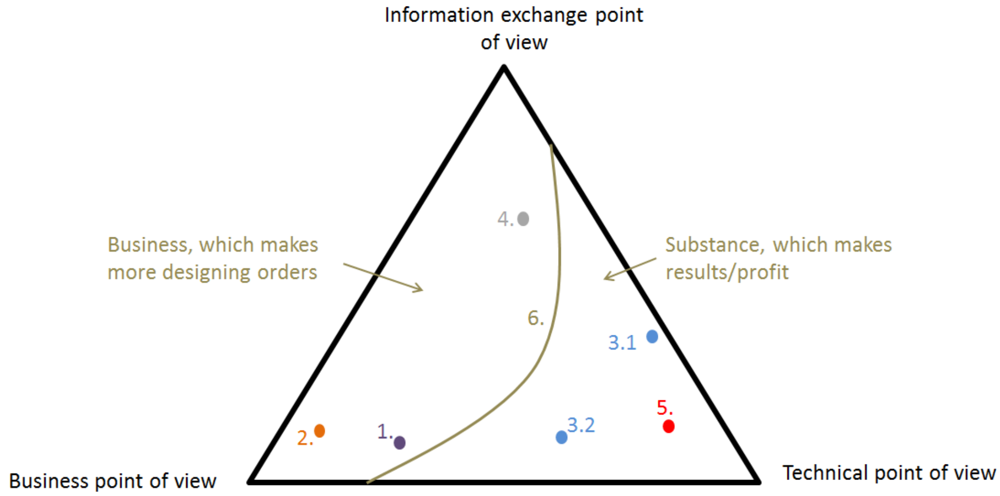


Figure 35. How interviewees see the PDM system: (1) PDM system vendor, (2) Design software vendor, (3.1 and 3.2) Sheet metal designers who use PDM, (4) Company X’s product and product design managers, (5) PC support who has experience installing the design programs and (6) Academic person who is familiar with PDM systems.

The designers (3.1 and 3.2) see the PDM system from a mostly technical point of view. It is a storage place for documents and it helps co-operation with the manufacturing unit. However, the system can also be seen from the information exchange point of view, and it was difficult for them to decide which one the system represents more. The only thing that was sure was that the designers did not hold a business point of view.

Company X’s product design manager (4) sees the PDM system from an information exchange point of view. Company X’s product manager shared this opinion. The reason is that the Company X is mainly using the system as a storage system for documents and drawings. According to the product design manager from Company X the system could be more technical if more programs from the company were integrated into it.

The academic person (6) sees the system differently than the other interviewees. The system cannot be a single spot anywhere in the triangle; it is a line which is more concentrated in the technical point of view corner. The exactly location depends on the business, which makes more orders to the design unit, and from the used substance, which makes results and profit for the company. The system does not solve the problem if the substance is missing. The company's main target is to provide the needed tools (i.e., programs) for the designers to get results. One possibility for measuring the meaning of the corners in the triangle could be by comparing internal and external cash flow: who is making money and with what kind of tools is this money made. The second possibility is to collect people's opinions and examine the result from the process point of view.

4.1.8 Feedback

Designers expect feedback from manufacturing: designers know that there is a manufacturing defect because of the use of the ready parameters from design software's library. In some cases, designers may not check the drawings for possible errors; they prefer to correct all possible mistakes according to the feedback from the manufacturing unit. However, in most cases, feedback does not come from manufacturing: the manufacturing personnel may make the corrections on site and do not report the error(s) to designers. When old designs are used as a base for the new design, the mistakes remain and again the manufacturing personnel will need to make changes. According to the designers, the company has one kind of Engineering Change Request (ECR) system, but it is not widely in use as it should. The employees in the manufacturing unit think that the system is difficult to use and the bureaucracy behind the changes is too heavy (changes do not take place fast enough).

Company X's product manager mentioned that the company collected feedback from the customer for its own feedback program. First, the people who are responsible for the feedback program analyze the feedback and send it forward to people who it concerns. The PDM system is not used to handle the feedback. Designers also get feedback from the manufacturing unit, but this mainly happens via e-mail, phone or face-to-face, so there is no written record of it for future designs.

4.1.9 Benefits of the PDM System

According to the academic person, in order to measure the benefit and productivity of the PDM system, one process should be selected as a target. The best would be to examine the situation before and after the PDM system is installed. In this way, the company can get a real answer whether the system helped the designers or not. If the measurement is based on people’s opinions, the result may be distorted because of psychological aspects. For example people may think that one minute of waiting can be worse than 15 minutes’ walk, just because of the psychological aspect. Same thing can be found from the system: it may feel easier to find the drawing from the paper archive than find the search word which describes the drawing in the system.

According to the design engineers, the PDM system cannot measure the efficiency of design engineers. Moreover, they feel that if the managers start to focus on the time spent on one drawing, they may attempt to make the designers do their work faster and as a result, with more errors. Company X’s product design manager did not have experience for not to have the PDM system, but he thought that the system is helping the designers work more efficiently.

The designers thought that the system properties are good when the system is familiar and one can determine how different things can be done. Some functions can be executed in different ways, which makes it possible to sidestep some warnings (for example leave some attributes out/empty). It takes years to learn to use the system properly and every time when a new employee comes and starts to learn the system, they may learn to use it in a different way than they should. Also, the format of the information, that has to be added to an item’s identification fields, may be unclear to new workers. This will automatically lead to the situation where miss-filled information is saved in the system, and this information is hard to find, if findable at all, later on in the process. These kinds of items will grow the number of the items inside the PDM system and in the end nobody knows what is actually inside the PDM system.

4.1.10 Disadvantages of PDM

The main problem seems to be carrying out searches of the system. PDM system vendors promise that the information can be found if the ground work has been done properly: the classification and classification-related parameters are set to respond to the needs of the different types of products. Attributes and descriptions can be used when doing the search from the database, but the correctness of the descriptions and attributes rely on users that have imported the information into the system. If, for example, the attributes are wrong, the search tool cannot find the part. The interviewed design engineers also mentioned that searching is the hardest part of using the system.

The product and product design managers from Company X explained that they have divided their products into different product categories (classification) which include the product templates. With the help of the classification, the product templates are easy to find from the PDM system. They also use so called ‘parent models’ as a base for new designs. If some problems or errors are noticed, the parent models are updated. In this way, Company X makes sure production errors are minimized.

According to the design engineers, one other main problem with PDM is the integration between different programs. The CAD programs can be integrated with the system but in some cases, the conversion may create an empty PDF file. Designers also wanted to have ‘easy to find’ design guidelines for their sheet metal designs. If sheet metal design is not a part of everyday work, the specific knowledge of how to do the sheet metal designs may be forgotten.

In some cases, the designers feel that the PDM system is slow, but the main reason is not actually the system, but the speed of the Internet. The 3D models are large in size and it may even take 20 minutes to open one document, and the same amount of time to saving and close the document. Another reason for the systems slowness seems to lie with the IT unit; they ensure that in every saving process no viruses are found from the models and this further slows down the document’s saving processes. The designers have spoken with their IT people about this issue but the problem has not been solved. The academic person agrees: the processing speed mainly depends on Internet speed. A final reason for a lack of speed may be inadequate equipment. The computers being used for design may be outdated and slow, or may just not have enough computing power to quickly handle the documents.

Company X’s product design manager had discovered that their PDM system includes some duplicates and some old information. The system should automatically remove the old information, but some cases this has not happened. The system should be cleared of old information and duplicated items. Nevertheless, Company X’s product design manager generally knows what the system includes, even when they have approximately 100 000 items in the system.

5 OBSERVATIONS

Table 6 shows all of the articles published by the author. The Table 6 comprises the abstracts and conclusions of each article, and the conclusion indicates how these articles contribute to the thesis. The contribution of articles is evaluated based on the following criteria: traditional PDM benefits related to sheet metal design, system integration, and data mining related to PDM data.

By using an imaginary part (used in article Huhtala et al., 2013), it is easier to understand that even a simple looking part includes several different pieces of information. Even a single bend will need information about material, material thickness, bending angle and the highness of the flange. When adding more design features to the part, the amount of information will increase. If designers cannot find the necessary information easily and quickly, they may have to rely on information that the design software supplies. If the design software information is not updated to correspond to the company's material database, the final result may be a manufacturing unfriendly product.

One common point in the author's articles is the problematic nature of terminology. It can be said that the PDM system is an old system, although it has been developed further from its release point. It seems that the markets like to release more and more software for companies' use and they invent new terms to replace old ones. If the terminology is not clear, the company may not know what kind of system is actually suitable for their problems.

To gain full advantage from PDM, the system has to work properly. This basically means that the system's internal classification has to correspond to the designed products/parts. Additionally, the used materials have to be updated and any extra (i.e., not in use) material has to be removed from systems/programs library. To do this, the company has to invest time and money into the project. The period from selecting the PDM system to optimizing its use may take even two years or more. During the selection period, the definitions and terms for the system have to be done properly (as can be seen from chapter 3.1, the definitions may be hard to do). When the company has decided and defined the necessary terms, the implementation of the system can begin with training the people who are going to use the system. Also, employees and anyone else affected by the system must be made aware that the main benefits of the PDM system will be seen after some years of use. By slowly proceeding in stages with co-operation between designers and manufacturing, the implementation has a better chance of being successfully taken into use.

Table 6. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[1] Huhtala, Räsänen, Lohtander, Eskelinen & Varis (2011): DFMA-Aspects of sheet metal product in case of low-cost strategy.	May 2011	This document is an illustration of one real sheet metal product, whose manufacturing is challenging and many problems occur in production. In this paper some point of views which should be take into consideration before the part can be produced without (or some minimal) problems are given.	The research target, the sheet metal grid, is located inside a vacuum belt filter. The grid's surface area is several square meters and consists of thousands of holes and hundreds of supporting feet. Surface straightness and feet bending angle demands are high to fulfill the operational requirements of the vacuum filter and moving filter cloth on the grid. Manufacturing know-how is in forms of doing and experience so when re-organizing production of certain product, the requirements, tolerances, and manufacturing processes to be used to produce a certain product should be clear. The designer always takes a stand on manufacturing with his drawing notes: everything should always be marked on a drawing and instructed with proper and unequivocal work instructions.

Table 6 continues. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[2] Huhtala, Lohtander & Varis (2012): Confusing of terms PDM and PLM: examining issues from the PDM point of view.	June 2012	In the early 1980's, Product Data Management (PDM) systems were created. The system is widely known, especially in manufacturing companies, and after its creation, the system has developed and grown rapidly. Its main principle is still the same but the terminology is becoming increasingly misleading. Product Lifecycle Management (PLM) is frequently confused with PDM, as the latest articles reveal. Although the main idea of PDM is the same, different articles define the term differently; sometimes it includes the lifecycle and in some cases not. This conference paper reviews the use of this definition throughout the last decade, also including software producers' opinions. After searching the articles, it was noticed that the impact factor (IF) on its own does not guarantee the value of the article. The source criticism seems to be too gentle today, and scientific liability seems to have disappeared. The correct and exact information is more often hard to find.	When searching the articles, the impact factor did not guarantee the value of the article. When referring to commercial articles, who has the scientific liability when presenting major definitions? For example, CIMData is an independent worldwide company whose main target is to sell PLM solutions; the information that it publishes may not be valid. Of course, it has long experience in this scientific field, but a critical approach has to always be kept in mind when considering a commercial company. Today's problem seems to be that information is really easy to find. However, that information is not necessarily valid; source criticism has quite often been forgotten. Little research has been done on PDM and that may be the reason why the confusion of these terms is quite common. For future use, the research criteria have to be more specific so that the needed information can be found. This paper was based on theoretical literature and the author's own industry experience. It was hard to find a clear difference between PDM and PLM

Table 6 continues. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[3] Huhtala, Lohtander & Varis (2013a): Product Data Management and Sheet Metal features – sheet metal part recognition for an easier designing process producing manufacturing-friendly products.	December 2013	PDM systems were created in the mid 1980's. The main goal was to organize the drawings and data sheets created during the design process. The integration of PDM and CAD led to a situation where an increasing number of features were required from the systems to help the designers. Finally, this situation developed to a point where no one was actually sure what contribution the PDM system was making. Currently, sheet metals are universally used in different kind of industries. Designing is challenging in many ways, therefore, if the PDM system could recognize sheet metal parts, it could help the design process. With the help of the PDM and the DFMA, the products should be more manufacturing-friendly and the designing time possibly shorter. This paper points out the complexity of designing sheet metals, and raises the question of whether the PDM system could be a helpful tool for designing manufacturing-friendly products.	The classification of designing shapes depends on the source; no universal standards exist for features. Almost all design software offers a feature-based library, where the features can be retrieved and added to the model. After adding the feature(s), it is then only necessary to change the dimensions to correspond with the functional structure. At this point, the designers will have a strong expectation that the shape can be manufactured, but it may be that the necessary machines are not available in their own machine shop. Even a simple-looking sheet metal part requires considerable information to make sure that it is manufacturing-friendly. Research has been done in the field of feature recognition but mainly the research is based on mathematical modeling. To help the designer, the design guidelines should be simple and easy to follow and feedback should be gathered from manufacturing. One solution is the PDM system, as it would recognize the part according to the selected group and its name. This recognition occurs when the designer saves the model in the system. When choosing a group, the PDM should remind the designer about the specific guidelines.

Table 6 continues. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[4] Huhtala, Lohtander & Varis (2013b): Manufacturability of sheet metal design with the help of Product Data Management (PDM).	September 2013	It has been said that almost the half of designing activities concentrates on sheet metals but the lack of knowledge of the typical sheet metal aspects and basic rules of designing has led to the situation where products are poorly designed. Consequently, this leads to a situation where products are not manufacturing-friendly. Decreasing the time getting the product to market means that the designing time is decreasing year after year; the pressure to design the part in a shorter time is increasing. Unfortunately, all of the design information and intent is processed and filtered to fit the Product Data Management (PDM) system. This paper deals with two distinct yet interlinked themes. The first theme is the new requirements set for the new Product (Life-time) Information systems that can save the product information and design intent and the second theme is the modern, light-weight and updatable product-services that allow manufacturability to be ensured before product realization. With the help of novel product-service (Design Manufacturing and Assembly) for sheet metal industry designers will able to design manufacturing-friendly sheet metal products in a shorter time.	Much research has been done concerning feature-based modeling, ontology and knowledge management. Yet many problems need to be solved before feature- based recognition systems will be correctly in use. In the meanwhile, it should be worthwhile to see how PDM systems can actually help make the design process faster. This may also be a cheap test; many companies already have a tailored PDM system, so there is no need to buy new system to help the design process. Globalization is increasing and the designers' knowledge is put to the test when designing a sheet metal part without the information of the machine which is going to be used. General guidelines with recognition of the part in PDM would be the first step to help designers.

Table 6 continues. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[5] Huhtala, Lohtander & Varis (2013c): Sheet metal design with the aid of Product Data Management (PDM) systems.	July 2013	Product Data Management (PDM) systems were created in the early of 1980's. Their development has increased rapidly as well as that of different CAD systems. However, problems still occur in linking these two systems together and getting the full benefit from the PDM system. Modern PDM systems, together with CAD software, do not take into account the different design aspects when designing, for example, sheet metal products. CAD software automatically gives some parameters for sheet metals but these parameters may not be correct. In almost every PDM system there is a possibility for giving almost real-time feedback between the designers and manufacturers, but this feature is rarely used. Only few system users actually know what kind of help PDM offers and what kind of add-ons can be added to the system. The main problem seems to be that there is not just one way to design a sheet metal product and transform it to the PDM system, even if all the users were using the same system with the same given introduction.	In some designs, the bending order should be marked; it saves time when the manufacturer knows which bend should be done first and so on. However, in this case, it is also important to know which machine and tools are going to be in use: otherwise, it may be impossible to design the bending order. In Järvenpää et al. (2011), an information model to represent the capabilities of the existing manufacturing resources was presented. This information about the available resources should be available for the product designers in order to improve the manufacturability of the designed products. The sheet metal features are often related to the machine, but in a global world, designers rarely know the machines which are going to be in use. Globalization and time management are the real challenge for the future; more parts should be done in less time.

Table 6 continues. The Author's experience based on earlier studies.

Title	Published	Abstract	Contribution to this thesis
[6] Huhtala, Lohtander & Varis (2013d): The role of Product Data Management (PDM) in engineering design and the key differences between PDM and Product Lifecycle Management (PLM).	April 2013	This paper will take a closer look at PDM (Product Data Management), which is one of the most important systems in industry today. Every day, designers produce large amounts of information, including drawings and related datasheets. This information has to be saved in a specific place where it is easy to find and modify. To facilitate this, PLM (Product Lifecycle Management) has increased its benefit to companies. Spare part sales have become an important factor for companies. In the case of spare parts, it is important that the PDM is working as it should; without correct PDM, the PLM system does not work and tracking an old product may even be impossible. This also increases the difficulty of selling spare parts. Knowing how the PDM system should work and what kind of information is possible to add to the system are the key elements for success.	PDM should more efficiently support the actual design process. The support should come in the form of features, such as the PDM system recognizing a part when it is saved to the system for the first time, and when the designer selects the name and the group for it. With the help of this feature, it can be assured that all the correct designing aspects have been taken into account and all the necessary data sheet(s) are added to the part. This will lead to the parts being more easily manufactured, as well as to considerable time savings. In the future, other similar parts will be easier to manufacture and design when the designer knows that the old part is correctly designed and documented. However, this will also need more co-operation between the manufacturing and the design departments. If the manufacturer notices something erroneous they will have to inform the designer so that the drawings can be corrected.

The main subject in every article in the Table 6 (page 95) was the simplification of the sheet metal design process. In the beginning of the articles, the PDM system is introduced and its main benefits explained. The aspects mentioned in the articles include (the references correspond the articles in Table 6):

- Project control and planning [1, 2, 6],
- Creation of manufacturing structures [6],
- The storage of information (e.g., drawings, models, data sheets) which is easy to find from the system according to item number, description and/or classification [2-4, 6],
- Time savings due to efficient search [2, 3, 6],
- Integration of PDM with the company's CAD and other design programs [3, 4],
- Controlling the data in the system [2, 4-6],
- Possible integration of DFM(A) with the PDM system [1, 3, 4],
- Part recognition possibilities through the PDM classification system [4, 5], and
- Data sharing possibilities [5-6].

Project control and planning are playing a crucial role when designing a part or/and product. Fast actions are needed to make the required changes to parts [1], and this requires good control of product structure [2, 6]. When *creating the manufacturing structures*, according to [6] "…all the necessary datasheets should be available simultaneously." So *storing of the information* is necessary and important. Most commonly the PDM system is a storage place for information, as written in [2] "Company produces various types of data in different formats, and PDM is a tool which collects this data together and helps workers to open it in certain format." Product related information (e.g. drawings, datasheets and calculated data) is the information that the PDM handles during the design and manufacturing process [3, 6]. And for the later use the PDM makes it possible to manage the lifecycle of data by being the core function of Product Lifecycle Management system, as mentioned in [4].

The data control in the system means:

- [2]: "…without the right control of data, the lifecycle management is difficult or even impossible"
- [4]: "…it is crucial that the data is organized and utilize in such way that the designers can easily find it"
- [5]: "The information, which is in PDM system, can be edited and exchanged during the designing and manufacturing."

- [6]: "…the product related data easier to find at different stages of the company's production"

All of these viewpoints are also affecting the *data sharing possibilities* and *time savings due to efficient search*.

To make it possible to gather all the information to PDM system it is important that the PDM system is *integrated with other software* in the company (e. g. CAD). The integration affects:

- [3] "To make data management easier, the PDM systems are often linked to different kinds of CAD software."
- [4] "PDM may be possible to integrate to CAD systems in that way that it could help the designers to check the parts manufacturability."

Currently unknown and not researched add-ons which could possibly be integrated into PDM are DFM(A) and part recognition. When *considering the PDM and DFM(A) integration*, the DFM(A) methodology includes, according to [1] "…simple rules which can be used to minimize design complexity and even give better manufacturability for product." So if the integration is possible the benefits can be following:

- [3] "…if the DFMA and the sheet metal design features can be integrated into the PDM it should help the design process to be even faster and easier to use"
- [4] "…with the help of knowing the features and DFMA it may be faster and easier to design manufacture friendly part/product"

When talking about the *part recognition* in general level, according to [4] "Ideal situation would be that the PDM is actually recognizing the part" and "Part recognition would be the first step when improving the PDM system." And when continued with [5] "In this stage the PDM could recognize the part and automatically suggest (for example with the help of a window pop-up) what kind of data sheets should add to Item"

All the viewpoints mentioned above are related to the contribution of this thesis. Table 6 showed author's different articles with their abstracts and a short introduction on how it contributes to this thesis. In the Figure 36 is shown a framework triangle that summarizes all the articles. The placing of the dots is based on the content analysis according to the author's intuition. Each paper was analyzed based on the content (the triangulation): whether the content dealt with the handling of information and CAD files between the manufacturing unit and design, and/or whether systems benefits could be measured from the business point of view.

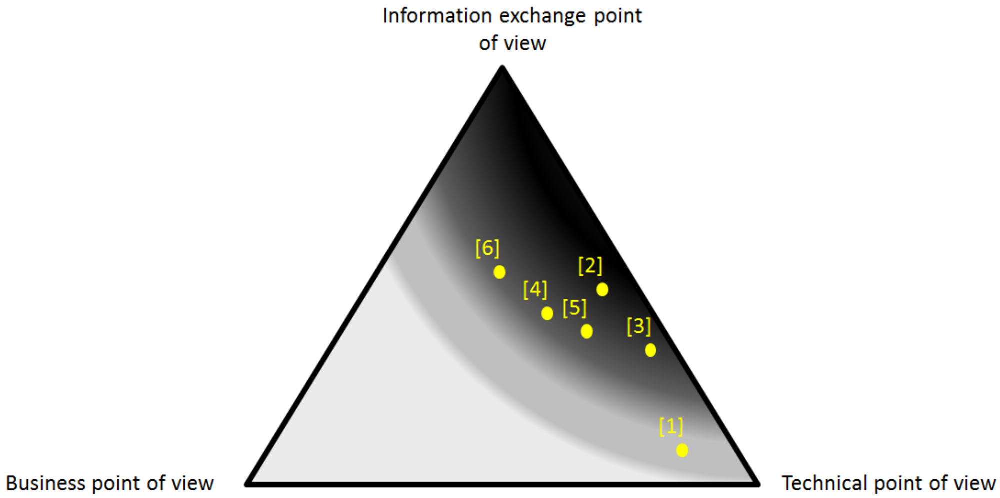


Figure 36. Author’s articles places on the thesis framework triangle.

The author’s observations and experience are reflected against the results of the literature research and Delphi interviews by analyzing the contribution of each scientific paper written by the author in Table 6 with the key observations from the two other research activities.

6 RESULTS

As it mentioned earlier in chapter 3, the literature research sources (Table 1, page 41 and Table 2, page 42) include the same articles that the author has referred to in her own articles. However, the articles which are included in the author's own articles are not included in the triangulation process. The number of independent articles forming the evidence space of the triangulation is 45 and the number of articles supporting the writing process of the author's own articles is 21.

The results of the utilized triangulation process presents the integration of the observations collected from the literature review, interviews carried out by using the Delphi method and author's experience together with her observations. Figure 37 shows a triangle and the thesis claim. In the middle of the triangle is the claim of this thesis and each corner point represents its own research method. Through the triangulation method, the claim is approached from these three different research perspectives.

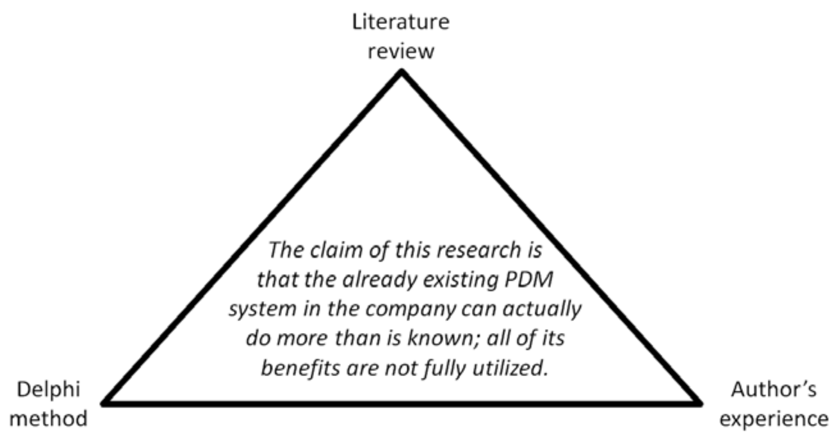


Figure 37. The analysis of the claim by using triangulation method.

The key results are presented in four Tables to ensure that the claim of this thesis is valid. In Table 7 through Table 10, the observations are presented for each data source and the discussion is divided into subjects mentioned in the claim. Firstly, a comparison is made of different viewpoints dealing with the expected properties and features of sheet metal in PDM systems based on three different research methods to show that there really is a gap between the utilized/unutilized or known/unknown system features in PDM. Secondly, the qualitative analysis of the similarities between different viewpoints dealing with the sheet metal in PDM systems is carried out to show where the different data sources support each other and how they strengthen the validity of the claim. Thirdly, this inquiry continues with the analysis of different viewpoints dealing with sheet metal in PDM systems which based on three different data sources (triangulation). This is done to recognize the viewpoints and aspects from different data sources which should be combined to form the overall picture of the current situation and the requirements for improvements of the PDM system. These findings are reflected in the claim. Finally, the results of the analysis, which show some contradiction between three different data sources, are examined. The purpose is to be objective and understand the limitations of the claim presented in this thesis.

In Table 8, the question dealing with the efficiency of the PDM system was left open without the definition of the term efficiency. The purpose of this open question was to clarify whether the PDM system vendors, design software vendors, sheet metal designers, Company X’s participants, PC support and academic expert see the efficiency aspects in different way. From the answers it was seen that interviewees regarded the efficiency of the PDM system mostly as efficiency of practical use.

In Table 10, possible contradictions were sought only from the literature review and interviews.

Table 7. Comparison of different viewpoints dealing with the expected properties and features of sheet metal in PDM systems based on three different research methods (triangulation).

DATA SOURCE → PDM STAGE	LITERATURE REVIEW	INTERVIEW BY USING THE DELPHI METHOD	AUTHOR'S EXPERIENCE AND OBSERVATIONS
CURRENTLY UTILIZED PDM ADD-ONS	***What features, properties and parameters are included in the current PDM systems according to literature?*** - *Product-related data: CAD models, drawings, calculation results, assembly instructions.* - *Managing revisions of the drawings – change management.* - *Vault for product and product related data (documents) – secure.* - *Product classification. Parameters can be added according to the classification to determine the product.* - *Integration between different CAD programs.* - *Product Lifecycle Management support.* - *Data sharing tool (between different users and applications): neutral format transfer (pdf).* - *Connecting the data to products.* - *Data finding tool: easy and fast.* - *BOM management.*	***What features and properties of PDM systems are mostly used currently in the sheet metal industry?*** - *Classification.* - *Version control.* - *Transferring drawings to manufacturing.* - *Project control.* - *Storage for documents.* - *Creating manufacturing structures.* - *Integration with design programs.*	***What features and properties are typically included with the current (sheet metal) PDM systems according to author's experience?*** - *Classification.* - *Version control.* - *Transferring drawings to manufacturing.* - *Storage place for documents.* - *Creating manufacturing structures.* - *Pdf-creator (model and dawning transformation to general form).* - *Integration with design programs.*

Table 7 continues. Comparison of different viewpoints dealing with the expected properties and features of sheet metal in PDM systems based on three different research methods (triangulation).

DATA SOURCE → PDM STAGE	**LITERATURE REVIEW**	**INTERVIEW BY USING THE DELPHI METHOD**	**AUTHOR'S EXPERIENCE AND OBSERVATIONS**
AVAILABLE BUT NOT FULLY UTILIZED PDM ADD-ONS	***What aspects does the literature review raise for improving the efficiency of the PDM system for sheet metal work?*** *- Feedback tool between manufacturing unit and design engineers.* *- Product-related data: simulation models, FEM-structures, object lists, NC-programs, test plans.* *- Workflow control.* *- Strategy tools inside the whole company.* *- Process management tool.*	***What properties of PDM systems do industrial experts wish to add to or improve in current PDM systems (although these properties may already be available)?*** *- Easier criteria to find the information from the system.* *- Better integration with other programs used.* *- Material database should be set according to used materials.* *- Used machines and tools should be known.* *- Easier to learn to use.* *- Work tasks should be possible to be done in only one way.*	***What aspects should be considered to improve the efficiency of the PDM system for sheet metal work based on the author's experience?*** *- Project control and planning.* *- Integration with project planning software.* *- Integration with the e-mailing and other programs in the company.*
UNUTILIZED AND UNKNOWN PDM ADD-ONS	***What kind of vision of the modern PDM system for sheet metal work is expressed in the literature?*** *- Not only CAD programs can be integrated to PDM.* *- Sheet metal feature recognition by products classification.* *- DFM(A) aspects.* *- Equipment available in machine shop.*	***What kind of vision of the modern PDM system for sheet metal work is expressed in the interviews?*** *- It can be more than just storage.* *- More commonly used programs should be able to be integrated into the system with more ease.* *- It should support more of what design engineers want.* *- Feature recognition system = machine readable drawings.*	***What kind of vision of the modern PDM system for sheet metal work does the author have?*** *- Recognition of sheet metal designs according to classification (in the PDM).* *- DFM(A) integration to PDM.* *- Design guidelines notification when adding part to certain class in the PDM.*

To summarize the expected properties and features in Table 7 it can be said that more features, properties and parameters have been found in literature than actually are in use. A graphical representation of the results in Table 7 is presented in Figure 38. First, the results from the literature review were added to the figure, then from interview answers was added, and finally, the author's observations were added. The colors in the table are as follow:

- Black: currently utilized PDM add-ons according to the literature review
- Red: currently utilized PDM add-ons according to the interviews
- Blue: available but not fully utilized PDM add-ons according to the literature review
- Green: available but not fully utilized PDM add-ons according to the interviews
- Brown: available but not fully utilized PDM add-ons according to the author's experience
- Purple: unutilized and unknown PDM add-ons according to the literature review

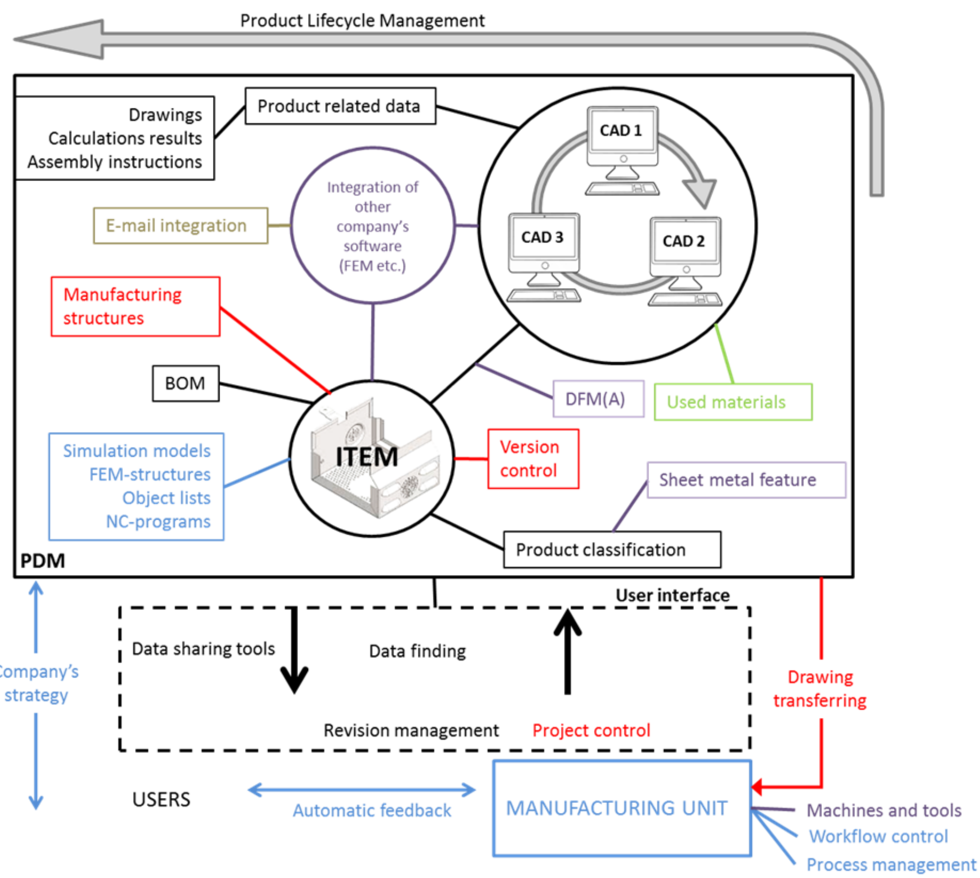


Figure 38. Summary of Table 7.

In theory all the information is in safe place in the PDM system and this information includes all the product-related data. Integration between PDM and different software, which are in use in the company, are fully utilized. And this has also led to situation where the product lifecycle is well supported.

The data, which is in the system, can be utilized in the design and manufacturing unit. The system itself is the data sharing tool: the drawings can be transferred to manufacturing unit fast and reliable. Once the information has been transferred to the system it is easy and fast to find: the workflow is easy to control.

When talking about add-ons that are not fully utilized or add-ons that are mostly unknown few main points pop up in literature review. Firstly, product related data can be created with different types of software, which are often not linked to PDM. Programs supporting design, such as FEM programs (Finite Element Method), are normally left out from the PDM integration. Secondly the PDM does not support the DFM(A) aspect by recognizing the parts.

But in real life, according to literature review (and also in author's experience), all PDM benefits are not in use. Firstly the PDM is most likely used as storage place. Secondly, PDM is used to handle the different revisions and control bigger projects. It was also seen that normally the system is integrated to basic CAD-software, but other used software (e.g. strength calculating software) are not integrated at all. Ando also the system was hardly used to transfer the drawings via PDM to manufacturing unit.

The most important notice was, in literature review, that databases in the systems are not updated to correspond to the company's, for example, used materials. Also the PDM users thought that the search criterion is not so simple to use as it should be and what the programs vendors are saying. Users also wanted to have more support when designing a sheet metal parts and this support may come from the most used system, PDM.

In authors experience DFM(A) integration should be possible and this integrations should help the design engineers to make more manufacturing-friendly choices. Unknown PDM add-ons (such as sheet metal recognition) are nowadays possible to do, but the main problem is that companies do not know that these kinds of possibilities exist.

Table 8. Analysis of the conformities between different perspectives on sheet metal in PDM systems based on three different data sources (triangulation).

DATA SOURCE	**CONFORMITIES FOUND FROM DIFFERENT DATA SOURCES**				
	What are the ways to improve the efficiency of the PDM system?	**What is the current weighting between the three main viewpoints of the PDM system (Figure 33, page 79)?**	**How should the organizational responsibility and accountability of the improvements of the PDM system be divided?**	**What is included in the relevant PDM data and who establishes the content of that data?**	**What aspects are included in the vision of a modern and efficient PDM system?**
LITERATURE REVIEW	- *Tailor made system for company's needs.* - *Defining what is relevant data for the system.* - *Full control of document management (knowing what is inside the system)* - *All product-related information inside the company should be in same place = PDM.* - *Include the system in the company's strategy.*	- *System is seen from technical and information exchange point of view because mainly users are design engineers and the data should be available to whoever may need it.* - *From the business point of view, the PDM will accelerate time-to-market time if document management is in control.* - *Business point of view can only be seen when buying the system.*	- *Drawings are imported to the PDM by the design engineers.* - *Design engineers update the data inside the PDM.* - *PDM system should have one main user, who updates user rights and who is responsible for updating the system to a new version.* - *Manufacturing unit is responsible for the reliability of used machines and tools.*	- *Designers mostly created the information.* - *Product-related data.* - *Information that describes the product.* - *Data that defines the product by its properties.* - *Data include value for part/products user.* - *Relevant data depends on the user (designer, manufacturer, purchaser etc.).*	- *Every used software or program can be integrated to be one part of the PDM.* - *Co-operation between manufacturing and design engineers.* - *All the product-related information inside the company should be in same place = PDM.* - *Comprehensive classification for products and good project management.*

Table 8 continues. Analysis of the conformities between different viewpoints dealing with the sheet metal in PDM systems based on three different data sources (triangulation).

DATA SOURCE	**CONFORMITIES FOUND FROM DIFFERENT DATA SOURCES**				
	What are the ways to improve the efficiency of the PDM system?	**What is the current weighting between the three main viewpoints of the PDM system (Figure 33, page 79)?**	**How should the organizational responsibility and accountability of the improvements of the PDM system be divided?**	**What is included in the relevant PDM data and who establishes the content of that data?**	**What aspects are included in the vision of a modern and efficient PDM system?**
INTERVIEW BY USING THE DELPHI METHOD	- *Clearer and easier functions for finding information from the PDM system = different search criteria.* - *Single-method operations. Ensured one-time transfer to general format (pdf)* - *Drawing transfer in electronic format to every manufacturing plant.*	- *Interviewees placed the spot in different area of the triangle (Figure 35, page 89): conformities between different interviewees difficult to see.* - *The main conformity is seen in the opinions between the PDM system vendor and design software vendor.* - *The scientific community sees the balance between the three points of view, but it is characteristic that each of them weights their own points of view.*	- *Every interviewee had a different point of view about who should be the person to update the system.* - *It is noticeable that the viewpoint dealing with responsibility and accountability highly depends on the interviewee's position: the common factor is that one's own point of view is emphasized.*	- *The information is created mostly by design engineers.* - *This information will take the manufacturing process forwards.* - *Relevant information depends on the users.* - *Relevant information depends on the manufacturing plant where the part is going to be produced.* - *Manufacturing method may be included in the relevant data.*	- *No extra data has to be added to drawings.* - *Feedback (from manufacturing to designers and vice versa) can be handled through the system.* - *Time spent on opening and closing large models should take less time = fast Internet connection to server.* - *It should not be possible to produce duplicates in the system.*

Table 8 continues. Analysis of the conformities between different viewpoints dealing with the sheet metal in PDM systems based on three different data sources (triangulation).

DATA SOURCE	**CONFORMITIES FOUND FROM DIFFERENT DATA SOURCES**				
	What are the ways to improve the efficiency of the PDM system?	**What is the current weighting between the three main viewpoints of the PDM system (Figure 33, page 79)?**	**How should the organizational responsibility and accountability of the improvements of the PDM system be divided?**	**What is included in the relevant PDM data and who establishes the content of that data?**	**What aspects are included in the vision of a modern and efficient PDM system?**
AUTHOR'S EXPERIENCE AND OBSERVATIONS	- *To clarify the definition of the independent PDM.* - *All product-related data should be found from the same place → time savings.*	- *The PDM system is mainly seen as a centerline between the information exchange and technical point of view. The system is 'a melting point' for different formats and system generates them to, normally, pdf-files. Also, the drawings can be sent to the manufacturing unit through the PDM system.*	- *Organizational responsibility is primarily shared by the designers and manufacturers: if only one party is updating the databases, the PDM's benefits are not gained.* - *The globalization of design and manufacturing is also changing the distribution of liabilities to match the global environment.*	- *The information which takes manufacturing forward is created by design engineers.* - *Information on the drawings should be relevant; the tolerances, requirements of the product(s) and manufacturing processes should correspond to the machines and tools in the manufacturing unit.*	- *PDM should support the design process.* - *Classification in the PDM system should be reflected in the product that the company is producing.* - *Designers' knowledge of manufacturing methods and their characteristics.*

Summarizing the conformities from Table 8, the literature review indicated that the ways to improve the effectiveness of the system is mainly to tailor the PDM system to correspond to the company’s needs. From the viewpoint of production, the data has to be defined to guarantee the optimal functionality of the system: what is relevant information to carry out the manufacturing process of the product. The interviews revealed that efficiency can be improved easily by adding clearer and easier functions for finding information from the system. This was also supported by the literature review. Also transferring drawings to the manufacturing unit via PDM will increase production efficiency according to the interviewees and the literature review.

In the literature review, all of the product-related data can be seen as relevant data which is needed to manufacture the product. Manufacturing requires data which fully describes the product. The main point is that data will always add value to the part/product and also be of value to the user and manufacturer. The interviewees said that the data is mostly created by the design engineers and that the relevance of the data depends on the persons themselves. Also the manufacturing method contributes to the characteristics of the product data. The same observation was made from the literature review.

The main responsibility for updating the PDM system, according to the literature review, rests on the shoulders of the user. The literature review indicated that if the system should be updated, the design engineers are the ones who know what to update and how.

According to the literature review, the PDM system can be examined from three points of view: information exchange, business and technical. The interviewees' points of view depended on their respective positions: all of them placed the PDM system differently in the triangle (Figure 33, page 79).

Based on the author’s experience, it can be said that the definition for relevant data is difficult to give: it depends on the manufacturing processes. Therefore, engineers should have knowledge about the processes which are in use. That enables defining what the product-related data is needed during the product manufacture.

Table 9. Analysis of different viewpoints dealing with the sheet metal in PDM systems which form the unity based on three different data sources (triangulation).

DATA SOURCE	**CONSTRUCTING THE UNITY FROM DIFFERENT OBSERVATIONS PRESENTED IN THE DATA SOURCES**				
	What are the options for measuring the efficiency of the PDM system and how substantial could the benefits gained in production be if the PDM system is appropriate enough?	**What is the importance of each main three viewpoints in the PDM development environment (Figure 33, page 79)?**	**What kind of organizational aspects should be taken into account when improving the PDM system?**	**In what ways does the PDM system make the manufacturing process easier and more reliable?**	**What aspects could be added to the vision of a modern and efficient PDM system?**
LITERATURE REVIEW	- *Number of iterations /corrections to drawing(s) during the design and manufacturing processes.* - *Time for searching the needed documents versus time for doing designing.* - *The use of storage capacity.* - *Reuse of earlier designs = designer's time savings.* - *Designing errors before and after utilization.*	- *Business point of view: improve productivity.* - *Technical point of view: everybody has a possibility to read/view items without the actual engineering software.* - *Information exchange point of view: design features will define the manufacturing costs. Co-operation between designers and manufacturing.*	- *User account rights: who can do what?* - *Needs from main users: designers and manufacturing unit.* - *Drawings should be checked by someone other than the person who designed the part.* - *Seamless co-operation between designers and manufacturing.*	- *Drawings can be transferred to production in electrical format → latest version always available.* - *Own database for machines and materials → DFM(A).* - *All product-related data can be found from one place.*	- *More flexible integration with other systems carried out by the company's internal IT person.* - *Easier to implement with company's systems.*

Table 9 continues. Analysis of different viewpoints dealing with the sheet metal in PDM systems which form the unity based on three different data sources (triangulation).

DATA SOURCE	**CONSTRUCTING THE UNITY FROM DIFFERENT OBSERVATIONS PRESENTED IN THE DATA SOURCES**				
	What are the options for measuring the efficiency of the PDM system and how substantial could the benefits gained in production be if the PDM system is appropriate enough?	**What is the importance of each main three viewpoints in the PDM development environment (Figure 33, page 79)?**	**What kind of organizational aspects should be taken into account when improving the PDM system?**	**In what ways does the PDM system make the manufacturing process easier and more reliable?**	**What aspects could be added to the vision of a modern and efficient PDM system?**
INTERVIEW BY USING THE DELPHI METHOD	- *Checking how much time an engineer spent on one drawing. This may however lead to the point where the engineer tries to finish the design as fast as possible, which will result in further errors.* - *To compare the situation before and after PDM: time versus money.* - *Workflow control→ improvement of productivity.*	- *Technical point of view: all information and data should be available in general form so it can be read.* - *Information exchange point of view: without co-operation between designers and manufacturers the mistakes will remain in the drawings.* - *Business point of view: investment in PDM should always make profit.*	- *Designers' opinion: their needs and wants.* - *At least one person should be the main user and control the system.* - *User accounts and different levels of access to employees who need them.* - *Manufacturers also need training in how to use PDM.*	- *Drawings in electronic format are easy to read and when necessary zoomed to different points in the drawing.* - *Manufacturers who have access to PDM should know how to use it.* - *Designer's knowledge of the used machines, tools and materials.* - *Different design features need different kinds of design information.*	- *Proper classification and classification-related parameters.* - *Money should not be the 'tool' for choosing PDM.* - *Easy searching tool.*

Table 9 continues. Analysis of different viewpoints dealing with the sheet metal in PDM systems which form the unity based on three different data sources (triangulation).

DATA SOURCE	**CONSTRUCTING THE UNITY FROM DIFFERENT OBSERVATIONS PRESENTED IN THE DATA SOURCES**				
	What are the options for measuring the efficiency of the PDM system and how substantial could the benefits gained in production be if the PDM system is appropriate enough?	**What is the importance of each main three viewpoints in the PDM development environment (Figure 33, page 79)?**	**What kind of organizational aspects should be taken into account when improving the PDM system?**	**In what ways does the PDM system make the manufacturing process easier and more reliable?**	**What aspects could be added to the vision of a modern and efficient PDM system?**
AUTHOR'S EXPERIENCE AND OBSERVATIONS	*- If PDM supports sheet metal design, the possible errors before and after production could be recognize and the frequency of them can be quantified.*	*- All three points of view are important when implementing the PDM system into the company's strategy.* *- The PDM is not just a tool for designers.*	*- Feedback from the manufacturing unit should always reach the designers.*	*- By designers knowledge of the basic sheet metal features, machines and tools.* *- With correct sheet metal design aspects and parameters, the part should be easier to manufacture.*	*- Sheet metal guidelines based on experimental tests.* *- Most companies already have a PDM system, so it would be worthwhile to try it to see if it helps sheet metal designing.*

Table 9 displays the different viewpoints dealing with the sheet metal in PDM systems. The substantial benefit in terms of efficiency (according to literature review) can mostly be measured from the number of iterations and corrections made to drawings. Efficiency can also be measured by time: how long it takes to find the product from the system. Time can also be measured when designing a product which is based on an earlier design: how long it takes to modify an already existing drawing versus to drawing a new design from scratch.

Figure 33 (page 79) gave three different points of view on PDM. The business point of view is always to improve productivity, the technical point of view is to make the information accessible without the actual design program (general format), and the information exchange point of view is to enable co-operation between the design and manufacturing unit. Both the literature and the interviewees shared opinions on these viewpoints.

The literature review clearly showed that drawings should be checked by a person other than the designer. The interviewees agreed. Furthermore, there should be one main user controlling the system. It was also clear that transferring drawings to manufacturing in electronic format will increase reliability and facilitate the manufacturing process.

In the future, a modern and efficient PDM system will include more accurate classification(s) and classification-related parameters. These parameters will also make the search easier and more effective. According to the literature review, also flexible integration into the company’s others programs will make the system more efficient. Moreover, co-operation between the design and manufacturing units has to evolve.

Table 10. Analysis of different viewpoints dealing with the sheet metal in PDM systems' utilization and development which show some contradiction between three different data sources (triangulation).

DATA SOURCE	**CONTRADICTIONS BETWEEN DIFFERENT OBSERVATIONS FOUND FROM THE DATA SOURCES**				
	Aspects dealing with the efficiency of the PDM system?	**Tasks and roles of the three different main points in the PDM development environment (Figure 33, page 79)?**	**Organizational aspects?**	**Manufacturability aspects of sheet metal products?**	**The vision of an efficient PDM system?**
LITERATURE REVIEW	*- DFM integration with CAD.* *- Designer's time spent.* *- Correct and unambiguous classification.* *- Specific definitions of used terms.*	*- In the author's experience, the roles can include two different points of view, and the stages of the product life cycle tied to PDM system development can also be found from the literature (i.e. Stark, 2005).*	*- Include the system in the company's strategy.* *- General knowledge of how the PDM system works = training of the human resources.* *- Knowledge of information which is needed in different units of company (different types of data).* *- The usage of data: who needs it and in what kinds of situation.*	*- Design guidelines are needed.* *- Necessary information available in the drawings.*	*- PDM will support product lifecycle management.* *- Fluent integration to company's other systems.* *- Knowledge of the meaning of PDM and its definition.* *- Not just a storage place or documentation sharing system.* *- Company's top managers should be making sure that the company's technology solutions are used properly in the implementation of PDM.*

Table 10 continues. Analysis of different viewpoints dealing with the sheet metal in PDM systems' utilization and development which show some contradiction between three different data sources (triangulation).

DATA SOURCE	**CONTRADICTIONS BETWEEN DIFFERENT OBSERVATIONS FOUND FROM THE DATA SOURCES**				
	Aspects dealing with the efficiency of the PDM system?	**Tasks and roles of the three different main points in the PDM development environment (Figure 33, page 79)?**	**Organizational aspects?**	**Manufacturability aspects of sheet metal products?**	**The vision of the efficient PDM system?**
INTERVIEW BY USING THE DELPHI METHOD	- *Starting point of the defining the requirements.* - *Only one main user who can control the system.*	- *Design engineers and PC support see the system from a technical point of view.* - *The company that manufactures sheet metal products sees the system from an information exchange point of view.* - *Vendors see the system from a business point of view.* - *Academic person sees the system from all of point of views depending on the context.*	- *Design engineers: updating materials is vendors' responsibility.* - *Vendors: the users have the responsibility to handle updating.* - *Company who manufactures sheet metal products: they update the system by themselves.* - *Determining the requirements once in a while.* - *Final check for the drawings: engineer or design manager.*	- *Knowledge of the used machines and tools.* - *The information in models inside of the PDM systems is thin and cannot be used as such in manufacturing.* - *General format (pdf) will destroy the information in the model.* - *Manufacturing method included in the drawings.*	- *Every PDM should be tailor made for the company's use.* - *Support the company from different points of view (triangle): information exchange, technical and business.*

Table 10 displays the contradictions between different sources when analyzing the PDM system from the sheet metal point of view. In the literature review, the efficiency of the system depends on the source. Some sources thought that only integration with CAD systems will improve efficiency. The terms related to the PDM system should also be defined. Some of the sources shared this thought: the terms must be defined to effectively employ the PDM system. Furthermore, the entire company has to be involved when purchasing and using the system: PDM should be part of the company’s strategy.

PDM is not a tool which solves all of the problems in the production and design units. Specific guidelines are needed to design manufacturing-friendly products and to make design engineers work more efficiently. In addition, the necessary information has to be available in order to create the drawings. This necessary information may be, for example, information about the used machines and tools. Nevertheless, the information may be difficult to obtain in the globalized world. The literature review showed that this information can be obtained from the PDM system, but the interview with design engineers suggested that the information in the system is not always valid or available.

The responsibilities for updating the design programs and material libraries are unclear. In the interviews, it became clear that every interviewee thinks that updating is somebody else's duty: nobody was eager to take responsibility for it. The literature review gave no straight answer to who should update the system. The literature review also clearly showed that design engineers should be involved in any plans to purchase a PDM system. In the interviews, however, it was observed that the design engineers are mostly excluded from this process.

7 CONCLUSION AND DISCUSSION

According to increasing sheet metal production it can be supposed that sheet metal design is also increasing. The trend also seems to be that even more companies are trying to be so-called global companies, and the designing activities may take place in a different country or place to where the manufacturing unit is located. As such, the PDM system has grown into a data sharing tool between different design and manufacturing locations.

The main purpose of this thesis is to gather together information about sheet metal design and PDM systems, and the possibility of their integration. Everything has to start from the definition of used terms, and as it was seen in this thesis, definitions may vary depending on the people who are looking at the subjects from different points of view.

The research questions were:

1. **Which sheet metal parameters affect manufacturability in the way that the product can be designed without errors in production?**

   The answer to this question is found from the literature review, interviews and from the author's experience. The literature review gave an extensive and specific answer about sheet metal design features and their relation to the tools and machines used for manufacturing the design. Every feature has its own specific parameters and all of these affect manufacturability. To make sure that the product can be manufactured easily, the specific sheet metal guidelines and DFM has to be known.

   The results from the interviews and from author's experience are similar to the results from literature review: material properties (e.g. thickness, type of material) and the created design features have to be familiar to the designer so that a manufacturing-friendly product can be designed. Also, the trust in designers' professional skills and knowledge of sheet metal designing will produce manufacturing-friendly sheet metal designs.

2. **Can PDM be the helping tool to determine these parameters? Would it be possible to add a function to the PDM system which helps the designers to choose the correct parameters for their sheet metal designs?**

According to the author's articles, it should be possible. By systematic classification inside the system, the PDM add-on should be possible to build. This add-on, after the parts transfer and classification to the PDM system, will indicate the basic guidelines and DFM aspects of sheet metal designing to designers. The key point is to build add-ons which also guide the production (PDM), not only the design work (CAD).

3. **How and to what extent would the 'possibly found' PDM sheet metal function affect the manufacturability, the number of defected parts in manufacturing process and the time needed for the actual design process?**

   According to the design engineers in the interview, the knowledge of sheet metal guidelines will help designers to choose right parameters. When the information can be found from one place, it should make the design process easier: time is not spent on finding information. When the parameters are chosen correctly, this will also reverberate in manufacturing and fewer defective parts should be manufactured. This is also the author's opinion based on observation.

4. **Are, in sheet metal designing, all the design features in software's library suitable to every design?**

   According to the design software vendor in the interview, the features and the numerical values are only guidelines. The responsibility to update these parameters to correspond to the company's production lies on designers. On the other hand, designers trust that the parameters and design software library's features are correct and they use them without question. In general, the automatic features do not suit every design if the automatic features are not set by the company who knows the used materials, machines and tools. Practical examples have also shown that the design features in most commercial software lack sufficient parameters.

7.1 Reliability, Validity and Objectivity

The claim has been analyzed from three different points of view by using triangulation. The validity of this thesis is based on three different points:

1. The literature review was based on extensive literature research. The number of resources in the beginning was significant (over 200 different references) and the final sources were selected after

tabulation using determined criteria. These sources were also widely used in the text.
2. The interviewees were selected from different industries and organizations of engineering industry: design engineers, sheet metal manufacturers, software and system vendors, and academic. The factor common to all interviewees is that they are related to the sheet metal industry.
3. The use of triangulation multiplies the reliability, validity and objectivity of the study. Triangulation helps expose the contradiction between different sources and hence gain objectivity.

In this thesis, the Delphi method together with detailed lettering was utilized. The objectivity of this thesis is based on:

- The author's own articles have gone throw an international review process.
- In the literature review, the selected literature was evaluated based on both substance and bibliographic characteristics.
- The interviewing situation always affects the answers of the interviewees. By removing the subjectivity from the results, the results become more reliable. This elimination of subjectivity was realized by sending the results to interviewees and giving them the opportunity to correct the answer after the main interview situation.
- In the thesis, the definition of the used terms was determined. By doing this, the author wanted to point out her point of view and from which situation the content should be examined.

7.2 Assessment of the Results and Sensitivity Analysis

The conclusions and triangulation in this thesis are based on several different sources. The literature review is done using several different sources to support the thesis. If one source is removed from the conclusion or from the triangulation, the final conclusion will not change. On the other hand, there would have been more benefit to interview more people involved in PDM and sheet metal design or manufacturing. In this way, the results may have been more extensive.

The answers to the research questions and research problems are based on triangulation. Depending on the research question, the weighting of the three different points of views (literature review, interview or author's experience) is different. When talking about the design aspects and the knowledge of sheet metal designing, the interview method and the author's experience are weighted. The weighting of the literature review can be seen when determining the definitions of terms and when examining the PDM system.

The hypothesis for this thesis was stated in section 1.4. and the following claim was made:

> *…the already existing PDM system in the company can actually do more than is known; all of its benefits are not fully utilized. It can support the sheet metal design process by giving design guidelines after the sheet metal part has been saved into the system and the category for the item has been chosen. When all of the company's tools and machines are updated, not only in CAD systems but in the PDM system as well, the design will be easier to manufacture because the recognition of appropriate/required parameters and the establishment of their magnitudes will be done correctly the first time. This means that the role of PDM systems is slightly changing from passive databases towards analyzing tools to support designers' work.*

When examining the first sentence of the statement "*…the already existing PDM system in the company can actually do more than is known; all of its benefits are not fully utilized*" the hypothesis seems to be valid. According to the interviews with different PDM users, it was noticed that the system was used in different companies in different ways and the vendors explained what kinds of things could be done by the system. When comparing the vendors' ideas to the reality of using PDM, the designers for example did not know that the feedback system can be handled with the PDM. It seems that companies use the system differently, so it stands to reason that there are properties that are not in use and properties that have not been utilized.

The final sentence of the statement "*when all of the company's tools and machines are updated, not only in CAD systems but in the PDM system as well, the design will be easier to manufacture because the recognition of appropriate/required parameters and the establishment of their magnitudes will be done correctly the first time*" concerns the sheet metal design aspects. It became clear from the interviews that the different interviewees had contradictory ideas concerning who is, for example, responsible for updating the system and who is responsible for the accuracy of software's material and feature library. Still, according to the literature review, interviews and author's experience, when the tools and machines are updated to correspond to the reality of production, fewer design and manufacturing error occur. The main consensus was that the needed information should be found from one place and that this place could be the PDM system. According to these findings, this claim was found valid.

The second sentence from the statement about the PDM that it can "… *support the sheet metal design process by giving design guidelines after the* *sheet metal part has been saved into the system and the category for the item has been chosen*" concerns the internal classification in the PDM system. In the literature review it was written that "…the classifications in the system are based on company's own grouping", which means that the PDM system has to have certain classifications for the items. From the interview, it was understood that "…the classification and classification-related parameters are set to respond to the needs of the different types of products", which indicates that the system has to have certain classifications for items and parameters set. These two findings corroborate that part of the thesis statement.

The PDM system can corroborate sheet metal design with the correct add-on. The three previous chapters hence support the thesis statement and claim.

7.3 Key Findings

In this study, the main key findings, in no particular order, are as follows:

1. Accentuate in triangulation and its angles (point of views of: business, information exchange and technical) depends on the background of the person. If the main field of activities is based on selling the PDM system, the emphasis will lay on the business point of view. This emphasis cannot be changed and this situation will lead to misunderstandings and the inefficient use of the system. In other words, the experience of the PDM system user will specify where the emphasis is situated in the triangle.

2. The classification in the PDM system will define the parameters that should be added to the system. The classification is based on the company's products and knowledge. The program's sheet metal parameters should also correspond to the company's manufacturing needs. When the experimental tests are done, the specific guidelines for the sheet metal designing can be created. Now the missing sheet metal aspects from the PDM system mainly concern the sheet metal guidelines and specific machine parameters. When adding this information to the system, the errors in design, and also in manufacturing, should decrease.

3. Based on the author's motivation, section 1.6, and the figures shown (Figure 4-Figure 7), the more efficient use of PDM is arguable. When the production of sheet metal blanks, and consequently industrial production, increases, this will automatically lead to a situation where designing work has to be more efficient. When most of the designing time (approximate 72%) is spent on something other than designing,

the actual designing time has to increase. Finally, the development of PDM markets is also increasing; therefore, developing the PDM system to the next stage would be useful.

4. The DFM integration to CAD seems to be possible; this is already a good step for starting to think about the integration of PDM and sheet metal designing.

7.4 Novelty Value of the Results

The sheet metal feature recognition and PDM systems are well-researched themes in the field of engineering and production engineering. Due to globalization, companies have realized that in order to control their products and product-related data, the PDM system seems to be best tool. The investments, which companies are ready to make, depend on the size of the company and the number of its users. A modern trend in program and software vending seems to be the development and production of new software every year. Because of this trend, software becomes quickly and easily outdated, and development is forgotten.

The PDM system still has potential elements that can be developed; some elements are not yet even in use. Why then invest in a new system if the company already has a system and experience in its use? By looking back, not to the future, the PDM system can be the tool to help designers to design more manufacturing-friendly products. The challenge concerns finding the right add-on and tailoring the system for the company’s needs and uses.

7.5 Generalization and Utilization of the Results

The claim of this study was based on the knowledge that most companies already have a PDM system in use in some way or another. The main research area was sheet metal design and its specific features. When it is possible to enhance sheet metal designing with an add-on in the PDM system, the add-on can of course be expanded. The design guidelines can also be created for other bulk materials than sheet metals.

The design guidelines and the rules-of-thumb are always based on the tools and machines which are in use. This means that the tools and machines have to be known if the company wants to design manufacturing-friendly products. It is possible to create a comprehensive designing add-on tool for the PDM system and in this way to improve the design and manufacturing process. When thinking further, the add-on can be developed and this way it may be possible to integrate it, for example, into the design software.

In this thesis, the main area of concern has been the technology. In the triangle, there is still the corner considering the business point of view. When talking about efficiency, it normally is reflected with time, and in the modern world, time is money. Therefore, when solving a technical problem related to engineers' time consumption, there will always be an economic meaning attached to it. With PDM, a company has the possibility to save money in helping the design engineers work more efficiently. Basically, more time is spent doing the actual designing work than, for example, wasted on finding the correct information.

Nevertheless, there is always a possibility that the company does not use all of the PDM system's properties. The reasons may be simple: for example, the company does not see the benefit of certain PDM properties, or there is no time to train the people to use those properties. In addition, the system vendors may not necessarily understand their customer's needs, and on the other hand, the customer may not understand the benefits of the software.

Because different kinds of people have been interviewed from different kinds of organizations and industries, the thesis can be generalized and used in industry. The information about sheet metal design features and PDM can be found in the same fold. The information is easy to find, such as the information should be from a PDM system.

7.6 Topics for Future Research

This thesis had two main themes: the PDM system and sheet metal designing. In the future, the research should concentrate on to how to make the PDM system actually support the sheet metal design process. The research should be based on how to program an add-on and what this add-on should include. Furthermore, the focus should be on sheet metal feature classification and the classification inside the PDM system.

Figure 39 shows the possible place for future research into the sheet metal designing add-on. It should be in action when designers transfer drawings or models to the PDM system and when they modify the existing drawings and models. The basis for the PDM control system is taken from an article written by Xie et al. (2008, p. 34). The add-on should work such a way that it could not be evaded without checking the important things from the drawing or model. This should mean that the parameters set to PDM are correct and the part is manufacturing-friendly. The used guidelines and features are based on the materials, tools and machines used in the company. Future research should concentrate on how the add-on is going to be built and what are the critical parameters and design features included in the add-on.

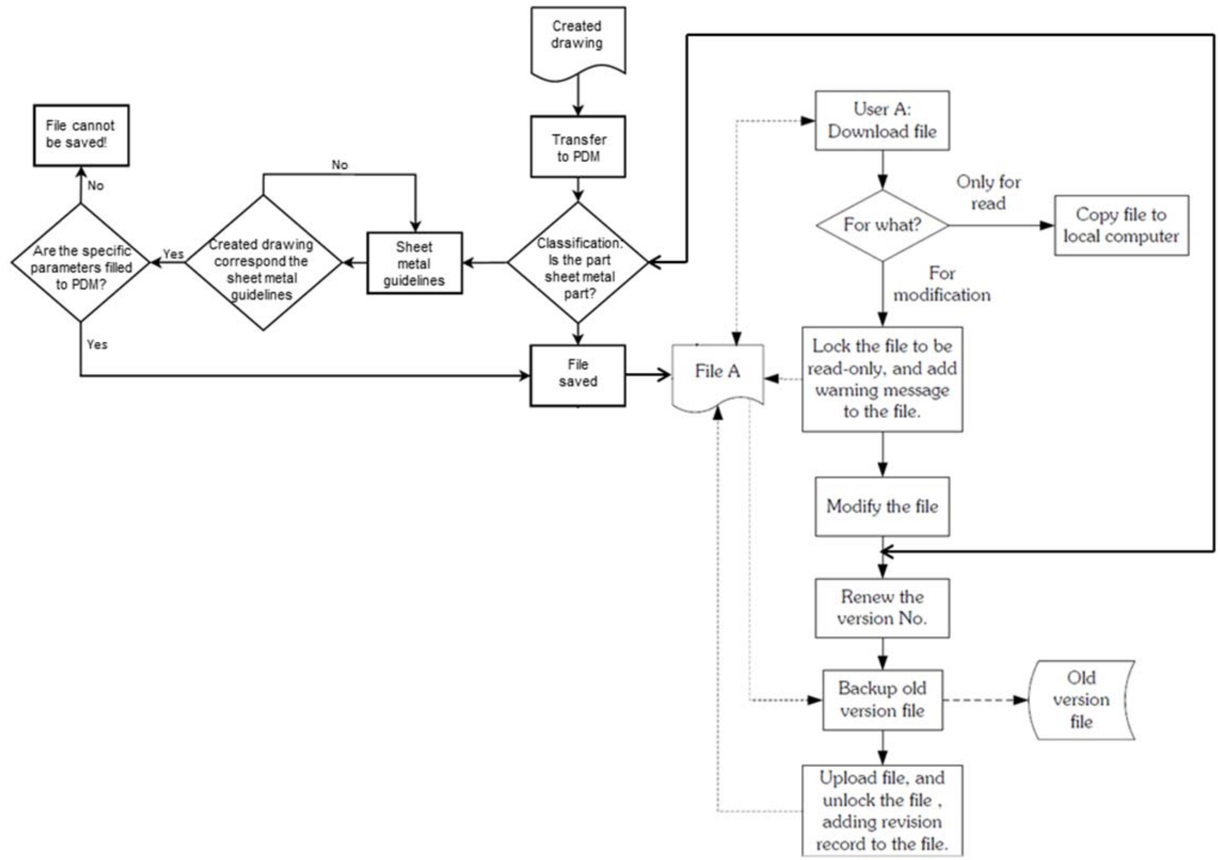


Figure 39. The place of the future sheet metal design add-on and its action places (grey part of the figure modified from Xie et al., 2008, p. 34).

8 SUMMARY

Globalization is a growing trend in today's industry. Designing may occur in a different place than the actual manufacturing: this puts pressure on designers to make designs that are easy to manufacture. They should be aware of the tools and machines being used to ensure that the part is able to be manufactured. Also, the knowledge of specific sheet metal features and the needed parameters helps designers to make a manufacturing-friendly product. However, this information may not be available and the situation may not be like this only in global company; this may also occur locally. This may lead to the situation where the designs include irrelevant information or where information is missing, making the product more difficult to manufacture.

The production of sheet metal products has increased, such as the manufacturing of sheet metal plates. Although the manufacturing of sheet metal plates is increasing, material costs are decreasing. This will put pressure on sheet metal design engineers to design products that can be manufactured from one trial. Also, 70% of the total costs of products are determined by the design process: not only do specific shapes increase the cost but the changes that have to be made to designs play the most significant role. When decreasing the amount of corrections, the total cost will also decrease. Furthermore, only approximately 28% of weekly work time is spend on designing; the rest is spent on finding information and solving problems.

Product Data Management, also known as PDM, is a tool whose one main function is to share the information with whoever may need it. The system is also used as a secure vault for drawings, models and all product-related data. The designers can find the information from the PDM system, which makes the design process faster and easier. The PDM system is not a new invention; it is almost 30 years old; its first purpose was to help with design engineers' workloads. The integration with CAD programs made it more effective and after some time, the integration with a company's other systems and programs have been possible. Despite the system's age, research concerning the PDM system is relatively new: the system has been researched and developed for approximately 20 years. The development has been considerable and the actual PDM system has grown to be a company's main data management system with different integrations, implementations and add-ons. Additionally, it may be considered that the original main idea of PDM and its content have been forgotten.

In this thesis, the PDM system is seen as an individual system, and inside a system there are products and parts (general term: items). Every item includes the information which will take the manufacturing process further. Furthermore, the information includes valid details for other departments inside the company: for purchasers, managers, service personnel for example.

Sheet metal features will add more information to the product data. The features can be thought of as geometrical (for example holes, pads and edges) or non-geometrical (for example tolerances, color, and material). The final production costs are determined according to geometrical features; therefore, understanding the features is then crucial. The definition of the term feature is hard to determine and an official (standard) definition is still missing. In general, it can be said that the feature carries the part data inside of it: it will give more information to the actual part. In addition, the official classification of features is missing, which creates problems for software vendors, which is how features classification should be done in the program's feature library. General classifications exist for 3D models and 2D drawings but because of a lack of official features, these depend on for whom the features have been invented and classified.

The main idea in this thesis is to study the possible implementation of PDM and sheet metal features in such a way that sheet metal design will be more effective and easier. Consequently, this will make manufacturing easier and less problematic. The basis for this research is the triangulation process: the research has been inspected from three different points of views. The points of views are: scientific literature review, interview by using the Delphi method and the author's experience.

The thesis hypothesis concerned a company's already existing PDM system and its known and unknown add-ons. The claim concerned whether the PDM system could support the sheet metal design process by giving guidelines for manufacturing-friendly production. The guidelines should include sheet metal features and specific parameters related to features. Also, it was mentioned that a company's tools and machines should be updated into the system to support the design process.

Four main key findings were found: (1) the area of focus in the triangle depends on the person's background and their role in the company, (2) the classification in the PDM system (and also in the CAD system) should include the used materials, tools and machines that are in use in the company, (3) the design process has to be more effective because of the increase of industrial production, sheet metal blank production and the designer's time spent on actual designing and (4) because DFM integration is possible with CAD programs, it should also be possible to integrate DFM into the PDM system.

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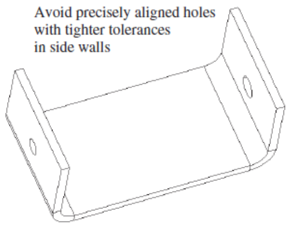
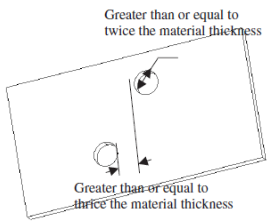
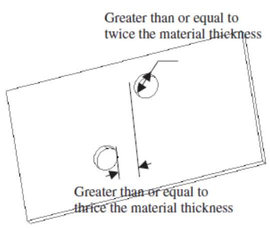
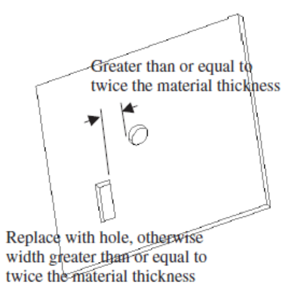
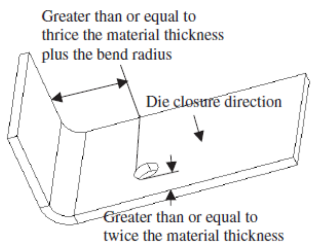
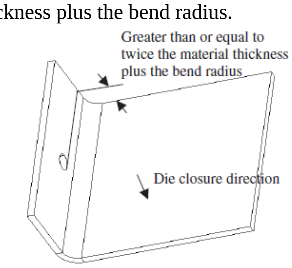
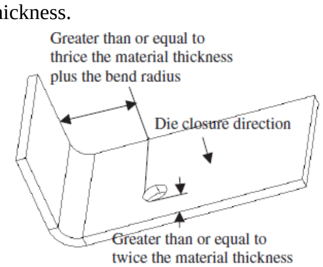
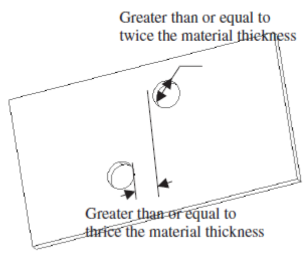
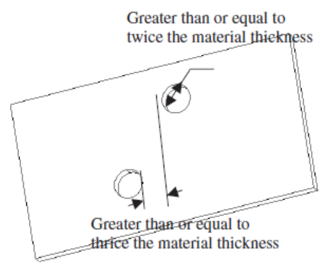
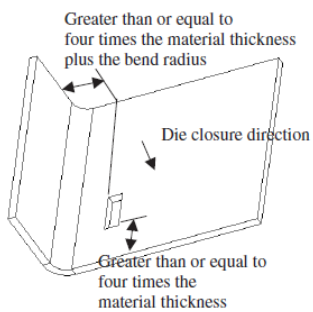
Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

Guideline	Importance
Hole	
Holes precisely aligned with tighter tolerances inside walls should be avoided.  	To eliminate piercing operations that require expensive cams or adding dies or die stations to the process.
Minimum diameter of a hole should be equal to twice the material thickness.  	To eliminate the requirement of fragile punches. Punch breakage becomes excessive if holes below the prescribed minimum are attempted.
Minimum distance between the edges of two holes should be equal to thrice the material thickness.  	To avoid distortion of narrow sections of the work piece material during punching. If the wall thickness is too little, the die's ability to resist the pressure of piercing is seriously impaired.
Minimum distance between the edges of a hole and a slot should be equal to twice the material thickness.  	To avoid distortion of narrow sections of the work piece material during punching.

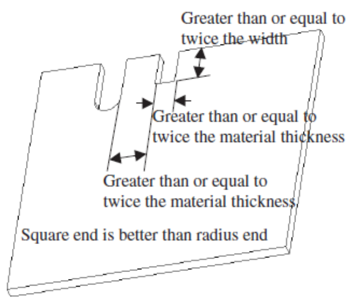
Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

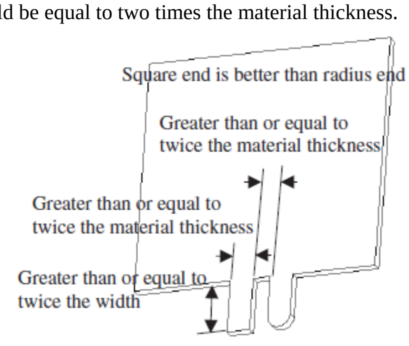
Guideline	Importance
Hole	
Minimum distance between the edge of a hole and a bend should be equal to three times the material thickness plus the bend radius.  	Holes located too close to a bend weaken die features, so that high die maintenance is required to avoid component distortion.
Minimum distance between the lowest edge of a hole and the other surface should be equal to two times the material thickness plus the bend radius.  	To avoid hole distortion.
Minimum distance between the edge of a hole and the adjacent edge of the blank should be equal to twice the material thickness.  	To avoid distortion of narrow sections of the work piece material during punching.

Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

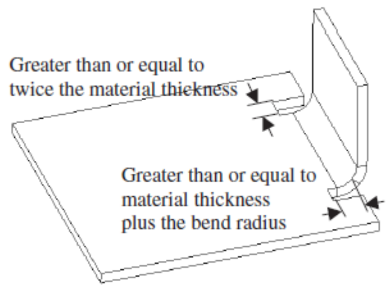
Guideline	Importance
Slot	
Replace slots by holes if possible. 	Tooling costs for round-hole punches and dies are far below those for holes other than round shapes.
Minimum width of a slot should be equal to twice the material thickness. 	To eliminate requirement of fragile punches.
Minimum distance between the edge of a slot and a bend parallel to its length should be equal to four times the material thickness plus the bend radius.	To avoid distortion and for economical tooling and production.
Minimum distance between the edge of a slot and the adjacent edge of the blank should be equal to four times the material thickness. 	

Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

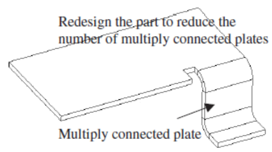
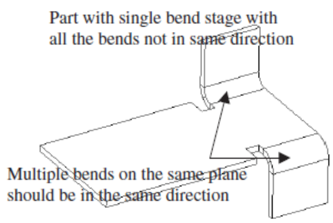
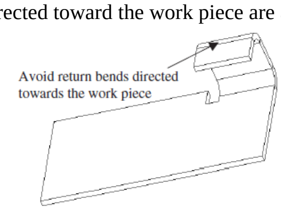
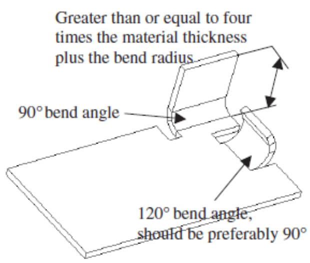
Guideline	Importance
Notch	
Square end notches are better than radii end notches.	To avoid feather edge burr on radii
Minimum width of a notch should be equal to twice the material thickness.	To eliminate narrow weak sections in either punches or die plates thereby reducing tooling cost.
Minimum length of a straight/radius end notch should be equal to two times its width.	To reduce the tooling cost.
Minimum distance between the edges of two notches should be equal to two times the material thickness. 	

Guideline	Importance
Projection	
Square end projections are better than radii end projections.	To avoid feather edge burr on radii.
Minimum width of a projection should be equal to twice the material thickness.	To avoid distortion and to eliminate narrow weak sections in either punches or die plates thereby reducing tooling cost.
Minimum length of a straight/radius end projection should be equal to two times its width.	To reduce the tooling cost.
Minimum distance between the edges of two projections should be equal to two times the material thickness. 	To avoid distortion.

Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

Guideline	**Importance**
Relief cut-out	
Minimum widths of relief cut-outs at the end of bend lines which terminate at internal corners in the blank profile should be equal to twice the material thickness each. Minimum lengths of relief cut-outs at the end of bend lines which terminate at internal corners in the blank profile should each be equal to the material thickness plus the bend radius.  	To eliminate tearing.

Guidelines for designing evaluation modified from the article of Ramana and Rao 2005 (pp. 3895-3903, modified).

Guideline	Importance
Bend	
Number of bend stages in a part should be kept to a minimum. This number can be reduced by reducing the number of multiply-connected plates. The number of multiply-connected plates can be reduced by redesigning the part.  Redesigning could be done either by eliminating some of these plates if they are not functionally important, otherwise the multiplicity in connections of the plates is to be reduced without any plate elimination.	
Multiple bends on the same plane should be in the same direction. 	Direct bending die is the most economical die to form a bend.
Return bends directed toward the work piece are avoided. 	Return bends create the need for added dies or die stations, which increase both fixed and variable costs. A return bend directed away from the work piece can be incorporated into the tooling at nominal cost.
Bend angle should preferably be 90º Minimum distance between a bend and the adjacent edge of the blank should be equal to four times the stock thickness plus the bending radius. 	Otherwise this could cause distortions in the part or damage to tooling or operator due to slippage.

Interview Question Pattern.

<u>PDM system vendor</u>

- *Users*
  - Who uses the PDM systems for designing sheet metals? References needed/wanted.
- *Requirements*
  - How the PDM system's requirements are defined when the system is supposed to purchase? How do the design programs fuse together with the PDM system?
  - What kinds of things are demanded from the PDM system?
  - What has to be done if the company wants to use a PDM system (installation, what kind of equipment has to have etc.)?
- *Facilities*
  - What developing points do PDM systems have?
    - Are these points somehow related to the triangle (Figure 33)?
  - What can be done with the PDM system?
- *Capacity*
  - How can the information be transferred to the wanted places?
  - How do PDM systems react with different standards such as ISO-EN and SFS?
  - Can the PDM system's capacity be measured with numbers?
- *Reliability*
  - What should the data in PDM system be?
    - What is relevant information to make sure that the production goes further?
  - What is the reliability that no information has gone missing?
  - What is the overall reliability of the PDM system?
  - How about the reliability when the PDM system is updated to the latest version - does it change?
  - Reliability and validity: how can it be made sure that the drawings come to other designers on time and the drawing is always the latest version?
- *Cost efficiency*
  - How is efficiency measured?
  - Can different kinds of statistics be retrieved from the PDM system, such as how many drawings have been created in certain time period?

Design software vendor

- *Users*
  - In what kind of field are you working?
  - What PDM system do you have and what kinds of design software are in use?
  - If something has been designed wrongly normally, the software will inform the designer with a red alarm. However, there are still things that the design software is not checking at all. What kind of freedoms do the designers have when choosing different designing and manufacturing parameters?
- *Requirements*
  - How the design program's requirements are defined when the system is supposed to purchase?
  - How the PDM system's requirements are defined when the system is supposed to purchase?
  - How do the design programs fuse together with PDM system?
  - What has to be done if the company wants to have a design program (installation, what kind of equipment is required etc.)?
- *Reliability*
  - Where do the material parameters come from? Are they related to the used machines or are they related to material batch?
  - What kind of parameters are there when talking about sheet metals? Where these parameters are based on?
  - Is the latest version of the program automatically updated to the computers? Do you know if the material library updates at the same time?
  - How about the reliability when the program is updated to latest version -does it change?
- *Cost efficiency*
  - How is efficiency measured?

<u>Sheet metal designers who use PDM</u>

- *Users*
  - In what kind of field are you working? What PDM system do you have and what kinds of design software are in use?
  - How much of the work concerns sheet metals?
  - What are the volumes for sheet metal products?
  - Are you using the design software's basic library? Do you make sure that the library's parameters are correct according to the used materials and machines?
  - If something has been designed wrongly, normally the software will inform the designer with a red alarm. However, there are things that the design software is not checking at all. What kind of freedoms do the designers have when choosing different designing and manufacturing parameters?
  - How this simple (Figure 34) part is going to be manufactured?
- *Requirements*
  - Products have certain demands. How are these demands marked on the drawings to make sure that the information also goes to manufacturing? Do these demands come from somewhere else or do the designers develop them by themselves?
- *Facilities*
  - What developing points do PDM systems have?
    - Are these points somehow related to the triangle (Figure 33)?
- *Capacity*
  - What kinds of things are demanded from the PDM system?
    - What can be done with the PDM system?
- *Reliability*
  - Where do the material parameters come from? Are they related to the used machines or are they related to material batch?
  - What should the data in the PDM system be?
    - What is relevant information to make sure that the production goes further?
    - Is there some kind of irrelevant information that just is in there?
    - How reliable is the information and what is this based on?
- *Cost efficiency*
  - How is efficiency measured?

<u>Company which is manufacturing and designing sheet metal products (Company X)</u>

- *Users*
    - In what kind of field are you working? What PDM system do you have and what kinds of design software are in use?
    - How much of the work concerns sheet metals?
    - What are the volumes for sheet metal products?
    - Approximately, how many dud parts are produced?
- *Requirements*
    - How the PDM system's requirements are defined when the system is supposed to purchase? How do the design programs fuse together with the PDM system?
- *Facilities*
    - Where does the feedback from the customers go? Does it go to the PDM system?
    - How are the manufacturing drawings transferred to production?
    - How does the feedback go from production to the engineers?
- *Capacity*
    - How have the PDM systems been selected?
        - What were the criteria?
        - How many systems were compared?
    - How do PDM systems react to product families?
- *Reliability*
    - What kinds of problem situation have occurred when manufacturing sheet metal products?
    - What should the data in PDM system be?
        - What is relevant information to make sure that the production goes further?
        - Is there some kind of irrelevant information that just is in there?
        - How reliable is the information and what is this based on?
- *Cost efficiency*
    - How is efficiency measured?

PC support who has experience installing the design programs

- *Users*
    - In what kind of field are you working? Have you installed any PDM systems?
    - You are working as PC support. What does this entail?
    - How much can the program user change the program setting?
- *Facilities*
    - How do you get the information about what kinds of add-ons have to be installed in CAD programs?
- *Capacity*
    - What has to be done before it is possible to install a program? (Installation procedure, what kind of equipment is required etc.)?
- *Reliability*
    - Different kinds of design software are included in material libraries; do you know where this information comes from
        - Who is updating this material information?
    - When the new version of the program is installed, is the material library also updated?
    - How can reliability be specified? What happens during black outs?

Academic person who is familiar with PDM systems

- *Requirements*
    - How the PDM system's requirements are defined when the system is supposed to purchase? How do design programs fuse together with the PDM system?
- *Facilities*
    - Can the PDM system be used in other ways than just as a documentation vault?
- *Reliability*
    - How can reliability and validity be measured in a PDM system?
- *Cost efficiency*
    - Are there any tools to measure the meaning of these sectors in this triangle (Figure 33)?
    - What are the benefits in Euros when a company starts to use a PDM system?
    - How is efficiency measured?

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