Implementation of SolidWorks Costing

The Implementation Process and Cost Estimation in Sheet Metal Industry

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KTH Industrial Engineering and Management

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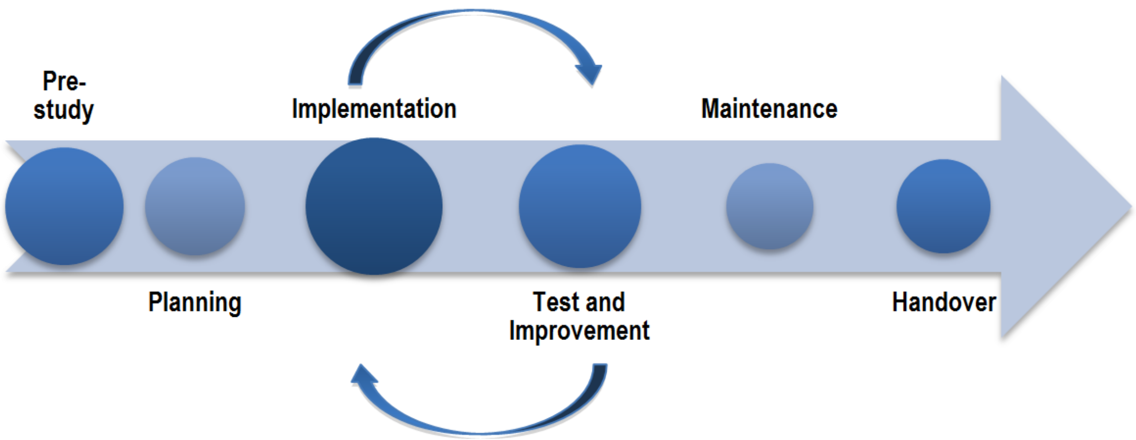

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Implementering av SolidWorks Costing

- Implementationsprocessen och kostnadsuppskattningar i plåtbearbetningsindustrin

Anna Holmberg

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Godkänt	Examinator	Handledare
2012-06-15	Lars Hagman	Diana Malvius
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Sammanfattning

Produktkostnader är idag en viktig faktor som bestämmer både företags konkurrenskraft och lönsamhet. Både tillverkare och konstruktörer kan påverka produktkostnader, antingen genom att bestämma tillverkningsmetoder eller konstruktioner för produkter. Lyckade beslut leder till fler ordrar eller fler sålda produkter, men för att rätt beslut ska göras behövs snabba och tillförlitliga kostnadsuppskattningar. För att underlätta detta beslutstagande har SolidWorks utvecklat en ny modul, SolidWorks Costing, som snabbt gör kostnadsuppskattningar baserade på geometrier av 3D-modeller direkt i CAD-programmet SolidWorks.

Detta examensarbete utfördes på uppdrag av SolidEngineer, SolidWorks återförsäljare. Syftet med examensarbetet var att utvärdera implementationsmöjligheterna av SolidWorks Costing. Möjligheterna undersöktes genom att studera hur kostnadsuppskattningar gjordes i industrin och SolidWorks Costing samt genom att utveckla en implementationsplan för programmet. En förstudie gjordes för att undersöka programmets funktionalitet. Kostnadsuppskattning för plåtbearbetning valdes att undersökas vidare och implementeras. Intervjuer med företag inom plåtbearbetningsindustrin gjordes för att ta reda på nuvarande metoder för kostnadsuppskattningar och två pilotstudier gjordes tillsammans med två partnerföretag för at testa implementation av SolidWorks Costing.

Intervjuerna visade att även om alla de intervjuade företagen använde sin egen metod för kostnadsuppskattning, använde de sig av samma parametrar när kostnader uppskattades. De nuvarande metoderna var ojämna och tidskrävande, trots detta hade tillverkarna full tilltro till dem och var skeptiska till att använda datoriserade kostnadsuppskattningar ända till pilotstudierna gjordes. I fall 1 blev den genomsnittliga skillnaden mellan SolidWorks Costings resultat och företagets efterkalkyler 9 %, för fall 2 gav SolidWorks Costing samma resultat som företaget. Båda partnerföretagen var nöjda med resultaten och partnerföretag 2 övervägde permanent implementation av SolidWorks Costing. Baserat på erfarenheterna från pilotstudierna och insamlingen av implementationsteorier togs även en implementationsplan för SolidWorks Costing fram.

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Approved	Examiner	Supervisor
2012-06-15	Lars Hagman	Diana Malvius
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Abstract

Cost of products is an important factor for a company's competitiveness and profitability. Both manufacturers and designers could affect product costs, either by deciding the manufacturing methods or the design of products. Right decisions will win orderings or sell products, but for right decisions to be taken, quick and accurate cost estimations are needed. To facilitate the cost estimation process, SolidWorks developed a new module, SolidWorks Costing, which performs quick cost estimations based on the geometry of 3D-models directly in the CAD-software SolidWorks.

This master thesis was commissioned by SolidEngineer, SolidWorks' reseller. The purpose of this thesis was to find the implementation possibilities of SolidWorks Costing. The possibilities were investigated by studying how cost estimations were made in industry as well as in SolidWorks Costing and by developing an implementation plan for the software. In the pre-study, the functionality of the software was investigated. Cost estimation for sheet metal was further studied and implemented. Interviews with companies in the sheet metal industry were performed to find how cost estimations were currently made, and a case study with two partner companies was performed to test the implementation possibilities.

The interviews showed that even if all interviewed companies used their own methods, all companies used the same parameters to estimate production costs. The current methods were irregular and time-consuming; still the manufacturers trusted them completely and were skeptical to computerized cost estimations until the case study was performed. In Case 1 the average accuracy of SolidWorks Costing was 9 % compared to the company's actual cost calculations, meanwhile the accuracy of Case 2 was the same as the company's cost estimations. Both partner companies were satisfied with the results and case study partner 2 considered permanent implementation of the software. Based on the experience from the case study and gathered implementation theories, an implementation plan of SolidWorks Costing was also developed.

Preface

This research is the final element in the Master of Science in Mechanical Engineering, Integrated Product Development at KTH. The research has been performed partly at SolidEngineer in Täby, partly at partner companies in the sheet metal industry. It has been an interesting journey and great learning experience to perform this thesis. We have grown experience and understanding in areas as sheet metal processing, cost estimations, software implementation, as well as working with larger projects. We would like to thank everyone involved to make this project possible, especially:

The colleagues at SolidEngineer for their warm welcoming of us at the company, especially Björn Lindwall, Karin Lindwall, Mie Sörquist and Daniel Hansson, for leading us in the right direction and proposing new interesting angels to investigate for the research.

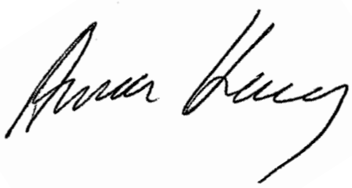
All the interviewees who took time to talk with us and provided us with invaluable information. A special thanks is directed to our partner companies, who let us into their workshops and showed us how sheet metal processing is made in real life as well as letting us use their cost data in the case study.

Professors at Machine Design Department at KTH, especially Lars Wingård, for the consultation in sheet metal processes and planning of this project.

Finally we want to thank our examiner Lars Hagman and our supervisor Diana Malvius for proofreading our report, pushing us to use relevant methods and create a clear structure for this research.

Stockholm, June 2012

Anna Holmberg and Amy Zhu



Glossary

Andragogy	Learning strategies focused on adults
CAD	Computer Aided Design, software for designing and modeling in a 3D-environment
CAE	Computer Aided Engineering, software for movement and simulation analysis in CAD
CAM	Computer Aided Manufacturing, software which provides material for manufacturing, as NC-code, from a CAD-model
IDEFØ	Integration Definition for Function Modeling, method to describe activities in a system or process
KBE	Knowledge Based Engineering, software which handles collected material of product variants, drafts and quotes
KTH	Royal Institute of Technology, where this master thesis was performed (In Swedish: Kungliga Tekniska Högskolan)
PDM	Product Data Management, software that provide a structure for CAD-model data management
PLM	Product Lifecycle Management, software that handles product data through the products life cycle
RDI	Result-Driven Incrementalism, implementation method that uses small feedback cycles

Economic Expressions

Actual cost calculation	A cost based on documented facts from the manufacturing of a product
Cost estimation	An experience based guess of the cost
Quote	Pricing process based on cost estimations and market prices

SolidWorks Expressions

Assembly	A collection of part files which are built together to make up a product
Costing template	A customizable cost database which is used for making cost estimations in SolidWorks Costing
Feature	A single element of a part, could be for example an edge or face
Part	A single detail which is drawn and saved as a part file

Production Methods

Bending	Shaping of sheet metal by straining the sheet around a straight axis.
Laser cutting	Method where details are cut out by a high-power laser.
Nesting	Method for maximizing how many details that can be fitted into one sheet of metal.
Punching	Cutting method where a tool is stamped through the metal sheet. The shape of the tool forms the shape of the hole.

Table of Contents

1. Introduction

Today, the cost of products lies in the center of industry's attention. In order to launch successful products, product and lifecycle costs are as important as product quality and functionality. (Layer et al., 2002)

With the desire of keeping cost down and the pressure of increasing competition, designers have to develop more time- and cost effective ways of developing products (Layer et al., 2002). Also manufacturers are interested in the cost of products because manufacturers need to deliver fast and accurate quotes. A fast response alone might get the manufacturer orders, but underbidding will hurt the profit as well as the credibility of the company and overbidding might mean losing customers (Veeramani & Joshi, 1997).

One way to achieve time- and cost-savings is investing in software. Software usage provides streamlined business processes, supports decision-making and gives competitive advantages (Chen & Norman, 1992). SolidWorks Costing is such software. It comes with SolidWorks 2012 and helps the software users to make well-based cost estimations directly from the 3D-model (SolidWorks, 2012a).

1.1. Background

To respond to the industry's demand of well-functioning cost estimation software, the reseller of SolidWorks in Sweden, SolidEngineer has proposed this master thesis to investigate the functionality and implementation possibilities of SolidWorks Costing in Swedish industry. In this chapter, basic information of the company SolidEngineer, the company behind SolidWorks and SolidWorks Costing as well as the software SolidWorks Costing, is described to reach a better understanding of this master thesis.

1.1.1. SolidEngineer

This thesis is performed at SolidEngineer in Täby, Sweden. SolidEngineer was founded in 1996 by Björn Lindwall and has today around 900 customers spread around northern Europe all in the industry sector. The company has around 30 employees and a total of seven offices in Sweden including a head office located in Täby. (SolidEngineer, 2012a)

SolidEngineer offers solutions for more cost effective and innovative product development, which include software for product development and management as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Knowledge Based Engineering (KBE) and Product Data Management (PLM). SolidEngineer also offers inspiration to successful practice of this software by providing educational programs and possibilities to reach a support office. (SolidEngineer, 2012a)

1.1.2. SolidWorks and SolidWorks Costing

SolidWorks is 3D-software, which includes CAD, Product Data Management (PDM) and simulation and sustainable design (Therrien, 2011). The software is developed by Dassault Systèmes SolidWorks Corporation. This company was founded in December 1993 and has now its headquarters in Waltham, Massachusetts, USA and also 23 local offices worldwide. SolidWorks is used in for example industrial, medical, scientific and consumer areas. (SolidWorks, 2011b)

As seen in Figure 1 Dassault Systèmes provides for a wide range of products (Dassault Systèmes, 2012). There are three versions of the 3D CAD-software SolidWorks: Standard, Premium and Professional. The two latter contains the new cost estimation tool, SolidWorks Costing. (SolidWorks, 2012b) That is focus of this thesis.

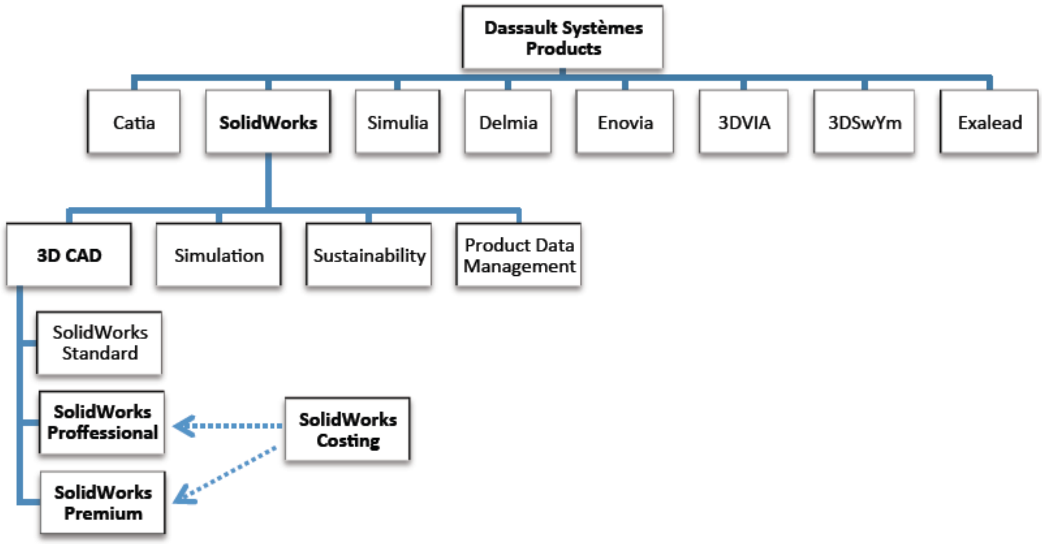


Figure 1. *Products supplied by Dassault Systèmes*

SolidWorks Costing makes it possible to calculate the cost of parts manufactured from sheet metal and machined parts by inserting data such as specified material type, manufacturing process and associated costs of these materials and operations. It is also possible to see cost updates directly in the program right after model inputs as size or material are changed. (SolidWorks, 2012a)

1.2. Problem Description

Investing in software is an effective way of facilitating cost estimations, but software is also a major investment and a large cost factor in many organizations. The implementation and management of this kind of system has become important, this to take advantage of the software's advantages, to make cost efficient products and thereby make good use of the organization's initial investment. (Chen & Norman, 1992)

To convince industry to use cost estimation software, the software's efficiency has to be well proved. Since SolidWorks Costing is newly released in 2012, it is unknown by the industry. There is hardly any record of the software's benefits and there are no implementation instructions. A functionality review of SolidWorks Costing and the implementation possibilities of the software therefore need to be analyzed to facilitate the use and maintenance of SolidWorks Costing.

1.3. Aims

The aim of this research is to investigate cost estimating methods in industry and the implementation possibilities of SolidWorks Costing in industry by SolidEngineer. The aim can be formulated as questions categorized into three areas:

Cost estimation in industry

I. How is cost estimation in industry made now?

II. Which aspects are the most important in a cost estimation process?

Cost estimations in SolidWorks Costing

III. What is the functionality of SolidWorks Costing?

IV. What are the benefits and limitations of SolidWorks Costing compared to using existing methods of estimating manufacturing costs?

Implementation of SolidWorks Costing

V. How should a SolidWorks Costing implementation plan for SolidEngineer look like?

VI. What kind of problems could occur during the implementation and maintenance of SolidWorks Costing, and what solutions are there to avoid the problems?

1.4. Delimitations

The user interface of SolidWorks Costing will not be analyzed or improved in this study and other modules in SolidWorks than SolidWorks Costing will not be evaluated. Neither will similar modules in other CAD-programs or usage of SolidWorks outside Sweden be researched.

There will be no actual development of the software during the thesis. However, this study includes providing suggestions of improvements that could be used by Dassault Systèmes SolidWorks Corporation to update the software until next software release in 2013.

2. Methodology

This chapter presents the theory and applications of the different methods used in this research. The overall work procedure was based on Integration Definition for Function Modeling (IDEFØ) to visualize and thereby facilitate activity planning. The first section presents an IDEFØ-diagram of the activities performed during the research and the structure of this report. The following sections describe the methods frame of references, interviews and case study, and how they were applied in the research.

2.1. IDEFØ

The method Integration Definition for Function Modeling (IDEFØ) was chosen to visualize the research structure and thereby secure fulfillment of the aims stated in Chapter 1.3. IDEFØ is a method to describe decisions, actions and activities of a system or process. The method is part of the modeling language family Integrated Definition (IDEF); and built on Structured Analysis and Design Technique (SADT). Use of the IDEFØ-method facilitates functional analysis of systems and communication between analysts and the customers. When developing new systems, IDEFØ is used to define requirements and specify functions, which then is used to design an implementation plan, which fulfills the requirements and performs the functions. An IDEFØ-diagram is based on box and arrow graphics. The function is shown as a box and interfaces to or from the function shown as arrows. When a function is connected to another, the boxes are connected with these arrows. (IDEF, 2010) The basic building blocks of IDEFØ are shown in Figure 2.

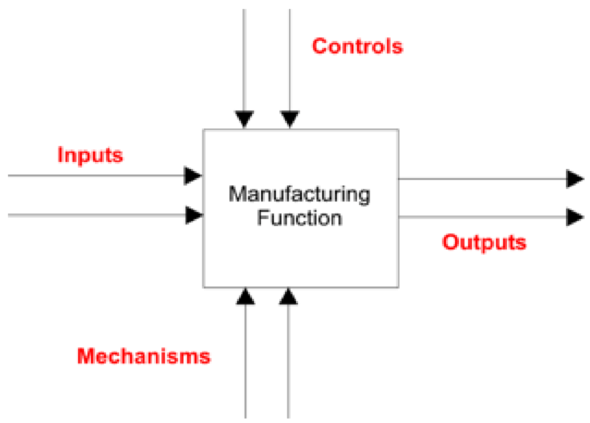


Figure 2. *The basic function regulations in IDEFØ (IDEF, 2010)*

The diagram for this research inspired by the IDEFØ-structure is shown in Figure 3. The figure shows the order and dependencies of this research's activities and how the activities and the blocks pre-study, conduction and analysis are connected to the aims. The order of the activities also corresponds to the structure of this research, see Table 1.

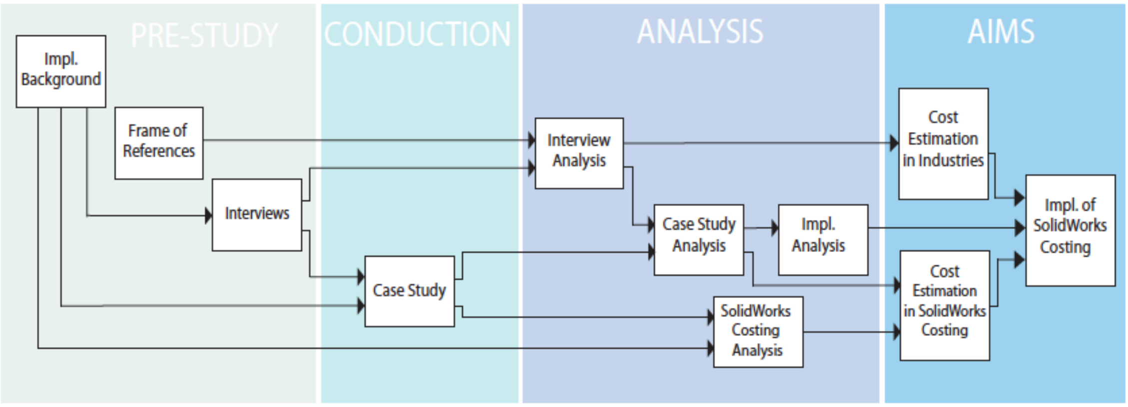


Figure 3. *The application of an IDEFØ-structure in this research*

Table 1. *The research's activities based of Figure 3 and the thesis corresponding chapters.*

Activity Block	Chapter
Pre Study	3. Implementation Background 4. Frame of References 5. Interview Results
Conduction	6. Case Study Results
Analysis	7. Interview Analysis 8. Case Study Analysis 9. Cost Estimation in SolidWorks Costing 10. Implementation of SolidWorks Costing
Aims	1.3. Aims

The pre-study included three activities. First activity, the implementation background for SolidWorks Costing was investigated in order to find possible interviewees and make an analysis of SolidWorks Costing. The background therefore included; test of the SolidWorks Costing's functionality, background research of SolidWorks Costing's development and an investigation of existing implementation models at SolidEngineer. The second activity, research of published work, was performed to have a frame of references for comparison and analysis of results. And the third activity, interviews, was performed in order to get an overview of how cost estimations in industry are made now, and also performed as a pre-investigation for the case study.

The conduction block included one single but time-consuming activity, a case study. The case study was set as an experiment of implementing SolidWorks Costing at two companies. The case study also functioned as an information source to develop an implementation plan.

The analysis block accordingly included analysis of the collected material from interviews, case study and frame of references to fulfill the aims of the research.

2.2. Frame of Reference

A frame of references was, as presented in Figure 3, a part of the pre-study block. Information was gathered to enable comparison between a theory base and the research results from interviews and case studies.

A frame of references, according to Taylor (n.d.) and The Writing Center (2011), is a gathering of collected information from published researchers and scholars. The information should be evaluated, summarized and analyzed according to the objective of the research conducted, the controversy of the literature should be identified and the questions for further research formulated. The purpose of the literature review is to inform readers of what knowledge that have been published on a topic, and which strengths and weaknesses these existing publications have.

The frame of references was gathered from three main areas, which can be seen in Figure 4. The first area was different methods of doing cost estimations. The area was investigated to find existing cost estimation methods, what they had in common and which elements that was required in a cost estimation method. The second area was implementation methods in order to find examples of existing methods and which problems that normally occurs during the process and which solutions that exist to these problems. The third area was learning styles and pedagogic. The third area was researched in order to find how education and support services as well as the implementation process should be shaped to create as good possibilities for the use of SolidWorks Costing as possible and also prevent misuse and discontinued use of the same software.

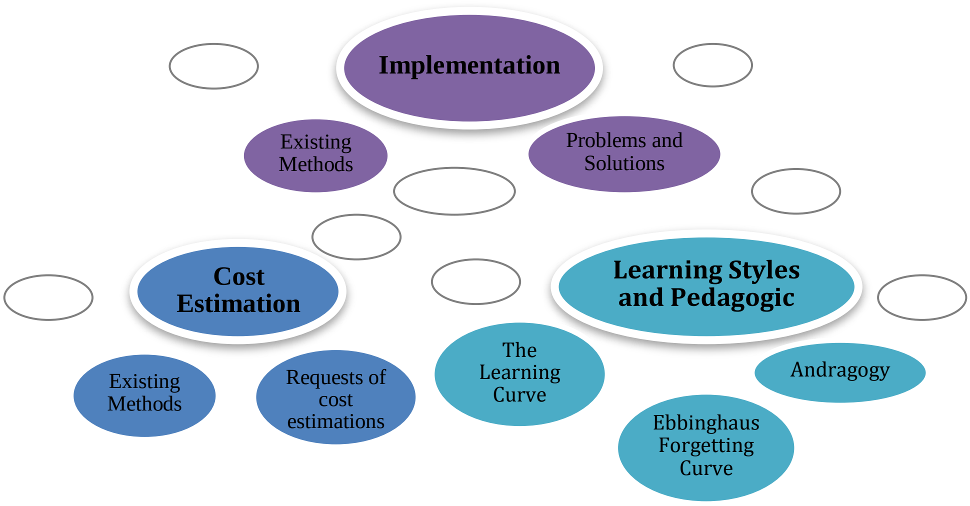


Figure 4. *The chosen literature areas for this research*

2.3. Interviews

Interviews were in this research used to learn how and why cost estimates are performed in industry today, what industry thinks about SolidWorks Costing and which functions that are needed in cost estimation software. The interviews were part of the pre-study block of the structure of this research as presented in Figure 3.

According to Osvalder et al. (2008, pp. 471-473) an interview is a qualitative method for collecting information of people's thoughts and beliefs. The procedure includes an interviewer, which speaks directly to and questions an interviewee. It can be performed in many ways, from a closed, fixed-response interview, which just leaves the interviewee the opportunity to choose from a few preset answers, to the informal interview, which includes no structure and is quite similar to a normal conversation. This research was chosen to use semi structured interviews as this method both have a preset structure to follow and also leaves the interviewer the possibility to change focus during the interview to investigate new more interesting angles.

Kvale (1996) describes a seven-step interview method, which stretches from planning till report. The particular method was used in this research. The included steps in Kvale's method and the corresponding chapters in this research can be seen in Table 2.

Table 2. *Kvale's seven step interview methodology and the corresponding chapters in this report*

Interview Steps (Kvale, 1996)	**Corresponding Chapter in this Report**
1. Formulate the purpose of the interview.	2.3. Interviews
2. Design how the interview will be held.	2.3.1. Interview Preparation
3. Execute the interviews based on an interview guide.	2.3.2. Interview Conduction
4. Write down the interview.	5. Interview Results
5. Analyze the material.	7. Interview Analysis
6. Analyze the reliability and validity of the results.	11. Discussion
7. Communicate the findings in written form.	This report

2.3.1. Interview Preparation

Preparations were done before conducting the interviews; this to make sure the interviews would be time-effective and fulfill their purpose in this research. Amongst others, the criteria of suitable candidates for the interviews were listed, followed by a selection of interviewees and creation of an interview guide.

Criteria of Interviewees

The interviewees needed to be familiar with the software SolidWorks, to have better understanding of the vocabulary and interface used in SolidWorks Costing. Also, the interviewees needed to be specialists in the same areas as SolidWorks Costing's functional areas, so that a fair comparison between different cost estimation methods could be made.

Selection of Companies and Interviewees

The first selection of companies was done with help from marketing engineers at SolidEngineer, who made a search among their clients to see which companies that could be relevant for this research. Among the 16 possible companies suggested by the marketing engineers, a further selection was made based on the interviewee criteria.

In the end six companies were interviewed, see Table 3. The first intention was to interview more companies but as coherent answers were given from all the companies more interviews were considered redundant. The interviewed companies had varied size, business focus and were spread around mid-Sweden. Among the companies, totally fourteen persons were interviewed. These interviewees were categorized into two groups, manufacturers and designers, dependent on if their cost estimates were used for quotes or design decisions. The manufacturers were CIO: s, production planners, purchasers or project managers. The designers were thus mainly designers. The interviewed manufacturers at each company are in Table 3 shown as squares and designers as round dots.

Table 3. *Selection of the interviewed companies and interviewees*

Company	Turnover (kSEK)	Profit Margin	Business Focus	Manufacturers	Designers
1	< 50 000	10%	Manufacturing	■■	●
2	< 50 000	15%	Prototype Manufacturing	■	
3	50 000-100 000	3%	Development and Manufacturing	■	
4	50 000-100 000	5%	Development and Manufacturing	■	●●
5	< 50 000	5%	Development and Manufacturing	■■	
6	> 100 000	5%	Development and Manufacturing		●●●●

Interview Guide

An interview guide was developed and used as a framework for the interviews. The questions in the interview guide were related to how cost estimation procedures at the company were managed, what data they used and which expectations they had of a cost estimation procedure. For the complete interview guide, see Appendix 1. Interview Guide.

Preparation of the Interviewee

The main questions from the interview guide were sent to the interviewee before the interview. In some cases a SolidWorks Costing video concerning use and benefits of the software was also sent. The questions and video were sent so the interviewees could have the possibility to prepare in order to better answer the interview questions, but the preparation was optional.

Demo

A sheet metal demo in SolidWorks Costing was made to show the functionalities of the software in case the interviewees had not used SolidWorks Costing before the interview. The demo was presented to the interviewees on a laptop where different commands were gone through and shown in their context directly in SolidWorks. The demo part can be seen in Figure 7.

2.3.2. Interview Conduction

In total, nine interviews were held. Three interviews were held on site at the company. Here the number of interviewees per interview varied between two to four persons and the time taken between one and a half to two and a half hours. The remaining six interviews were held by phone due to travel limitations. The phone interviews were held with one person at a time and lasted between 30 minutes to an hour. The time difference between phone and on site interviews was due to the demo showcase and tour of the company facilities which were included with all the onsite interviews but not with the phone interviews.

2.4. Case Study

To develop the implementation plan for SolidWorks Costing, a case study including two cases was done onsite at two companies in the sheet metal manufacturing industry. There were both similarities and differences in the companies' business and manufacturing processes to avoid providing a generalized conclusion from a single case.

A case study is an ideal method when undertaking a holistic investigation. By using multiple data sources, it is possible to bring out the details of the participant's viewpoints (Feagin et al., 1991). According to Yin (1993) and Stake (1995), there are six specific types of case studies: *Exploratory, Explanatory, Descriptive, Intrinsic, Instrumental* and *Collective*. In this thesis, the case study is instrumental, and used to find similarities between cost estimating in industry and SolidWorks Costing and thereby develop a user adapted implementation plan.

This thesis followed the four stages of the case study methodology by Yin (1984). The corresponding chapter of each stage is shown in Table 4.

Table 4. *The case study methodology and the corresponding chapters*

Case Study Methodology (Yin, 1984)	Corresponding Chapter in this Report
1. Designing the case study protocol	2.4.1. Case Study Preparation 2.4.2. Case Study Conduction
2. Conduct the case study	6. Case Study Results
3. Analyze the evidence of the case study	8. Case Study Analysis
4. Develop conclusions, recommendations, and implications based on the evidence	10. Implementation of SolidWorks Costing

2.4.1. Case Study Preparation

According to the first stage of Yin's (1984) case study methodology, a case study protocol was designed. In the protocol, the background of the case study, the design, case study partner selection, procedure, data collection, analysis and limitations were presented. To view the case study protocol, see Appendix 2. Case Study Protocol.

2.4.2. Case Study Conduction

The second stage of Yin's case study methodology was conduction of the case study (Yin, 1984). During the conduction of the cases, possible difficulties and problems could occur as well as action plans could be found. Both problems and solutions could be used to make the implementation plan more complete.

The first step of the case study conduction was to collect material- and operation cost data. The needed data were collected on-site while performing the cases. In order to select relevant data the most commonly used operations were needed. An investigation was done based on the interview results and complemented by touring the machine workshop. Based on the investigation this research was selected to study the cutting and bending operations in SolidWorks Costing.

Cost data was collected in order to find the needed parameters to put into SolidWorks Costing. Collected data came from two sources; setup costs and costs per hour of the machines were given orally from the case study partners meanwhile set up schedules and actual cost calculations were given in form of documents from earlier processed orders. The cost data was then recalculated for both material costs and cutting and bending operations to suit the templates of SolidWorks Costing.

After the SolidWorks Costing template was created, the template was tested and adjusted with help of different test parts in order to receive higher accuracy for the representative test parts. In Case 1, these test parts had already been manufactured in the machine workshop. Estimations from SolidWorks Costing were therefore compared to the actual cost estimations. In Case 2, as a result of the existing data resources, estimations from SolidWorks Costing were instead compared to the partner company's own cost estimations. For each case all operations were first compared alone, and then followed a combined comparison with all cutting and bending operations included.

Material

To calculate the material cost of a detail, the general kilo price of the material was given by the partner companies and inserted into SolidWorks Costing. Different types of materials were tested separately. Material types and numbers of tested parts in both cases are shown in Table 5.

Table 5. *Tested materials in the two cases*

Case 1		**Case 2**	
Material types	**Numbers of tested parts**	**Material types**	**Numbers of tested parts**
Aluminium	7	Steel	6
Aluminium-zink	5	Stainless Steel	3

The material cost per part from SolidWorks Costing was compared with the material cost per part from the partner companies' material cost estimation. An average percentage difference between values from SolidWorks and actual cost calculations values was found. The material kilo price in SolidWorks Costing was then adjusted with the percentage difference according to Equation 1:

$$new\ cost\ per\ kilo = old\ cost\ per\ kilo * (1 - \ average\ difference) \tag{1}$$

The new material kilo prices were inserted into SolidWorks Costing again to calculate the new material cost per part. The material costs per part were compared between SolidWorks Costing and the partner companies' actual cost calculations to find and improve the accuracy of the estimations.

Cutting: Case 1, Punching

In Case 1, cutting was done by punching. Punching is a common cutting operation, where a tool is stamped through the metal sheet in order to make a hole or cut out a shape. The shape of the tool forms the shape of the hole.

To find the average speeds of the punching machine, 136 setup-schedules of earlier manufactured orders were collected. The average speeds together with a value of the hourly labor and machine cost given from the partner company was then used to calculate the cost per punch from values in Table 6 according to Equation 2.

Table 6. *Information provided by the punch-machine's setup schedules*

Setup Schedule	Material	Material thickness	Operating time	Number of punches
Schedule ref.	...	*t*, mm	*T*, seconds	*x*, punches

$$\boldsymbol{Cost\ per\ punch} = \frac{\boldsymbol{T}}{\boldsymbol{x}} * \mathbf{3600} * \boldsymbol{cost\ per\ hour} \tag{2}$$

In order for an evaluation to be made in SolidWorks Costing the cost per punch needed to be recalculated into cost per millimeter. Therefore the values were recalculated with an estimation of the most commonly used punching tool's length according to Equation 3,

$$\boldsymbol{Cost\ per\ millimeter} = \frac{\boldsymbol{Cost\ per\ punch}}{\boldsymbol{Tool\ lenght\ (mm)}} \tag{3}$$

The punching cost was expected to rise with the thickness of the material since smaller tools and thereby more punches and more time was needed to cut the thicker sheets. Costs per punch and millimeter were calculated for different thicknesses from the setup-schedules and inserted into SolidWorks Costing. The cost estimations for cutting cost per part were then compared to the partner company's actual cutting cost estimation to find and improve the accuracy of SolidWorks Costing estimations.

Cutting: Case 2, Laser Cutting

In Case 2, cutting was done by laser. The output of a high-power laser is directed by a computer to cut out the material. The computerization secures data given by the laser machine, which was why the laser machine data was chosen to be used for Case 2. The machine data came in form of an average speed per material thickness, which also made it easy to recalculate to fit SolidWorks Costing.

The cutting speeds for different sheet thicknesses of the laser machine and the laser machine's hourly cost were given by the partner company. The laser cost per millimeter for a certain sheet thickness was calculated according to Equation 4,

$$\boldsymbol{Cost\ per\ millimeter} = \frac{\boldsymbol{laser\ machine\ hourly\ cost}}{\boldsymbol{laser\ machine\ speed}} \tag{4}$$

The costs per millimeter for different thicknesses were then inserted into SolidWorks Costing for 9 test parts. The cutting cost per part from SolidWorks Costing was compared to the cutting cost from the partner company's own cutting cost estimation to find and improve the accuracy of SolidWorks Costing.

Bending

Bending in sheet metal industry means shaping the sheet by straining the metal around a straight axis. Some examples of bending operations are flanging, hemming and seaming. The bending operation was tested in both Case 1 and Case 2.

For bending operations, cost per bend needed to be calculated to fit the structure of the SolidWorks Costing template. In Case 1, 20 test parts were used for data collection and in Case 2, 12 parts were used. The reference cost per bend was calculated according to Equation 5.

$$\boldsymbol{Cost\ per\ bend} = \frac{\boldsymbol{total\ actual\ caculated\ bending\ costs}}{\boldsymbol{numbers\ of\ approved\ parts * numbers\ of\ bends\ in\ each\ parts}} \qquad (5)$$

Since the cost of bending could depend on several different factors and as a clear connection between bending costs and a certain variable could not been seen, several variables were tested to find a connection. A linear equation and an exponential equation were created from the graphs of each variable to analyze possible connections. The tested variables are shown in Table 7.

Table 7. *The test variables used for the bending operation.*

Bending Test Variables
• The greatest length of the part • Square surface area of the flattened part • The thickness of the sheet • The total weight of the part • Number of bends in the part • The total volume of the part

Cost per bend dependent on each variable was calculated in SolidWorks Costing for the same parts used in the punching study. The total bending cost of these parts were compared to the total actual calculated bending costs, to find the variable that could give bending costs closest to the reference. Then the bending costs calculated from SolidWorks Costing dependent on this variable was compared to the reference bending costs to find and improve the accuracy of SolidWorks Costing estimates.

3. Implementation Background

An investigation of the implementation background was as presented in Figure 3, included in this research's pre-study. The implementation background was investigated to make a current situation analysis of SolidWorks Costing and SolidEngineer and thereby find the possibilities for implementation of SolidWorks Costing in industry. This chapter holds a description and evaluation of the capabilities of SolidWorks Costing, the thoughts and research behind the development of SolidWorks Costing and a description of an existing implementation model at SolidEngineer.

3.1. Functionality of SolidWorks Costing

SolidWorks Costing consisted of two main parts, a design and analysis window and cost databases called *templates*. The cost estimating possibilities in the design and analysis window are shown in Figure 5.

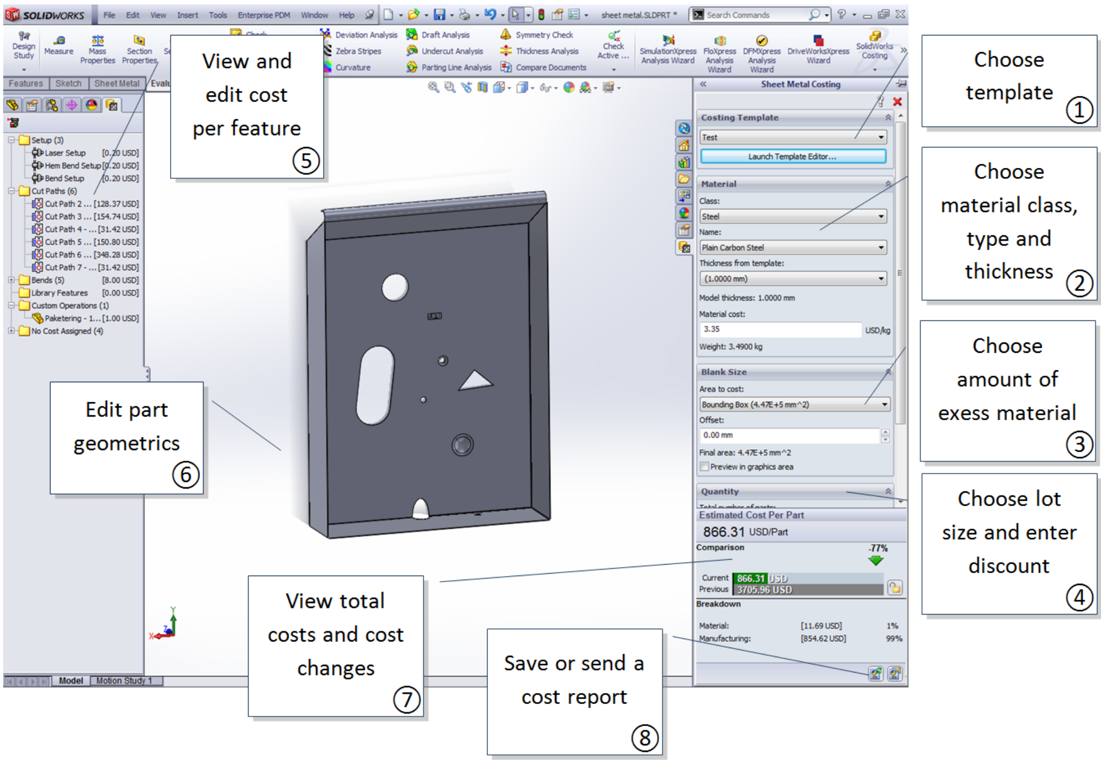


Figure 5. *To the left the design and analysis window and to the right a template*

The templates looked similar to Excel sheets and had several categories for inputs. The input categories varied between Sheet Metal and Machining Costing, see Figure 6.

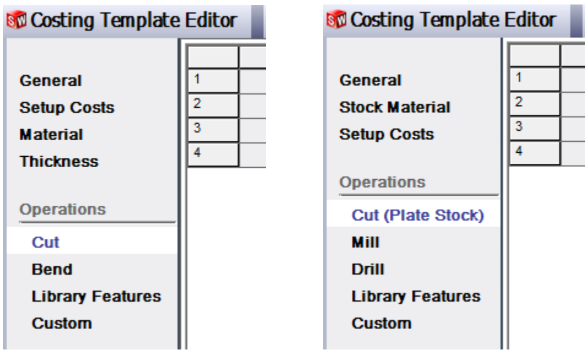


Figure 6. *Template Editor for Sheet Metal Costing (left) and Machining Costing (right)*

The needed input data for templates can be seen in Table 8. Sheet Metal Costing mainly used input in form of cost per millimeter meanwhile Machining Costing used time per millimeter.

Table 8. *Types of input that was used in Sheet Metal Costing respectively Machining Costing*

Sheet Metal Costing		Machining Costing	
Cuts	Cost/mm	Cuts	Time/mm
Holes	Cost/feature	Milling	Time/mm
Bends	Cost/feature	Drilling	Time/mm
Library Features	Cost/ feature	Library Features	Cost/feature
Custom Operations	Cost per; part, weight, area, length or feature	Custom Operations	Cost per; part, weight, area, length, feature or time

3.1.1. Estimation in Sheet Metal Costing

The capabilities of Sheet Metal Costing can be seen in Figure. The software could calculate the cost of bends, holes, cuts and library features.

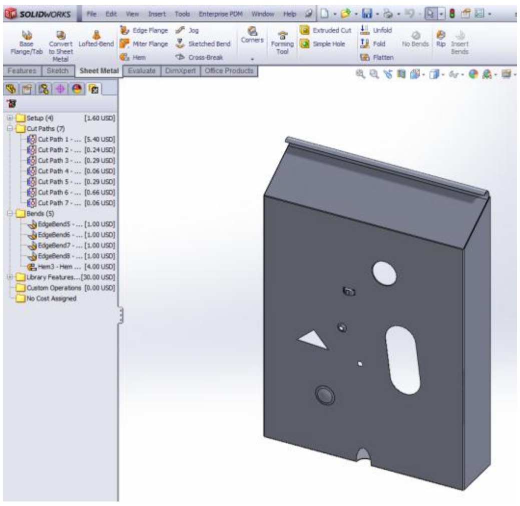


Figure 7. *Sheet metal part showing some of the possible features for cost estimates in Sheet Metal Costing*

3.1.2. Estimation in Machining Costing

In Machining Costing, the software could calculate the cost of holes; slots and pockets but there were limitations, see Figure 8. In the figure, the two slots could be cost estimated, but the middle pocket was not even recognized by the software, and the rounded edges were given no cost. As seen in the figure, the model contains five mill and hole operations, but the map tree to the left only shows four (red circle). Further is known by the software; that it was only capable of calculating cost for parts manufactured by a 2.5 axis machines, it could not turn a part and mill the opposite side, or do milling of features as edges and round shapes, neither could it make estimations of casts or extruded stock machining (SolidWorks, 2012c).

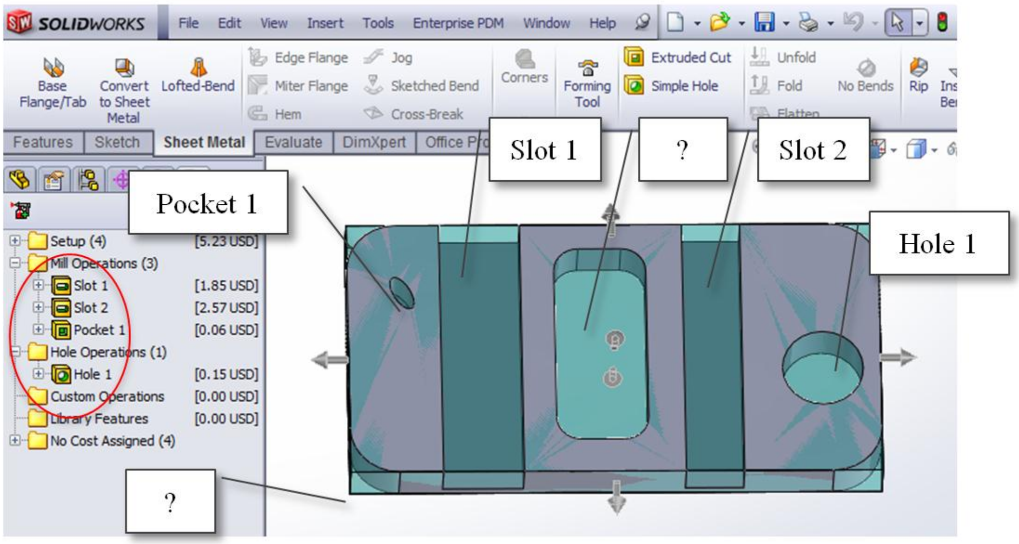


Figure 8. *Limitations in Machining Costing*

Due to the capability limits in Machine Costing, only Sheet Metal Costing was chosen to be further investigated for implementation possibilities. However, the two variants of SolidWorks Costing work similarly and have the same structure. The methods and process of implementation should be similar to both variants of SolidWorks Costing. Therefore implementing of Sheet Metal Costing should be representative of implementing both versions of SolidWorks Costing.

3.1.3. Assemblies

SolidWorks Costing was created for parts only and did not support assemblies. But the cost estimations of the individual parts in an assembly could be done in SolidWorks Costing, and then compared and evaluated in their context, see Figure 9. There was though the trouble of having to estimate the cost for each part before being able to show the result in the assembly.

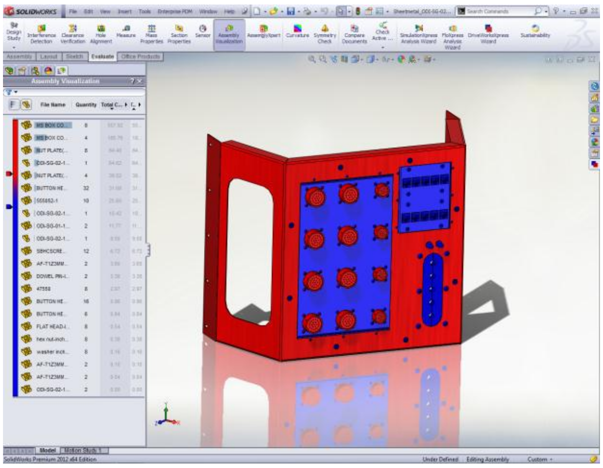


Figure 9. *Showing the cost of each part in the assembly, where red parts are more costly than the blue parts*

3.2. The Research behind SolidWorks Costing

SolidWorks realized that there was a demand for easier and faster methods for making cost estimations and quotes. After worldwide research involving surveys, case studies and observations, the relevance of a solution to the problem became clearer. (Therrien, 2012)

As Figure 10 reveals, many thinks cost estimations was too time-consuming. There were companies who used specially designed software or other automated methods, but the majority relied on spreadsheets and experience from vendors, coworkers or already processed jobs. (SolidWorks, 2011a)

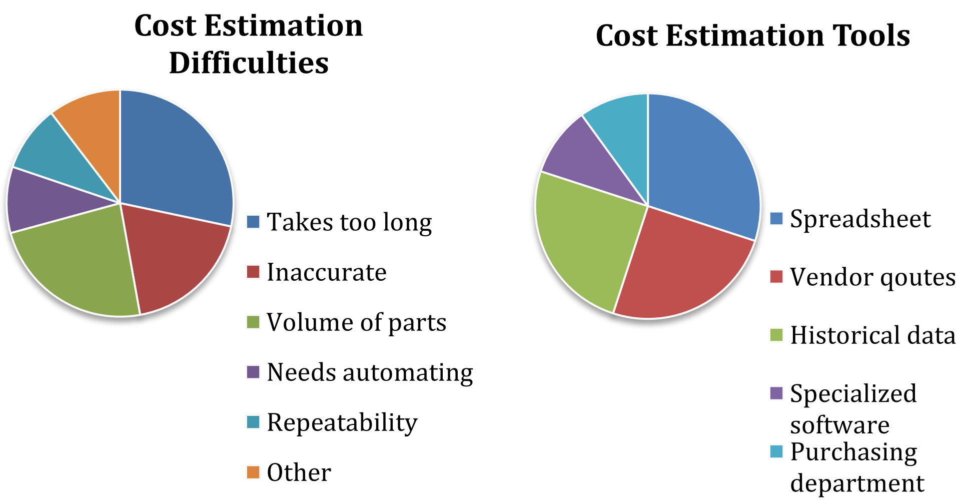


Figure 10. *The troubles and the tools for cost estimations in industry*

Amongst the existing methods for cost estimates, spread sheets were found to give the best results regarding time spent and accuracy. The spreadsheet method was simple. The costs were calculated with cost information stored in a sheet and with geometrics from the part to be manufactured. As it was, the estimator had to measure and estimate the size and weight of the part by hand, which was time-consuming. SolidWorks' CAD-system on the other hand had already this function built into the software. (Therrien, 2012)

With the spreadsheets as an inspiration SolidWorks Costing was developed. It was targeted on the user categories that did the most cost estimations, those who did quotes and those who used cost estimates for design decisions; these were managers, manufactures and designers. (SolidWorks, 2011a)

SolidWorks was developed to be easy to use. For example information that needed to be inserted into the program reminds of the values inserted into spreadsheets. As the machining manufacturers entered values as time, this is what is done in Machining Costing. Sheet metal manufacturers on the other hand inserted their values as discrete costs per length of a cut; therefore this is how it also works in Sheet Metal Costing. (Therrien, 2012)

3.3. Implementation Model at SolidEngineer

SolidEngineer already offers implementation services for different software. Their implementation model includes three steps as described in Figure 11.

Pre-investigation: Information about the specific company is researched and investigated with the purpose of custom making the implementation plan for the customer. A pilot study is also made.

Implementation: The implementation plan is executed. Adaptations to the plan have been made dependent on the pilot study.

Test: A final test of the system is made to assure the accuracy and efficiency of the system.

(SolidEngineer, 2012b)

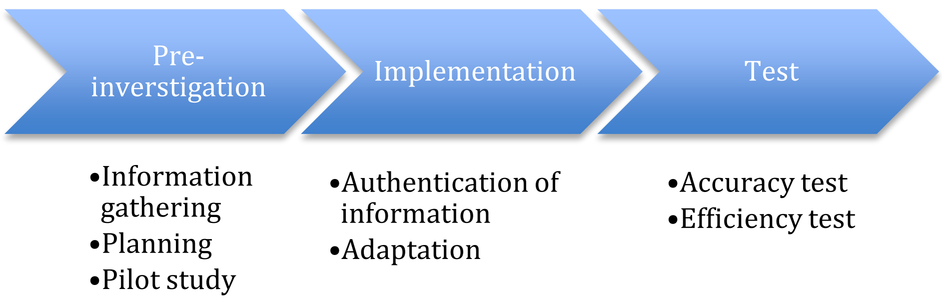


Figure 11. *Overview of the implementation model at SolidEngineer*

4. Frame of References

This chapter presents the results corresponding to the activity block frame of references presented in Figure 3. The frame of references includes three main areas of earlier published work; different cost estimation methods, implementation of software in manufacturing organizations and learning styles and pedagogic. An overview of the literature areas are presented in Figure 4.

4.1. Cost Estimation Methods

High product quality, manufacturing flexibility and low production cost are the best ways of being competitive in today's market. This means that cost estimation are always of primary concern. (Wei & Egbelu, 2000) With this in mind, this section presents different cost estimating methods for designers and manufacturers and also the requests of a cost estimation method.

4.1.1. Cost Estimation for Designers

During the design stage, as much as 80 % of the cost of a product is committed. Therefore it is essential to give designers efficient cost estimation tools (Duverlie & Castelain, 1999). However, according to Layer et al., (2002) even if it is at the design stage cost estimations should be done most frequently; the reality shows that designers generally only have their own experience to base decisions on.

Cost estimations are traditionally made at the end of the product development. This is shown in Figure 12. The feedback loop is extremely time and resource consuming. If more than one loop is required in order to reach the targeted costs for the product, the losses are even more extensive. The product may have vitally changed during the feedback loop and when information is available, necessary changes may not be able to be done. Another problem is the loss of time cause in a more demanding market, the ability to deliver and deliver fast gets more and more important. (Layer et al., 2002)

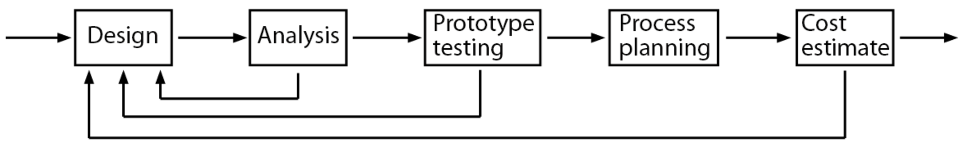


Figure 12. *Traditional engineering and traditional cost estimation system. (Wong et al., 1991)*

In Figure 13 cost estimations are done on a more regular basis making sure to develop cost effective solutions right from the beginning (Wong et al., 1991). By reducing the cost of a product at the design stage, it will assure better and less expensive results than trying to do the same at the manufacturing stage. (Feng et al., 1996) During the design stage the material is chosen, measurements set and form deliverables tested, and it is therefore it is here the decisions which will identify the product are made, and it is also here the frames for the product cost are set (Layer et al., 2002). Moreover it is during the design stage that errors as inability to manufacture and high production cost could be minimized or even eliminated (Wei & Egbelu, 2000).

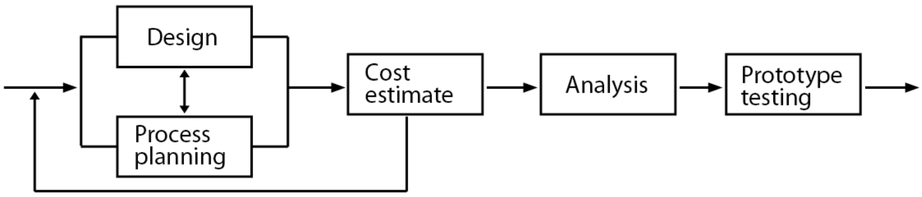


Figure 13. *Iterative cost estimation during the design stage in order to early detect and reduce cost. (Wong et al., 1991)*

Dewhurst & Boothroyd (n.d.) claim that, to make up for the demand of early design stage cost estimating, several methods have been developed. Among these are *Design for Cost* and *Design for Manufacturing,* these are powerful methods but they are merely guide lines. In order for them to work efficiently additional cost estimation tools are needed.

There are two other ways of making cost estimations during the design stage. One involves *between the fingers estimations,* which could be performed by the designers. Here the accuracy is low but on the other hand this shows fast results and could be done regularly. For more precise cost estimations usually *cost-planning department involvement* is used. This means that the designers hands a product description to the cost-planning department to perform the cost estimation. Information of the cost estimation is then sent back to the designers, which then has the task to make accordingly changes of the product depending on the results from the estimation. (Layer et al., 2002)

4.1.2. Cost Estimation for Manufacturers

To compete on the market, according to Veeramani & Joshi (1997), the ability to deliver quickly has become more and more important for manufacturing companies. This also complies with the ability to make fast and exact quotes. The time spent on making quotes have severe effect on the ability of capturing an order. It is important for the quotes to not be just fast but also qualitative. Underbidding may win the job, but may also affect the probability of the company whereas overbidding might mean loss of the job to a competitor.

Cost estimation for quotes is time-consuming and requests knowledge and experience. The resulting estimation is much dependent on the personnel available and could be distinctively (Bidanda et al., 1998). The traditional quotation process is lengthy; it contains several steps and includes several people spread over different departments, usually the product development, pricing and manufacturing departments. The quotation procedure is iterated until satisfaction with all included parts is reached. (Veeramani & Joshi, 1997) According to Wei & Egbelu (2000), right after a request from the customer is received, the process starts by investigating the manufacturability of the product. The manufacturing method is then chosen, cost estimations of the parts performed and the outcome is a quote.

4.1.3. Requirements of a Cost Estimation Method

Cost estimation methods are established in companies today, but there are still areas where improvements could be made. Layer et al. (2002) presents a number of requirements of a cost estimation method, see Table 9.

Table 9. *The requests of a cost estimation method (Layer et al., 2002)*

Requirements	Description
Easy to track	Cost estimation calculations should be easy to overview, this in order to find and eliminate unnecessary costs.
Regular cost estimations	Cost estimations should be able to be performed concurrently and on regular basis during the development phase.
Adaptable	Cost estimation systems should be able to adapt with the companies changes, for example, if the machines or tools are changed so will the system.
Estimates for complex parts	A cost estimating tool should be able to estimate costs of more complex parts.

Moreover, traditional cost estimation systems are never integrated with CAD-systems for automatic information extraction of the product parameters. They are also often slow and are thereby no effective tools for decision-making. (Wei & Egbelu, 2000)

The cost estimation systems also need data input. According to (Wong et al., 1991) a general cost estimation system consists of five steps. Meanwhile (Wei & Egbelu, 2000) means traditional cost estimating methods consist of seven steps. The two sources different cost estimation steps are presented in Table 10.

Table 10. *The needed input data when performing cost estimates according to Wei & Egbelu (2000) and Wong et al. (1991)*

Input Data (Wei & Egbelu, 2000)	Input Data (Wong et al., 1991)
• Process sequences • Machining costs • Set-up costs • Fixture costs • Material handling costs • Processing times • Hourly rates for labor and machines	• Material cost • Labor cost • Operation cost • Overhead cost • Production cost

4.2. Software Implementation

Almost all advanced production technologies today, such as CAD/CAM, workflow-management, *Enterprise Resource Planning (*ERP) etcetera, either have essential software components or are fully embedded in software (Quinn et al., 1996, pp. 11-24). There are both advantages and disadvantages in technology implementation to have broad software flexibility. It amplifies the potential benefits of IT-investments when the flexibility enables new ways of working. But it can also transform implementation projects into risky organization- or innovations changes. The users are offered a lot of different functionalities, and also have to choose wisely among these applications of strategies to complete the organizational processes and policies (Fichman & Moses, 1999, pp. 39-42).

4.2.1. Result-driven Incremental Software Implementation

According to Fichman and Moses (1999, pp. 39-42), there are two ways for software implementation – the traditional way and the incremental way, see Figure 14. The traditional implementation is characterized by a long period of selecting and confirming functionalities of the software, following by a "big-bang" finish, a concentrated interval when the whole system would be switched on. But this "all-at-once" implementation usually is not appropriate for technologies embedded in software since in many cases the big finish never occurred (Leonard-Barton, 1988a, pp. 603-631).

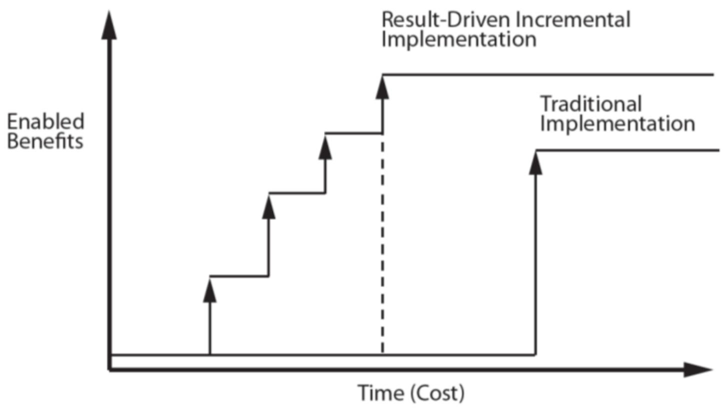


Figure 14. *Result-Driven Incrementalism versus Traditional Software Implementation (Fichman & Moses, 1999, pp. 39-42)*

The other way of implementing software is based on the principles of *result-driven incrementalism* (RDI). According to RDI, the implementation process should be divided in a series of short but intensive cycles of implementation and after each cycle a business benefit is delivered. This way software implementation can reduce the risk of failure since it promotes organizational learning, maintains focus and momentum in implementation and avoids over engineered technology solutions. When implementing a system of indivisible technology, RDI is to prefer (Fichman & Moses, 1999, pp. 39-42).

Advanced software often includes many features and data items that can behave in different ways. The implementation process involves learning and adjustment processes, the costs of these processes often exceed the costs of the technology itself (Fichman & Kemerer, 1997, pp. 1345-1363). To achieve desired implementation results, adopters need to engage in repetitive adaptation cycles (Leonard-Barton, 1988b, pp. 251-267).

Methodology and Benefits

In a RDI process, targets are linked, tactical decisions made during implementation process and project outcomes evaluated during and after the implementation process (Fichman & Moses, 1999, pp. 39-42). To specify the technology to be implemented, there are five key principles of RDI methodology to be tailored before implementation. They are:

- Use targeted business results in decision-making
- Divide the whole implementation into a series of concurring increment
- Make sure that each increment obtain the desired results
- The cycle time of each increment should be short
- Adjust the following increments by using results of each result

(Fichman & Moses, 1999, pp. 39-42)

RDI methodology provides learning-related benefits. First, sequence of learning is provided when using numerous increments and the process of learning can be divided into adaptable segments. Second, by listing targets of each increment, it is easier to see which learning is relevant and avoid over engineered solutions. Due to the short cycle time, results can be observed regularly and soon after taken actions and also, the implementation team intensively learns about each increment. At last, completing each increment lays a foundation of knowledge for the subsequent increments. (Fichman & Moses, 1999, pp. 39-42)

4.2.2. Acceptance of IT-tools

Research has shown and described several implementation problems which origins with the users' resistance to change (Joshi, 1991). These problems have many explanations, but they also have many solutions (Martiko et al., 1996; Joshi, 1991). This chapter describes some of the problems as well as the solutions.

Implementation Problems

Problems during the implementation phase for a new IT-tool can raise dependent on several sources. One source is the personality of and the natural tendency to resist change within the human. Another could be that the tool is not adapted for the users; this could be problems within the design or interface of the tool as well as the problems with functionality, accessibility and speed of the tool. (Martiko et al., 1996)

The reactions when met by a new IT-tool vary between different personalities claim Martiko et al., (1996). Either the person will accept or resist the change. The affects could be satisfaction or it could be hostility, anger, stress, fear, apprehension and anxiety. The symptoms of resistance behavior could for the latter case be; low level of use, lack of use or dysfunctional or harmful use, in short terms the tool would be used inefficient or not at all. Moreover, individuals who are the most likely to resist implementation and contribute to this negative outcome are those who believe in a negative outcome of the tool, that the tool will not be an help to them or they do not feel they understand or have the required knowledge to use the tool.

Lapointe & Rivard (2005) presents a collective view of four models of resistance of implementation. In the collective view the cause of resistance is described as a mismatch between routines of the old process compared to the implemented process. The mismatch will result in, stress and fear as well as a feeling of loss of efficiency, power and equiety.The outcome of the implementation will in such a case be negative with lack of use, misuse or no use of the new tool at all.

Solutions to Implementation Problems

Implementation problems exist, but it should be remembered that all changes do not automatically lead to resistance (Joshi, 1991). According to Martiko et al (1996), influences on a person's behavior to change can be both internal and external. External are the behavior of coworkers, the characteristics of technology and the support from management. Internal influences on the other hand are for example the person's prior experiences.

Joshi (1991) describes several solutions which could be applied on an implementation process in order to facilitate and improve the result, and promotes an introduction which includes well-designed training programs, on-demand help and extra temporary staff during the implementation.

During the process Joshi (1991) also describes it is important to emphasize the benefits of the implementation for all parts (including the company, coworkers and the customer) as well as the single person's benefits. Benefits could be:

- Saving time or reducing cost
- Working in a modern, high-tech environment
- Learning new skills

However, Joshi (1991) proceeds, it is also important to clarify the benefits of the process for the single person. This could be done by forming a positive equity in training programs and information meetings, by praise, recognition or awards as well as increasing a salary or grade. In the clarifying process, it is also important to inform of future prospects and not to forget if the implementation would mean a loss of employment.

According to an empirical study conducted in 18 manufacturing companies and interviews with 24 managers, implementation of application software could be improved by following specific rules:

- Continuous interaction between software producers and end users, and that interaction should be supported by management.
- Focus of divisions and corporate should not be overly loaded on productivity or efficiency of the software.
- There should be a support between users and the software before, during and after the software implementation. Support could be such as back-up resources, training and allowing risk-taking.
- Manufacturing and other functions should combine their efforts in planning of the implementation process and rules setting, to fulfill the corporate's overall policy.

(Geisler & Rubenstein, 1987)

4.3. Learning Styles and Pedagogic

There are different definitions of learning. Some features in most of these definitions include a process or act of gaining knowledge by study, instruction or scholarship (The free dictionary, 2012).

There are different styles of learning, three of them are described by Learning guide (2012). The first style is for auditory learners, *learning by hearing*. The auditory learners learn better when hearing things explained for them than reading by themselves. A common study method for the auditory learners is to play music in the background. The second type of learning is *learning by seeing*. The visual learners learn by watching a demonstration and graphics. But they may have a difficulty listening to an explanation while watching the graphics. The third type of learning is *learning by touching*, the kinesthetic learners learn better by actually doing an activity. They feel that writing things down makes it easier to understand.

To make the learning process more effective and improve learning results, individuals need to understand their own learning styles and habits to reveal learning strength (Cherry, 2012a). Still, a combination of multiple learning styles is recommended. According to Judy Willies (2008, pp. 31-316), "The more regions of the brain that store data about a subject, the more interconnection there is. This redundancy means students will have more opportunities to pull up all of those related bits of data from their multiple storage areas in response to a single cue. This cross-referencing of data means we have learned, rather than just memorized."

4.3.1. Learning Curve

The rate of learning is important to the learning results. A graphical representation of the changing rate of learning is called a *learning curve* and was first introduced to the aircraft industry in 1936 by T.P. Wright (NASA, 2007). Wright concluded that "consistency in improvement has been found to exist in the form of a constant percentage reduction in time required over successively doubled quantities of units produced. The constant percentage by which the costs of doubled quantities decrease is called the Rate of Learning" (Wright, 1936). This means, an initial slow increase in the beginning, followed by a rapid period of improvement, and finally grow a certain amount of knowledge (Dewey, 2007). This type of learning is also called *learning by doing*; knowledge of a given subject is acquired through a progression of steps (Hanley, 2010). When the task is repeated, the required time to perform the task decreases. As more units are produced, the amount of improvement decreases (Wright, 1936). The learning curve is shown in Figure 15.

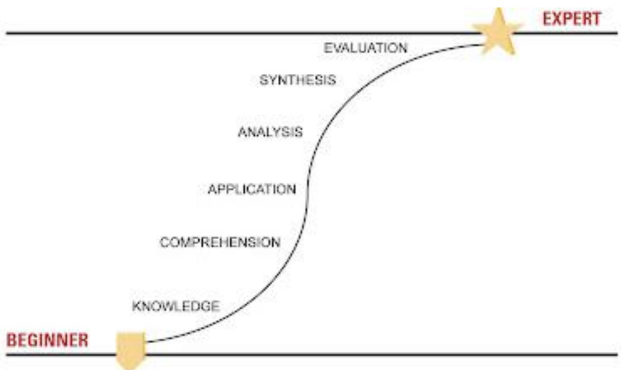


Figure 15. *The S-shaped learning curve (Hanley, 2010)*

4.3.2. The Ebbinghaus Forgetting Curve

Another learning curve used in theories of learning, is better known as the Ebbinghaus Forgetting Curve. It is a hypothesis of the exponential nature between forgetting and time by Hermann Ebbinghaus in 1885. The level of information retention depends on the strength of memory and the amount time been passed since learning (Savara, 2012). Information is often lost quickly after learning. Though the forgetting curve would change and retention of memory can be improved by frequently repetitions. And when the material is repeated multiple times, the retention will become more permanent, also more timed will be needed between reviews (Cherry, 2012b). The relation between elapsed time since learning and retention is shown in Figure 16. In the diagram to the left, the difference between learning without and with one repetition is shown, in the diagram and to the right the information has been reviewed multiple times.

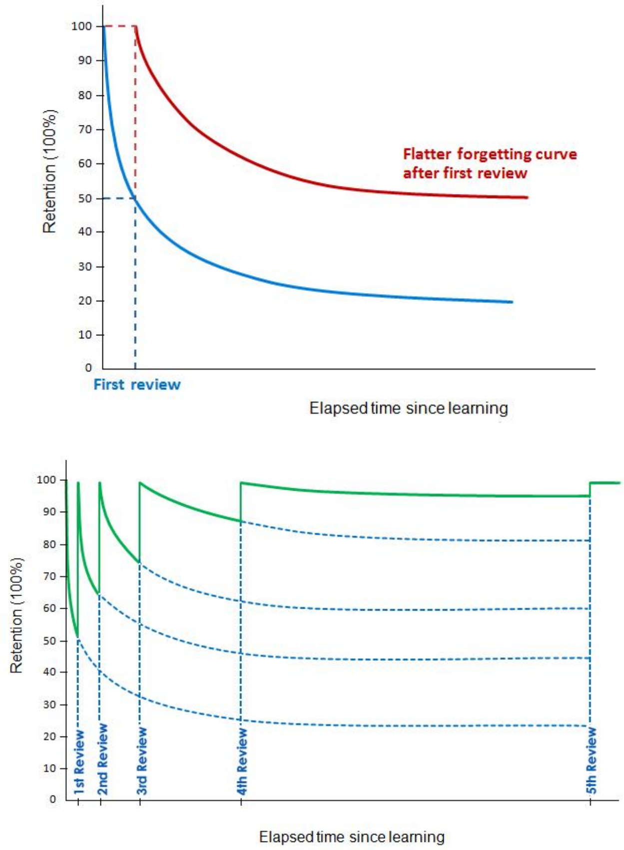


Figure 16. *Information retention after the first review to the left and after multiple repetitions to the right (Superflashcard, n.d.)*

4.3.3. Andragogy

Andragogy consists of learning strategies focused on adults (Bangaoil, 2011, pp. 14-20). Education of adults has long been different from children education in both theory and practice. In adult education, more pedagogical teaching strategies are needed (Cooper, 2009). According to Knowles Andragogy theory (Knowles, 1980), the prime objective of adult learning is self-actualization.

The assumptions of adult learning according to Knowles (1990) are:

- **The need to know.** It is important for the learners to know why before undertaking to learn it.
- **Learner self-concept**. Adult learners need to be responsible for their own decisions.
- **Role of learner experience**. One of the richest resources for adult learning is the variety of experience an adult has. However, these experiences could be imbued with bias and presupposition.
- **Orientation to learning**. If the adults can perform the confronted tasks in their life situations, they become more motivated to learn.

(Based on Knowles 1990:57)

5. Interview Results

This chapter contains the results from the interviews and is a part of the pre-study block, as presented in Figure 3. This chapter treats the subjects how cost estimations are done in industry today, the results expected from cost estimations and the difficulties in the procedure. The interviewees' opinions and requirements of SolidWorks Costing are also presented.

5.1. The Existing Cost Estimating Procedure

This section describes the purpose and necessity of cost estimations, how cost estimations are made and which resources are needed.

5.1.1. Purpose and Necessity

For the manufacturers, cost estimations were a necessity. The manufacturers had two ways of setting the price of a product. One was to refer to the market prices; the other was to do cost estimates. Cost estimates were also used to check the profitability of the jobs they performed.

The designers were less interested in cost estimates. One designer said he did not care of costs at all, the other designers said they usually spoke with the production team to find out which design was the most cost-effective. The designers did not do much cost estimations on their own, and when they did they only did quick, rough calculations. When designers wanted more exact cost estimates, they sent geometric data from the detail to the production team and got a cost estimation from production after 3-4 days.

5.1.2. The Procedure

The cost estimation procedure was basically the same on all the interviewed companies. When making cost estimates all the companies looked at the parameters shown in Figure 17.

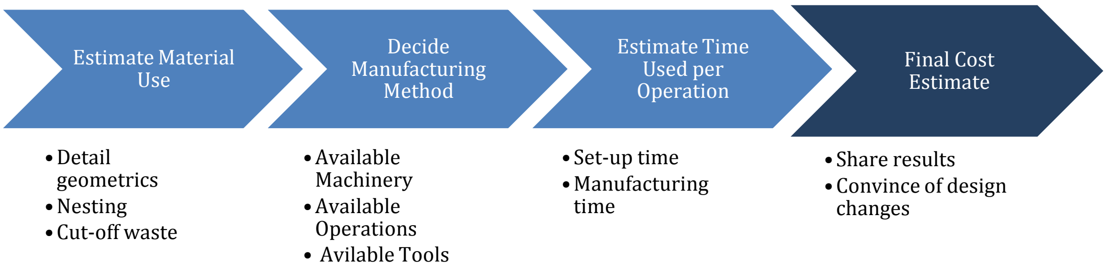


Figure 17. *The cost estimation procedure*

Material use: The material needed to manufacture the details and how much waste material that would be cut off. The waste depends on how many details that could be fitted into one sheet of metal.

Manufacturing method: The operations needed to manufacture the detail, the required tools, the sequence of the operations, etcetera. The main operations used in the companies can be seen in Table 11.

Time used per operation: The time used per operation is estimated and later transformed into costs. The total time is the combined cost of setup costs and manufacturing costs.

Table 11. *The main operations used in the interviewed companies*

Class	Main Operations
Cut	Punching Laser cutting
Bend	Bending
Other	Welding Packaging Surface treatments (grinding, galvanizing, painting)

5.1.3. Needed Tools and Resources

This section presents the tools and resources the interviewees used to make cost estimates. This section sometimes compares the smaller and larger companies of this research. The larger companiesrefers to the companies with a turnover over 50 million SEK, which are company 3, 4 and 6 and the smaller companies are subsequently the companies 1, 2 and 5. An overview of the interviewed companies can be seen in Table 3.

Tools

The larger companies used cost estimation software to calculate the cost of their products. The software needed input as geometrics from the detail and manufacturing times. This kind of software did not exist at the smaller companies.

All companies used other cost estimation tools for some part of the estimations. It could be Excel sheets for calculations and nesting software together with Computer Numerical Control (CNC) software to estimate work hours tied to cutting a detail from a metal sheet.

Data

The larger companies had a database of common manufacturing costs. These databases were a result from research measuring manufacturing hours. The smaller companies also did cost investigation in their companies but not to the same extent. Either did they document these measurements in the same way. Still, commonly also the smaller companies knew the numbers of cost per hour per machine and cost per punch or cost per millimeter cut.

Experience

In the larger companies the experience between positions were more differentiated. The designer worked only with development and there was a specific person who managed the cost estimates. In smaller companies one person could be both designer, cost estimator and production manager.

Cost estimates were always made by persons who worked close to the production. The person also had wide knowledge and experience of sheet metal processing. The interviewees all agreed upon that it was hard or maybe even impossible for a person without experience of sheet metal processing to estimate costs correctly. Moreover, there was no other way for a newcomer to learn how to make cost estimates than by trial and error.

Time

All the interviewees found it hard to estimate the hours spent on making cost estimations. The manufacturers meant, that the larger a job was the more time was needed on a quote. But there were exceptions. One manufacturer told an example where he spent just an hour of work for a job that was to be ten percent of the company's turnover, and the same amount of time for a much smaller job. A detail similar to those the company already has manufactured did however in general take less time to estimate.

One of the manufactures estimated his time spent on cost estimates to 25 % of his workday. The designers on the other hand, mostly did quick rough estimates, but if they wanted a more accurate cost estimate they sent a request to the production team. Thy result was normally sent back to the designers within 3-4 days.

Moreover, three companies mentioned that the time spent on a job is as relevant as the cost of a job in order to be competitive. For the prototype manufacturer the time was even more relevant than the cost. And also, all the manufacturers wanted to make more actual cost calculations to improve their cost estimation methods but none of them had enough time.

5.2. Expectations

This section presents the interviewees' required accuracy of cost estimates as well as their thoughts of which the main difficulties connected to performing cost estimates were.

5.2.1. Accuracy

The accuracy needed in cost estimates was uncertain for the interviewees. Even though all interviewees wanted cost estimates to be as exact as possible, most interviewees could not tell which accuracy they required. One manufacturer mentioned he wanted at least 10 % accuracy from the calculations but another would settle for 20 %.

In addition to the uncertainty of which accuracy that is needed, one interviewee told he knew their existing cost estimating program sometimes added tool switches, which added unnecessary manufacturing costs to the detail. He also told that he knew one of their cost estimating programs had a fault margin and therefore always calculated with an error factor when performing his cost estimates.

Even though the interviewees did not know which accuracy they needed, all the interviewees were content with the estimates they performed at present. They were aware of that their existing cost estimate was neither exact nor totally wrong.

At present the interviewers had two ways of receiving more secure and accurate cost estimates. One way was to ask a coworker for a second opinion. The other way was to actually manufacture a prototype to see what it would cost.

5.2.2. Difficulties

When asked about which parts of the cost estimates were the most difficult, the manufacturers answered the quality of the input material. The input material for an ordering could be anything, from a CAD-part file to a hand drawing on a piece of cardboard or a description of a detail retold from a phone call which made it hard to evaluate and cost estimate.

The manufacturers also found it hard to estimate work hours. The human is a non-precise parameter which works better some days and slower some days. The time also varied between who did which job. Also, all interviewees agreed it was especially hard to estimate costs of new products because they then there were not an old reference job to compare with.

That designers do not have enough knowledge about sheet metal production was another common problem. Often the designers designed things that could not be manufactured or was expensive to do so. This could depend on how the designers look at the details in the computer. In CAD software it is possible to zoom in and it is hard to see how big things really are. This meant that production often either gave advice for the designers to re-design their products more cost effective or production made the changes themselves.

Other difficulties that were mentioned were difficulties in estimating costs for products with different tolerances and the problem of convincing customers of that certain design changes would affect the cost of a product.

5.3. SolidWorks Costing

This section treats the interviewees' opinions of SolidWorks Costing. This section also treats the interviewees' requirements for future cost estimation software.

5.3.1. Opinions of SolidWorks Costing

The manufacturers thought the designers could have better use of SolidWorks Costing. They did not believe it would calculate the cost with as good accuracy as was needed for quotes. The designers, though, could use the program to compare costs of different designs, as a comparison does not need as good accuracy.

There was also a common concern amongst the interviewees of letting software do all the work. Most expressed they were afraid of leaning too much on the software so they would loose their ability of doing cost estimations manually.

One interviewee commented that SolidWorks Costing would certainly work for whole automatic processes where the human is not involved, for example injection molding of plastic details, but not for their processes.

Mainly there was a dislike against SolidWorks Costing. No one seemed to trust the software, but what all the interviewees liked, and what especially the designers liked, was that it was possible to make adjustments in the CAD-part and right away see the impact on the cost.

5.3.2. Requirements of Cost Estimation Software

The interviewees were asked which features they wanted in a cost estimation tool; these are presented in Table 12.

Table 12. *The interviewees' wishes for a cost estimation tool*

Requirements	Description
High Accuracy	It should give as good accuracy as possible but the interviewees could settle for less.
Reliable	It should provide a baseline which could be used for comparison with self-made cost estimates.
Adjustable	It should be customizable to fit the company and there should also be a possibility to update the system to get more accurate cost estimates.
Adaptable	It should be able to adapt with the companies' changes, for example, if the machines or tools are changed so will the tool also be.
Easy to understand	It should be easy to understand, all interviewees wanted to be able to see where all specific costs came from in order to be able to change them if necessary.
Repeatable	It should give repeatable results, so that every customer could be given the same prize for the same job.
Quick	It should be quick to give cost estimations
Visual proofing	It should be able to be used for convincing customers how the cost depends on the design of a product.
Static cost dependent	It should take other cost as heating, rent and investment cost into account in the cost estimate.
Customizable for different customers	It should use data which are adaptable for different customers as different customers want different surface roughness and so on.
Estimate assembling costs	It should have the possibility to estimate cost for welding, packaging, surface treatment and assembling.
Show manufactur-ability	It should tell if it the product is able to be manufactured.
Human factor included	It should take the human factor into account.
Find optimal lot number	It should find the optimal value of how many details which should be manufactured to get a low cost.

6. Case Study Results

In this chapter, the results from the case study in this research are shown. First the results from the separate operations; material, cutting and bending are shown, and then follows the combined result of a comparison between all three operations.

6.1. Material

Calculation of material cost was made according to Chapter 2.4.2 and the results are shown in Appendix 3. Case study Results: Material.

6.1.1. Case 1

The materials of the used test parts in Case 1 was aluminum and aluminum-zinc. The differences between material cost per part calculated from SolidWorks Costing and the partner company's actual material costs calculations were compared. The material cost from SolidWorks Costing was averagely 9% lower than the actual cost calculation. An adjustment of 9% was added to the kilo prices inserted into SolidWorks Costing. The new average percentage difference between SolidWorks Costing and the company's actual cost calculations then became 1%.

6.1.2. Case 2

The materials of the test parts used in Case 1 was steel and stainless steel. The differences between material cost per part calculated from SolidWorks Costing and the partner company's material costs estimations were compared. The material cost from SolidWorks Costing was averagely 3% lower than the cost estimations. An adjustment of 3% was added to the kilo prices and inserted into SolidWorks Costing. The SolidWorks Costing estimations then had averagely the same values as the company estimations.

6.2. Cutting

This section presents the results from Case 1, where cutting was done by punching and Case 2 where cutting was done by laser. The results from both operations can be seen in Appendix 4. Case Study Results: Cutting.

6.2.1. Case 1: Punching

The relation between sheet thickness and cost per punch was investigated according to the method described in Chapter 2.4.2. First the significance of the material type was investigated, see Figure 18. The red markings in the figure are steel, the blue markings are aluminum and the green markings symbolize other material types. As the figure shows, there was no clear connection between material type and the punching cost.

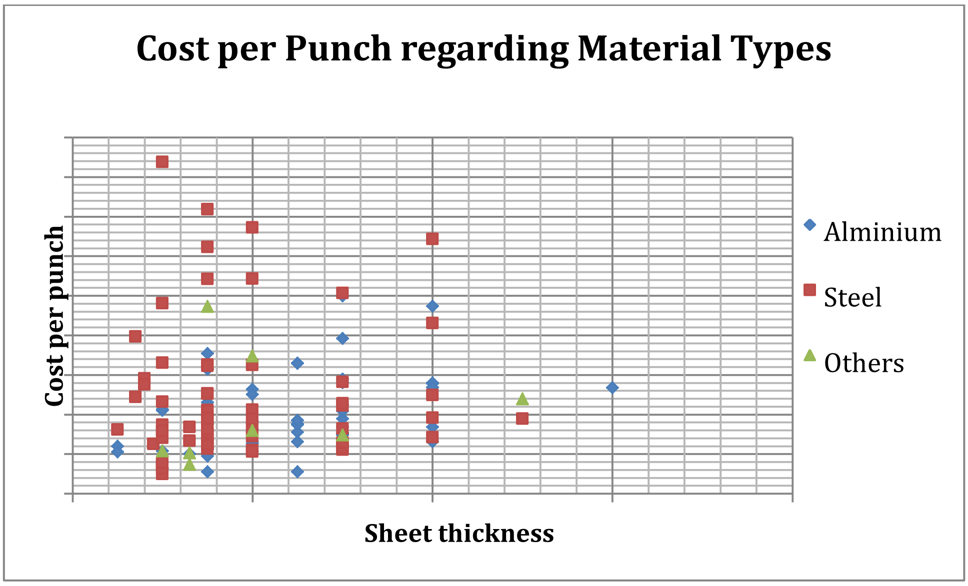


Figure 18. *The spread of the different materials*

Two types of relations between the cost per punch and the sheet thickness were investigated, a linear and an exponential. In Figure 19, both a linear and an exponential trend line were drawn through the points. The chart was developed from Figure 18, where the too distinguishing points were eliminated.

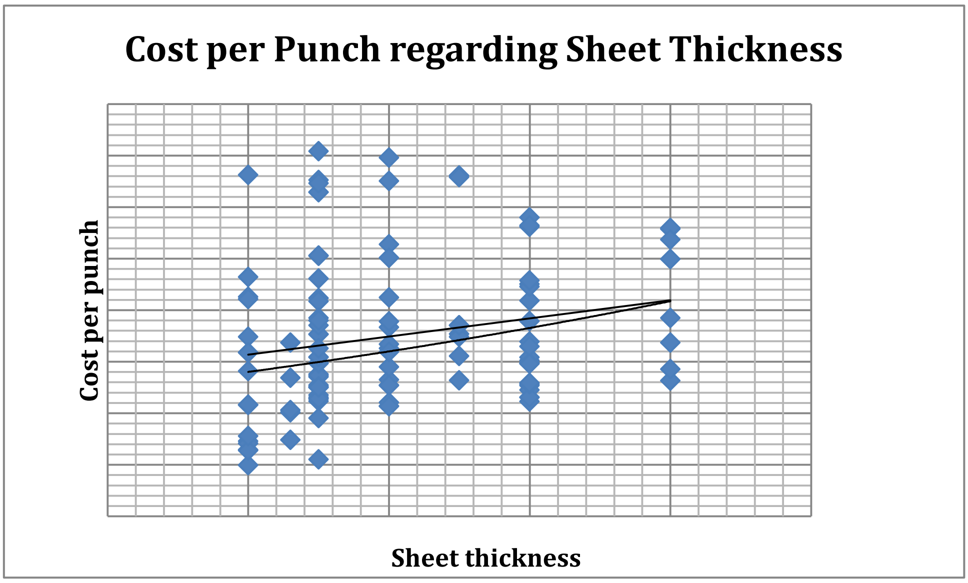


Figure 19. *Chart of the cost per punch compared to the material thickness of different materials where a linear and an exponential trend line have been added*

The costs per punch from different thicknesses from both linear and exponential curves were re-calculated into cost per millimeter and inserted in SolidWorks Costing for 12 test parts. For each part, an estimation of cutting operation (punching) was made and compared to the partner company's actual cost calculation. The comparison showed that costs per millimeter from the exponential curve were nearer the actual cost calculation than values from the linear curve were.

The comparison between the cutting cost estimation from the exponential values inserted in SolidWorks Costing was averagely 16% lower than the actual cost calculation. So in the adjustment, 16% was added to the cost per millimeter inserted into SolidWorks Costing. With the new values, the average percentage difference between SolidWorks Costing and the actual cost calculation became 2%.

6.2.2. Case 2: Laser Cutting

The cost per millimeter for laser cutting was calculated according to Equation 3. Also, besides the time it took for the machine to laser-cut the pattern, it took averagely four seconds to reposition a hole. Knowing the laser machine's hourly cost and the time spent on repositioning the holes on the test parts, the cost of repositioning was calculated. A new cost per millimeter including both cutting cost and repositioning cost was calculated and inserted into SolidWorks Costing and compared to the partner company's own estimations. The comparison showed that the laser cut cost per millimeter and the sheet thickness had a linear relation.

The differences between laser cutting cost per part calculated from SolidWorks Costing and the partner company's own costs estimations were finally compared. The laser cutting cost from SolidWorks Costing then gave the same average values as the partner company's own estimations.

6.3. Bending

The bending operation was tested in both Case 1 and Case 2 according to the method described in Chapter 2.4.2. The results from the bending operation are shown in Appendix 5. Case Study Results: Bending.

6.3.1. Case 1

Besides the 12 parts used in the punching study, see Chapter 6.2.1, eight additional bending data were used to calculate the reference cost per bend, according to Equation 4. The spread of the reference values is shown in Figure 20. As seen, there were three values that differed much from the other values. These odd values were removed in later calculations so that the reference bending costs could be as close to the most common values as possible.

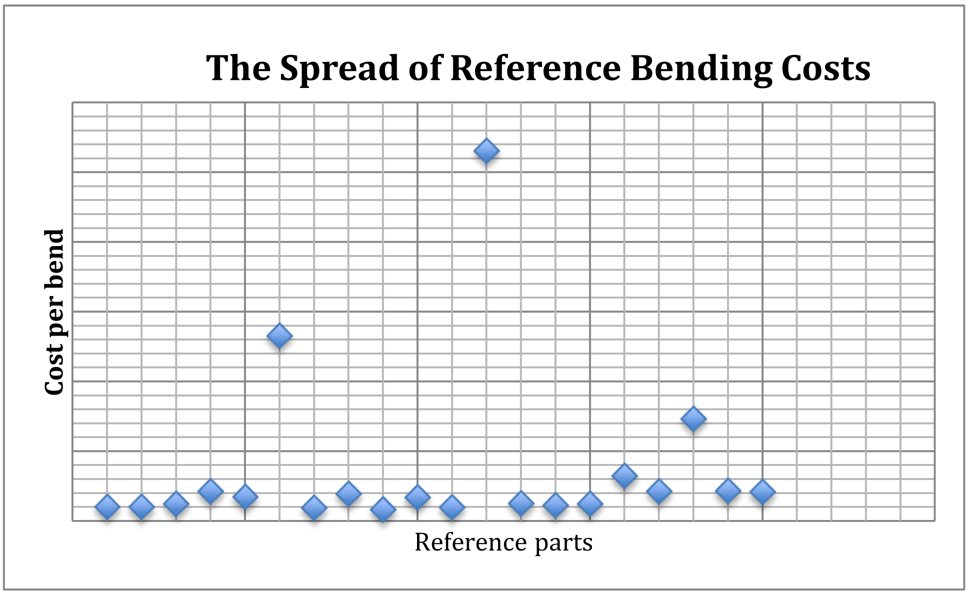


Figure 20. *The spread of reference bending costs*

A comparison between the reference bending cost per part from the partner company and bending cost from SolidWorks Costing were made for the six variables described in Table 7. Compared to the reference values the exponential equation based on sheet thickness came closest. Both the exponential and linear curve dependent on sheet thickness can be seen in Figure 21.

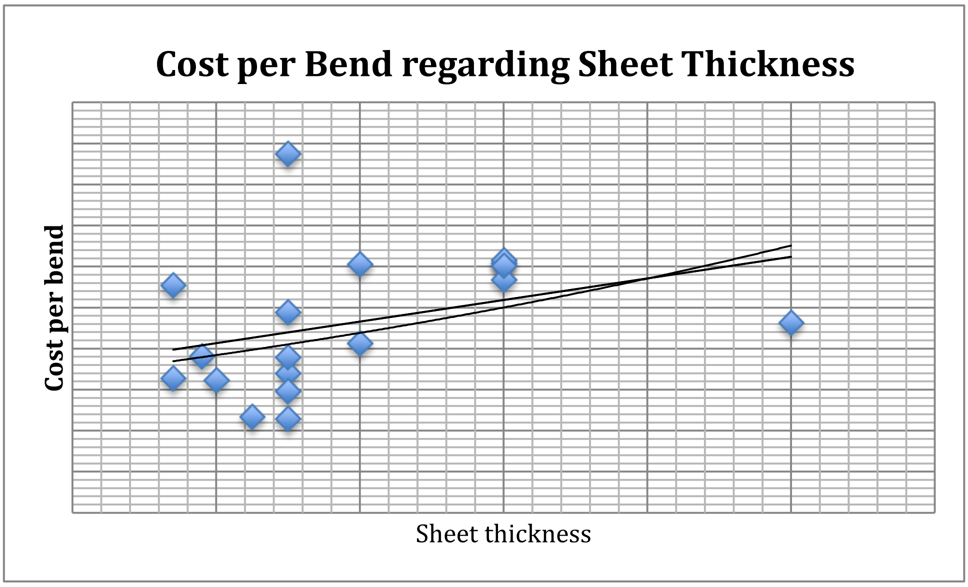


Figure 21. ***Relation between cost per bend and sheet thickness***

A comparison between the cutting cost estimations from values of the exponential curve inserted into SolidWorks Costing and the company's actual bending cost calculations showed, the cutting cost from SolidWorks Costing was averagely 4% higher than the actual cost calculation. So an adjustment of 4% was done to match the company's actual cost calculations.

6.3.2. Case 2

Besides the nine parts used in the punching study, see Chapter 6.2.2, three additional bending data were used to calculate the reference cost per bend, according to Equation 4. Also in this case, the comparison between the reference bending cost per part from the partner company and bending cost from SolidWorks Costing depended on the six variables described in Table 7 were made. Likewise with Case 1 the values, which came closest to the reference values came from the exponential equation based on sheet thickness, see Figure 22. In the figure, both the linear and exponential curves are shown.

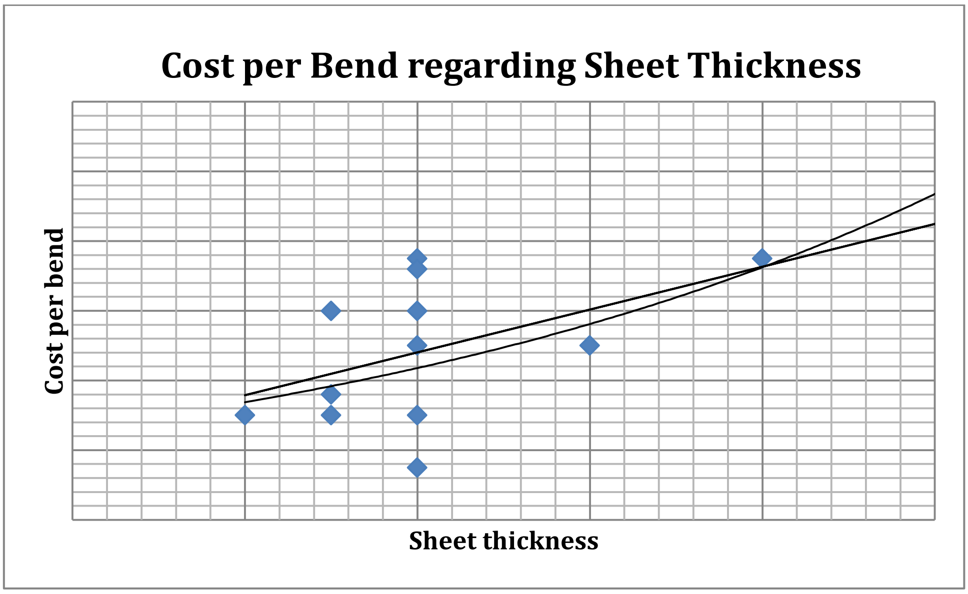


Figure 22. *Relation between cost per bend and sheet thickness*

The comparison between cost estimations based on the exponential curve from SolidWorks Costing and the bending cost estimations showed, the cutting cost from SolidWorks Costing was averagely 1% lower than the cost estimation. So an adjustment of 1% was added to the cost per millimeter value inserted into SolidWorks Costing to match the cost estimation.

6.4. Combined Results

This chapter presents cost comparisons between whole parts, including material, cutting and bending operations, where cost estimations from SolidWorks Costing was compared to the partner companies' own cost estimations or actual cost calculations.

6.4.1. Case 1

The comparison of cost estimations between the partner company in Case 1 and SolidWorks Costing are shown in Appendix 6. Case Study Results: Collective Results. As seen, the original cost per part from SolidWorks Costing was averagely 14 % lower than the actual cost calculations. In calculations with adjusted values, cost per part from SolidWorks Costing was averagely 9% lower than the actual cost calculations.

6.4.2. Case 2

The comparison between cost estimations from the partner company in Case 2 and SolidWorks Costing are shown in Appendix 6. Case Study Results: Collective Results. As seen, the original cost per part from SolidWorks Costing was averagely 1% lower than the company estimation. In calculation with adjusted values, cost per part from SolidWorks Costing gave averagely the same values as the company estimations.

7. Interview Analysis

In this chapter, the interview results are compared to results from the frame of reference according to the overall activity structure of this research presented in Figure 3. Also material from the implementation background is analyzed when appropriate interview analyses are presented.

This chapter, similar to the Chapter, Interview Results, sometimes compares smaller and larger companies of this research. The larger companies refer to the companies with a turnover over 50 million SEK, which are company 3, 4 and 6 and the smaller companies are subsequently the companies 1, 2 and 5. An overview of the interviewed companies can be seen in Table 3.

7.1. Cost Estimation in Industry

This section analyzes the purpose and necessity, the procedure and the tools and resources used performing cost estimations.

7.1.1. Purpose and Necessity of Cost Estimates

Low cost clearly could give competitive advantage and cost estimates are an important tool in order to achieve low cost, which both published theory and all interviewees agreed on.

SolidWorks (2011a) proposed two specific groups which would benefit from using SolidWorks Costing. The two groups were manufacturers and designers and the two groups each had a corresponding goal, which were making quotes or making design decisions.

Manufacturers

Interviews showed manufacturers used cost estimations on a daily basis when making quotes. Moreover, Veeramani & Joshi (1997) proposed that if too high price is given, customers will be lost, and if too low price is given, the company will lose income and credibility. This balance act was something the interviewees all agreed on and something which meant cost estimates were so important. As the manufacturers were so dependent on their cost estimates, they certainly would like a tool which could help them make better based quotes. But also for them to make a decision of using a tool the manufacturers would need proof of the accuracy of the tool and be impressed by the result, otherwise they would never use it.

Designers

The designers on the other hand did seldom make their own cost estimates. But regularly performed cost estimates during the design phase will most securely result in lower production cost for products. As much as 80% of the product cost is set during the design phase and it is therefore also important for designers to have efficient cost estimation tools (Duverlie & Castelain, 1999). That cost estimations are important in order to make cost effective products was something the designers did agree on. However the designers did express their fear of having to do extra work as they did not perform cost estimates at the moment. Therefore, the designers need to have more knowledge of the importance of cost estimates for the whole company in order to recognize a tool’s benefits.

7.1.2. The Procedure

This section analyzes the cost estimation procedures for manufacturers followed by the same analysis for designers.

Manufacturers

The manufacturers' cost estimation procedure was complex and also took time to perform. The complexity of the procedure would make it hard to change the procedure in order to just calculate better cost estimates. Therefore the first step for implementation of a cost estimation tool should follow the current cost estimation procedure as much as possible. The manufacturers' cost estimation process could be broken down into three main steps, estimation of material use, deciding of manufacturing method and estimation of work hours.

Wei & Egbelu (2000) proposed a cost estimation process which included the steps; evaluation of manufacturability, deciding of manufacturing method and cost estimation of each included operation. Adding these steps to the process resulted from the interviews would give a process wich could be applied to a wider range of users. The combined method can be seen in Figure 23.

Figure 23. *The cost estimation procedure*

The quotation procedure as a contrast to the cost estimation procedure also included a pricing process. According to Veeramani & Joshi (1997) several departments have to be included in the pricing process, which was true for the larger companies in this research, but in the smaller companies the cost estimating and pricing was often made by the same person whereas the cost estimation process and the quotation process could be seen as the same process for manufacturers.

Designers

As it was now the designers only did rough estimates, if more exact estimates were needed, the designers sent a request of a cost estimate from the production team. It would normally take 3-4 days before the estimate was sent back to the designers. Literature described these two methods as *between the fingers estimations* and *cost-planning department involvement* (Layer et al., 2002).

Also the importance of making cost estimates repetitively during the whole design phase was recommended by several literal sources (Layer et al., 2002; Wong et al., 1991). How often the interviewed designers did their cost estimates were unclear but since the designers more exact estimates had to be sent for from a different department which took several days, there should be room for improvements in this area. Cost estimates made by designers instead of the production team could save waiting time and make it possible for designers to take cost based decisions earlier in the design phase, which would give better possibilities of cost effective products as an outcome.

7.1.3. Needed Tools and Resources

There was a need of both tools and resources in order to be able to make cost estimates. More exact, the need of tools, experience, time and data is described in this chapter.

Tools

All the companies seemed to want tools for cost estimates even if they nowadays did not use a well-described method. The want of tools was proofed by all the interviewees' use of the tools they knew as Excel and nesting-software. The pre-investigation by SolidWorks (2011a) also showed that tools as Excel spreadsheets were commonly used.

Both interviews in this research and SolidWorks pre-investigation (Therrien, 2012) showed that many of the applied tools used today needed input of the details geometrics in order to calculate the costs. As SolidWorks had the geometrics of the details already stored in the software, this would imply a great advantage with SolidWorks Costing. Also Wei & Egbelu (2000) implied that the use of cost estimations integrated with CAD-systems would be of great advantage by complaining of the slowness of systems, which lacks this integration.

The designers used methods as *Design for Cost* and *Design for Manufacturing* which literature described and recommended. Literature also prescribed use of additional cost estimation tools in order for effective use of the two methods (Dewhurst & Boothroyd, n.d.). The designers seemed to like the thought of effective cost estimation tools as long as it did not lay extra work on their shoulders.

Experience

A person has to have experience to be able to estimate costs. That was what the interviewees said. Literature tells, cost estimates are dependent on the personnel available and the result may be distinctive (Bidanda et al., 1998). The interviewees also knew the differences between estimators. As most of the interviewed companies did not have a database or any other record of costs and cost estimation methods the need of experience was even higher. The only way for a new person to learn how to make cost estimations was by trial and error.

A database common to SolidWorks Costing or other would make it easier for companies to transfer knowledge between employees and make sure the know-how would stay in the company. But although a database would make cost estimations easier, the cost estimation procedure is complex and a database would only be a tool. Experience would still be of great importance in order to estimate costs and make best use of the database.

Time

That cost estimates takes too long to perform were the main issue in industry according to SolidWorks (2011a). Time is on the other side important in order to make fast deliveries and stay competitive on the market (Layer et al., 2002).

The result of the interviews in this research showed manufacturers spent as much as 25% per day on cost estimates, where each estimate would take from minutes to several hours dependent of the character of the job. A cost estimate from SolidWorks Costing would instead just take a few seconds. The designers on the other hand, spent 3-4 days waiting for a cost estimate. With SolidWorks Costing they would have an answer within seconds which could mean the possibility of finishing a product 4 days earlier than with nowadays method.

Data

Some companies had a database and some had experience based figures as hourly rates and cost per punch which they used for making cost estimates. But even if some companies had a database also these companies needed to complement their data with knowledge from other sources this often meant asking the machine operator or likewise for their opinions.

Wei & Egbelu (2000) and Wong et al. (1991) presented similar beliefs of needed input data. The interviewees' input data varied between different jobs, but the main parameters were, material use, machine operations and work hours. On a more detailed level, the interviewees' input data could be described with the method either Wong et al. (1991) or Wei & Egbelu (2000) proposes. The combined data from all three sources with different detail levels can be seen in Figure 24.

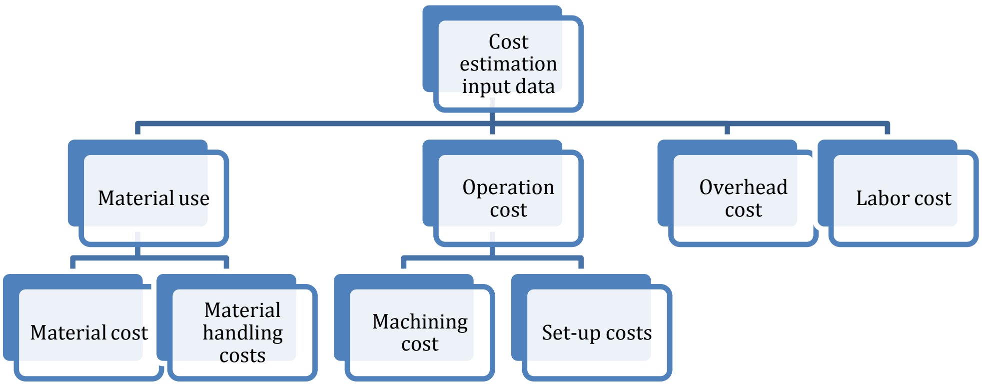


Figure 24. *The input data needed for cost estimation in different detail levels*

7.2. Expectations

This section analyses the interviewees' expectations of accuracy and their perceived difficulties of making cost estimations.

7.2.1. Accuracy

The expected accuracy of the cost estimations varied between 10-20 % with the interviewees. One interviewee also told of his program making errors whereas he made calculations including an error factor to get better accuracy.

The requested cost estimation accuracy shows a trend of being the double value of the company's profit margin, see Figure 25. The trend might suggest that the companies' have good knowledge about their own cost, this as an accuracy of for example either plus or minus 20% would give an average profit of 10%. The trend also suggests that if better accuracy in cost estimates could be achieved, also the profit margin would rise.

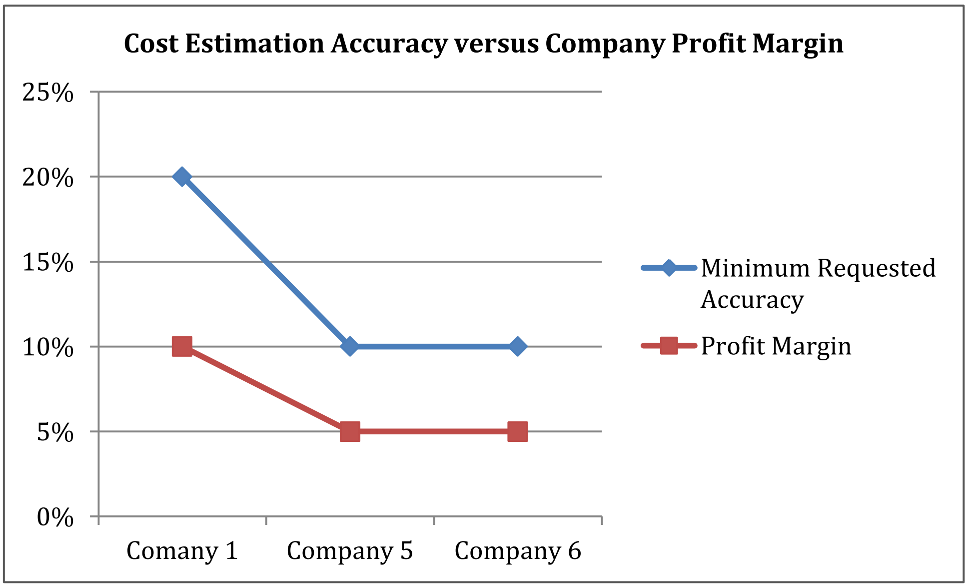


Figure 25. *Diagram showing the companies' profit margin compared to the companies' requested accuracy of cost estimates*

Moreover, the pre-investigation from SolidWorks (2011a) suggested that in the beginning, the repetitiveness of results was more important than the accuracy of the results. A repetitive result would make it easier to correct values and thereby improve the accuracy of the results later.

There also seemed to be a demand for security in the cost estimates. As it was now a cost estimator asked another person of their opinion in order to secure the cost estimate. Software could be another base line to which to compare estimations in order to get even reliable results.

7.2.2. Difficulties

This chapter discusses how SolidWorks Costing might solve the difficulties of cost estimations that were proposed by the interviewees of this research, see Chapter 5.2.2.

The input material is hard to read

If a CAD-part was created instead of a draft on a piece of paper this problem would not exist. It would also be easier to discuss the geometrics with the customer when having a visual object to point at. However, only the use of SolidWorks Costing would not solve the problem of ill made drafts.

Work hours are hard to estimate

With SolidWorks Costing there is no need of estimating work hours to manufacture a part as the work hours are already taken into consideration in the software. When all values are inserted into the templates, the calculations are only based on geometrics of the part.

Designers often have low knowledge in sheet metal manufacturing

The visual and interactive environment in SolidWorks Costing where designers directly inside the program can see what is affecting the cost could both guide and increase the designers' knowledge about costs and manufacturing methods.

Different tolerances make it hard to estimate costs

SolidWorks Costing would provide a database where costs of different tolerances could be stored. The regularity of the results would make it possible to update the system and thereafter make improvements of the cost estimates which would work for different tolerances as well.

It is hard to convince customers of the bond between manufacturing and costs

When convincing a customer to make design changes SolidWorks Costing could be used as a visual proof of the savings made with the design change.

8. Case Study Analysis

This chapter analyses the case study results from Case1 and Case 2 compared to results from the frame of references and implementation background of this research.

8.1. Material

First case study trial for both cases the material cost estimation accuracy in SolidWorks Costing resulted in only negative values, see Chapter 6.1. SolidWorks Costing calculated the cost based on a bounding box area which size was equal to the rectangle that the flattened part just fitted into. The company's cost estimation was on the other hand based on the material needed for the part as well as an amount of overflow material dependent on the manufacturing method.

The negative values from SolidWorks Costing were found to be a result of estimation based on too little excess material. There were two solutions to the problem; either a manual change of the bounding box area had to be made with each cost estimate in SolidWorks Costing or an representative adjustment of the kilo cost could be made. The first solution was rejected on course of the extra effort that was needed to perform the estimation. The second solution was easier to use but on the other hand, as a representative kilo cost was used, the estimates could be misleading of the actual material cost and also harder to adjust when the company's purchase material prices changed.

8.2. Cutting

This section analyzes case study results for the cutting operations punching and laser cutting.

8.2.1. Case 1: Punching

As seen in Chapter 6.2.1, the average difference between the result from SolidWorks Costing and results from the partner company's actual cost estimation was 2 %. There were a few options that could have been experimented further to reduce the time to implement and increase the accuracy of the software. These options were:

Increase the variance of tested data

This research cutting data had a good number of data points for the middle span of thicknesses meanwhile more thick and less thick sheets had few representing data points, see Figure 18. In order to receive better accuracy with these thicker and less thick sheets in SolidWorks Costing more data could have been collected from manufacturing of the targeted sheet thicknesses.

Amount of collected data

The number of data points could have been less and given a similar answer. Also the evaluation parts could have been less. Although, the exact amount of needed data remained unknown.

Improve the used reference data

For the punching operations, setup-schedules were used as reference data for comparison with SolidWorks Costing. But the accuracy of the setup-schedules was not certain. The operating time of punching was a total operating time calculated from the punching machine, not specific for every punch.

Also, setup-schedules and actual cost estimations were compared as appropriate reference data. Setup-schedules were chosen because the process was all handled by machine, which eliminated the possibility of mistakes by humans.

Figure 18 showed that punching of aluminum sheets required lower cost than steel sheets. The lower cost depended on the difference between the stiffness of the materials as the stiffer material needed more power to be punched through. The power applied by the punching machine was fixed, but stiffer materials required a smaller sized punching tool which centers the used power on a smaller area to go through. Therefore to be able to punch out the same pattern, the required number of punches was more for steel sheets than aluminum sheets and thereby the cost difference. Consequently, when calculating the costs, a separate calculation for each material could also improve the reference data.

Calculation with the tool length

The length of the punching tool used in every reference setup-schedule was considered the same during Case 1. Taking the length differences into account would also improve the results due other tool lengths were used besides the commonest one.

8.2.2. Case 1: Laser Cutting

The results of laser cutting were good, the SolidWorks Costing and the partner company's own estimation was averagely the same see Chapter 6.2.2.

Laser machine speed

The accuracy of SolidWorks Costing laser cutting results depended on the good accuracy of the inserted data based on laser cutting machine data. The machine's cutting speed came from the machine's manufacturing data; it was constant and non-human related which provided a foundation for the high accuracy of the laser cutting costs from SolidWorks Costing.

Hole-reposition time

Also, the laser reposition time for each part depended on the number of holes in the part. In this case, an average cost per reposition was calculated for all the nine test parts. Even the average difference between estimation from SolidWorks Costing and company's own estimation was 0 %, the average of absolute difference was 14%, see Chapter 6.2.2. More test parts could be used to lower the average absolute difference also a specific cost per hole could be used as a complement with a cost per millimeter value instead of just using an average cost per millimeter. The last proposition could increase accuracy further but would however initiate extra work for the SolidWorks Costing user manually specifying each hole before calculating each cost estimate.

8.3. Bending

Compared to cutting, it was more difficult to find a mathematical formula to calculate the cost per bend. The difficulty partly depended on the insecure input variables, partly on the insecure reference values. During the cases, the results from the exponential equation based on sheet thickness were closest to the reference values. However results from all the variables landed at the same level, the advantage of sheet thickness was narrow. Factors that could have affected the bending results were:

The setup cost

During the experiment, it was uncertain if the setup cost was included in the actual cost estimation reports. According to the manager at the partner company in Case 1, the setup cost should always be considered included. However, on two of twelve of the references, the total bending costs were lower than the bending setup-cost, which lowered the credibility of the reference data and made it harder to read the results from different variables and understand the accuracies of them. The setup cost was clearly separated from the operation cost in Case 2.

More secure reference values

Besides the insecurity of setup costs, there were other facts that could affect the credibility of the reference data. The operating time of bending from the actual cost calculation was in Case 1 signed by the machine operator. The human handled process increased the risk of misjudging time and costs.

In Case 2, no actual cost calculations were made, the only reference was the partner company's own estimations. The lack of reliable reference was therefore also in Case 2 an issue.

Multiple immeasurable variables

During the two cases, all six possible variables, see Chapter 6.3, that could affect the cost per bend were tested individually. There are also other immeasurable factors that could affect the costs, such as carefulness during the process, needed manpower and required surface quality. The cost per bend would more likely depend on not only sheet thickness, but also multiple factors.

Amount of collected data

Twelve reference parts were used in Case 1, and in Case 2, nine reference parts were used. Larger amount of data collection could improve the results. Also, data from more typical orders could better represent the capability of the bending machine, thus improve the accuracy of SolidWorks Costing.

8.4. Analysis of Combined Results

The expected average accuracy of cost estimations was 10 % - 20 %, according to the interviews, see Chapter 5.2.1. Overall, both case studies have reached good average results, especially after adjustments; see Chapter 6.4. With an average percentage difference of - 9 % from the company's actual cost calculation in Case 1. In Case 2, SolidWorks Costing reached the same results as the company's own estimations. Hence the user's expectations were fulfilled.

8.4.1. Accuracy

However, not all individual test parts had accuracy higher than 20 %. As seen in Appendix 6. Case Study Results: Combined Results, part 8 differed 64% from the company's actual cost calculation. And in Case 2, part 5 had a maximum difference of 45% between the cost estimation from SolidWorks Costing and the partner company. The high individual differences could depend on different factors. The specific part could have been designed so it would have to undergo special treatment to be able to be manufactured; or there could have been an accident during the manufacture so the part could not be finished on time; or the uncertain result could depend on incorrect reference values.

The results from both cases have been shown to the partner companies for consultation. Both companies claimed that due to time shortage and resource limit, good average accuracy was more important than accuracy in every individual ordering. Also as seen in the research behind SolidWorks Costing, see Chapter 3.2 and Figure 10, timesaving besides accuracy also was an essential factor to sheet metal manufacturers in the cost estimation process.

Besides the ways to improve individual results in material, cutting and bending described earlier in this chapter, there were other facts that could affect the overall accuracy of the whole parts;

- To improve the results from SolidWorks Costing, the input parameters needed to be improved since calculation in the software was based on the input data and the part's geometry. However the input data came from the partner companies' own estimations, which meant the estimation from SolidWorks Costing could only get as close to real cost values as the companies' own estimations, even with adjustments.
- Besides the inputs, the quality of results from SolidWorks Costing also depended on the quality of the test parts. The test parts needed to be representative of the companies' business and manufacturing abilities. If, not, the final adjustment of SolidWorks Costing values might negatively affect the overall result.
- The numbers of collected test parts could also affect the quality of templates in SolidWorks Costing. The amount of test parts needed to be just enough to make good estimations and adjustments, because too many test parts would only cost too much time and resources during implementation and creation of templates.
- Another way to improve the quality of templates in the software was to create different templates for different kinds of manufacturing jobs.

8.4.2. Custom Operations

Besides the material, cutting and bending operations, there were many other custom operations that could be calculated in SolidWorks Costing. The custom operations used in industry were different between different companies dependent on their business areas, specialties, abilities, working staff and machine parks, see Table 8. Because of the variance, custom operations were not a part of the case study. However, costs of custom operations could be calculated and improved by the same methods as in cost of material, cutting and bending operations.

9. Cost Estimation in SolidWorks Costing

This chapter, as presented in the Analysis block in Figure 3, analyses the functionality, advantages and disadvantages as well as provides for a list of suggestions of further development of SolidWorks Costing.

9.1. Functionality

The functionality of SolidWorks Costing is in this section analyzed in two areas. First, how SolidWorks Costing fulfills the requirements of cost estimation tools. Second, how much time is needed and the accuracy achieved with SolidWorks Costing compared to existing cost estimation procedures in industry.

9.1.1. Requirements

SolidWorks Costing fulfills most of the requirements of both the interviewees (Chapter 5.3.2) and by literature (Chapter 4.1.3). The requirements of a cost estimation tool compared to the abilities of SolidWorks Costing can be seen in Table 13.

Table 13. *The combined requests of a cost estimation tool from interviews and the frame of references*

Requirements	Description	SolidWorks Costing Ability	Comment
Regular cost estimations	Cost estimations should be able to be performed concurrently and on regular basis during the development phase.	✓	
Data storage	It should provide a place for where to look up data instead of having to ask the production team of costs	✓	
High accuracy	It should have as good accuracy in cost estimates as possible but the interviewees could settle for less.	✓	SolidWorks Costing has as good accuracy as input data
Reliable	It should be a baseline, which could be used for comparison with self-made cost estimates.	✓	
Adjustable	It should be customizable to fit the company and there should also be a possibility to update the system to get more accurate cost estimates.	✓	

Adaptable	It should be able to adapt with the companies' changes, for example, if the machines or tools are changed so will the tool also be.	✓	
Easy to understand	It should be easy to understand, all interviewees wanted to be able to see where all specific costs came from in order to be able to change them if necessary.	✓	
Repeatable	It should give repeatable results, so that every customer could be given the same prize for the same job.	✓	
Quick	It should be quick to give cost estimations	✓	
Visual proofing	It should be able to be used for convincing customers how the cost depends on the design of a product.	✓	
Static cost dependent	It should take other costs as heating, rent and investment cost into account in the cost estimate.	✓	Possible, if taken into calculation when inserting especially setup costs in templates
Customizable for different customers	It should be adaptable for different customers, as the customers want different surface roughness and so on.	✓	Possible, but troublesome. More templates have to be created.
Estimate assembling costs	It should be able to estimate costs for other operations as welding, packaging, surface treatment and assembling.	✓	Possible, but troublesome. More operations have to be created.
Manufactur-ability	It should tell if it the product can be manufactured.	✗	
Human factor included	It should take the human factor into account.	✗	Not possible, but average values of work hours could make as good estimations
Find optimal lot number	It should find the optimal value of how many details, which should be manufactured to get a low cost.	✗	
Estimate complex parts	It should be able to estimate costs of more complex parts.	✗	

9.1.2. Time and Accuracy

The use of SolidWorks Costing could save time. As presented in Chapter 5.1.3 manufacturers can spend 25 % of their hours on cost estimates meanwhile the designers could wait 3-4 days for cost estimations from the production team. SolidWorks Costing on the other hand, as were proved by the case study, gives cost estimations within seconds.

The case study also showed SolidWorks Costing gives as good results as the companies' own cost estimates, see Chapter 6.4. As mentioned in the pre-investigation made by SolidWorks (Therrien, 2012), SolidWorks Costing also provides the possibility of storing data and thereby gives coherent results of every estimation. The stored data can then be updated and improved which would mean SolidWorks Costing with proper maintenance could give better accuracy than the methods currently used in industry.

Actual cost estimations are an important factor for successful improvement of the accuracy of SolidWorks Costing. To be able to improve template data a secure reference is needed and actual cost estimations seem to be a relatively easy way of getting this secure reference. It is by the case study a proved fact that the accuracy of SolidWorks Costing will never be better than its reference source.

9.2. Advantages and Disadvantages

This chapter describes and analyses the advantages and disadvantages connected to using SolidWorks Costing for making cost estimations compared to the cost estimation procedure currently used in industry described in Chapter 5.1.2. This chapter also provides a list of suggestions for further development based on the disadvantages discussed. A collection of the discussed advantages and disadvantages can be seen in Table 14.

Table 14. *The advantages and disadvantages of SolidWorks Costing*

Advantages	Disadvantages
• Integrated with CAD • Fast cost estimations • Concurrent cost estimation and design • Consistent cost estimation results • Data could be saved for later use • Easy to up-date and adapt • Provides cost estimation reports • Visual	• It takes time to fill in the template • It do not support assemblies • Uses length instead of time • A part file is needed • Poor functionality for some operations • Do not support several operations

9.2.1. Advantages

In this section, the advantages of using SolidWorks Costing for cost estimations, which are presented in Table 14, are analyzed.

Integrated with CAD

The integration between CAD and cost estimations do save time, this with the elimination of inserting geometrics into another program as proposed by both Wei & Egbelu (2000) and the pre-investigation made by SolidWorks (Therrien, 2011).

Fast cost estimations

SolidWorks Costing makes fast cost estimations that provides timesaving, see Chapter 9.1.2. The saved time could then be spent on other tasks. For example more cost estimations could be made. For a manufacturer more cost estimations would mean that more jobs could be quoted which led to increase of orderings. For designers on the other hand, cost-affecting decisions could be taken more regularly, which, according to literature (Layer et al., 2002; Wong et al., 1991; Feng et al., 1996) would reduce both product development costs and product costs.

More actual cost estimations could also be performed during the saved time. As the interviews showed, the interviewees did not have time for making actual cost estimations when following their current cost estimation procedure. However if more actual cost estimations could be done, this would give companies the possibility to analyze their actual costs and thereby improve their cost estimations even further.

Constant cost estimations

Inconsistency was a common problem with today's cost estimation methods according to both the interviewees (see Chapter 5.2.1) and SolidWorks' pre-investigation (SolidWorks, 2011a). As the cost estimate depended both on the cost estimator's experience and daily frame of mind, see chapter 5.2.2, the result of a cost estimate could differ sufficiently from day to day. SolidWorks Costing would instead provide the exact result every time the same part is estimated. The consistency in the cost estimates would ease comparison and analysis of actual cost estimations and thereby make it easier to improve cost estimations further.

Data could be saved for later use

The possibility to save data has the following advantages:

No time need to be spent on searching for the right person who could tell how much an operation would cost or how long time the operation would take. Instead the data could be found directly inside SolidWorks Costing.

Saved data makes it easier to introduce new employees to the cost estimation task, as all information is collected in one place. The database would also give the new employee a baseline to compare cost estimations without using the trial and error method described in Chapter 5.1.3.

Saved data, also makes it possible to estimate parts never manufactured before. The interviewees found new jobs difficult to estimate, as they did not have an earlier job to compare with, see Chapter 5.2.2. As SolidWorks Costing bases its estimates on geometrics instead of work hours, this allows SolidWorks Costing to make cost estimates of new jobs using material of already made jobs, which today's procedures do not allow.

Easy to up-date and adapt

The templates in SolidWorks Costing are easy to adapt and customize, see Chapter 3.1.1, which makes it easy to be implemented.

Provides cost estimation reports

SolidWorks Costing can make automatic cost estimation reports. These are quick to make and have a general layout, which is easy to follow. The reports' quickness and consistent layout would make it easier for departments and managers to communicate and share results concerning product costs.

Visual

SolidWorks Costing provides a visual link between design and cost, which gives educational advantages. Designers and new employees can learn how their design decisions affect the cost, and SolidWorks Costing could also be used to show customers why design changes should be made in order to reduce costs.

9.2.2. Disadvantages and Future Development

This section discusses the disadvantages of using SolidWorks Costing for cost estimations presented in Table 14, as well as presents suggestions for future development as solutions to the problems. The final suggestions for improvement can be seen in Table 15.

Table 15. *Suggestions of future development of SolidWorks Costing*

Area	Suggestion of Future Development
Templates	• Lessen template creation and updating time by making it possible to import cost data from for existing data table to templates • Make it easier to create and update templates by using the in-data; o Cost per length: for laser and water jet operations where machine data is used to estimate costs o Cost per hour: for punching, bending, and operations where work hours are used to estimate cost
Assemblies	• Now: Develop welding cost estimation • Later: Develop assembling cost estimation
Functions	• Widen the possibilities of which details that could be cost estimated with for example machining. • Include a function to calculate the optimal amount of manufactured details and still get a low price, e g where setup costs per part do not get remarkably lower.

Takes time to fill in the template

It takes time to fill in the templates for making cost estimates in SolidWorks Costing. The input data need to be as accurate as possible in order to receive accurate cost estimates. Both the effort of collecting the data and inserting the data into the template must be taken into calculation.

Collection of data is necessary to cost estimation methods but time taken. Inserting data into the templates could on the other hand be faster. As many companies currently use Excel-tables for data storage, the solution of importing data directly from the existing tables could provide timesaving.

A part-file in SolidWorks is needed

SolidWorks Costing needs a part-file functioning in SolidWorks to make a cost estimate. SolidWorks can convert 3D-files but not 2D-files into part-files. A drawing or description described by phone on the other hand also need to be transferred into a part file before a cost estimate could be made.

Do not support assemblies

Assemblies are only partly supported, see Chapter 3.1.3. Assembling is though one of the difficult operations to estimate according to the interviewees, see Chapter 5.2.2. A future development would be including the assembly operation in SolidWorks Costing. However, assembling would need a lot of other operations as machining to work properly before being of use and therefore the assembling function in SolidWorks Costing lies even further in the future.

Uses lot cost instead of time cost

SolidWorks Costing's estimations are based on cost per length for cutting and cost per bend for bending, see Table 8**Error! Reference source not found.**. However, the interviewees instead based their calculations mainly based on work hours, see Chapter 5.1. The two types of in-data make it necessary to recalculate data; the recalculation could be avoided if the templates were designed differently.

According to Therrien (2011) the appearance of the templates was based on demand from users. A possibility to the different demands could be different requirements for different operations. When calculating cost of laser cutting, it was easier to insert cost per length, since the data was provided from the laser machine data. But for other operations such as punching and bending, inserting cost per work hour could be more suitable since that is the method is in use today.

Some operations needed to be developed

There are limitations of which operations that could be cost estimated in SolidWorks Costing. The main operations as cutting and bending, see Chapter 5.1, had sufficient support but operations as welding and surface treatments could be developed further.

Not suitable for all operations

There were limitations of which operations could be estimated. SolidWorks Costing only supported sheet metal processing, and then mainly cutting and bending operations. Other sheet metal operations as deep drawing could not be estimated. Machining Costing, according to Chapter 3.1.2 needs to be developed further since the functions are not complete. In future versions of SolidWorks Costing more operations should be supported in both Sheet metal and Machining.

10. Implementation of SolidWorks Costing

The case study was performed partly as an implementation experiment of SolidWorks Costing. The case study method was consequently used to find a general implementation process and thereby develop an implementation plan, which SolidEngineer could use to implement SolidWorks Costing in sheet metal companies. This chapter describes the difficulties which may occur during the implementation, a customer profile for the users most benefitted from SolidWorks Costing as well as presents the final implementation plan.

10.1. Difficulties and Solutions

There were certain difficulties during the case study. Seen from the interviews and existing researches, problems during the cases and some other potential difficulties existed in the whole sheet metal manufacturing industry and were barriers of the implementation of SolidWorks Costing. The difficulties and corresponding sections of suggested solutions are presented in Table 16.

Table 16. *Potential difficulties and solutions for implementation of SolidWorks Costing*

Potential Difficulties for Implementation of SolidWorks Costing	Corresponding Sections of Suggested solutions
Low trust in software	10.1.1. Experience-based Cost Estimation
High cost of software	10.1.2. Software Purchasing Cost
Short service life of software	10.1.3. Software Service Life
Too much time spent on learning new software	10.1.4. Time and Resources on Software Learning
Lack of data to make a proper template in SolidWorks Costing	10.1.5. Quality of Input Data
Bad quality of data led to bad output from SolidWorks Costing	10.1.5. Quality of Input Data
Needed functions not included in SolidWorks Costing	10 1.6. Missing Functions

10.1.1. Experience-based Cost Estimation

The negative approach to SolidWorks Costing and problems during the implementation phase was described in Chapter 4.2.2. According to Martiko et al., (1996), one source could be the trend to resist change within the human, or that the tool was not adapted for the users. Furthermore, Martiko et al. (1996) claims that different reactions depend on different personalities and how much the users are about to be affected by the tool.

Experience in sheet metal processing was the most important factor in the cost estimation process according to the interview analysis, see Chapter 7.1.3. The importance of experience was also noticed during the case conduction, both partner companies applied cost estimations based on experience as references for a final test of SolidWorks Costing accuracy. Experience was rated highly, and trusts and interest in testing new software was generally low, see interview results in Chapter 5.1.3; the interviewees believed that the existing cost estimation methods were well-functioning and software could not estimate as accurate as human experience.

According to existing research prevention of resistance to implementation could be done by informing of benefits and build a foundation of trust for the software (Joshi, 1991). The following tasks could therefore be done to show the benefits of SolidWorks Costing and facilitate the implementation phase:

- Convince of the quality and speed of SolidWorks Costing. This by showing how SolidWorks Costing could provide results with high accuracy, see Chapter 8.4.1 as well as provide timesaving.
- Show other well know and well-functional software, and the similarity between the software and SolidWorks Costing.

10.1.2. Software Purchasing Cost

The investment in software needed is a large cost factor (Chen & Norman, 1992), which could also be a barrier of the implementation of SolidWorks Costing. By knowing the time spent on existing cost estimation process and the cost of working time, the needed usage time for the software to pay off could be calculated and showed. Nevertheless, as SolidWorks Costing comes as a built-in module in SolidWorks Professional and Premium (SolidWorks, 2012b). Owners of these two SolidWorks versions already have SolidWorks Costing which gives the software implementation advantages.

10.1.3. Software Service Life

Another common issue of software is its service life, at times; According to Martiko et al. (1996), a common implementation problem was discontinued use of the implemented system that the service life of the software ended before the software use had paid off. This means short service life could be a potential threat also to the implementation of SolidWorks Costing. To ensure the implementation start of SolidWorks Costing and for keeping a long service life, the following suggestion could be recommended:

Provide incremental implementation

According to Fichman and Moses (1999, pp. 39-42), the incremental implementation provides better results than traditional implementation and lasts longer. The incremental implementation means dividing the whole implementation into a series of concurring increment and a short cycle time of each increment.

Applying the theory to implementation of SolidWorks Costing, it would mean implementing the software in different steps. The implementation could start with using SolidWorks Costing to estimate only material costs. At the beginning, the software could also just be used as a complement to existing cost estimation methods to make sure and convince that the software worked correctly. When the users started to accept the software, implementation of another function in the software could begin. So, function by function, user by user more would be included, until all the users could accept and handle all the functions: material, cut, bend and other custom operations.

Provide information of the implementation

According to Joshi (1991) information is important for a successful implementation. The users should be informed of the benefits of the implementation as well as the problems which may occur during implementation. Moreover, it is important to answer the question of work load and possible loss of job. It is also important that the management is involved in and supports the implementation (Geisler & Rubenstein, 1987).

10.1.4. Time and Resources on Software Learning

One problem during the implementation phase according to Martiko et al., (1996) is the trend to resist change within the human nature. General trust in experience also made the thought of learning new software seem unnecessary, see Chapter 7.1.3. However, the users must learn to handle the software well in order to reach a successful implementation. Following tasks could facilitate the learning process of SolidWorks Costing and extend the software's service life:

Explain the strategies and reasons behind the implementation

According to Knowles assumption of adult learning, it is important for adults to learn why before undertaking the learning (Knowles, 1990). In this implementation, it means to teach potential users the functionality, advantages and disadvantages of SolidWorks Costing. Following up with well-designed training programs and support could provide a good outcome of the implementation (Joshi, 1991).

Define the implementation scope and involved positions

Another assumption of andragogy is the learner self-concept (Knowles, 1990). By defining system aims, delimitations, owner and maintainers as well as their responsibilities, the implementation process of SolidWorks Costing implementation could become clearer. Also, defining a maintenance plan at early stage could provide a long service life of SolidWorks Costing.

Combine SolidWorks Costing and existing estimation methods

To take advantage of the students' earlier experience is also an important task in adult learning (Knowles, 1990). In this research, all interviewees pointed out the importance of experience in cost estimation, see Chapter 7.1.3. By including and comparing with the existing estimation methods, the learning process of SolidWorks Costing could become easier to understand and accept.

Different learning styles

According to Learning guide (2012), there are different styles of learning. Combing different teaching styles when learning to handle SolidWorks Costing would make the learning process more effective and individually adapted.

Repetitions

To repeat the newly learned knowledge is also a part of incremental implementation (Leonard-Barton, 1988b, pp. 251-267). According to the theories of learning curve (NASA, 2007) and the forgetting curve (Cherry, 2012b), the information retention and learning results could be improved after multiple repetitions. During the implementation of SolidWorks Costing, each phase need to be repeated until well established before advancing to the next phase.

Feedback and support

The interaction between software and users is important and should be supported by management to improve the results of the implementation (Geisler & Rubenstein, 1987). The implementation of SolidWorks Costing should involve both experts from SolidEngineer and the customer companies. The customers themselves must grow an understanding of the software and especially management need to inform of the benefits and also the problems that will occur during implementation to encourage acceptance; also SolidEngineer should apply support services to facilitate the implementation and usage of SolidWorks Costing.

10.1.5. Quality of Input Data

When using cost estimation software, the customer's desire is that the calculated results would be as close to the actual cost as possible. In this research, the users required an accuracy of 20 %, see Chapter 5.2.1. However, it was impossible to find actual cost data from the machine workshop. The only given data was the companies' own estimations, both as input and reference. The calculation from SolidWorks Costing could only be as accurate as the inserted data.

The input data could be the costumer company's own cost estimation, actual cost calculation or other cost data provided by the company. The quality of input data was important for cost estimations in SolidWorks Costing, since both the accuracy of the results and the software's reliability dependent on the input data. Therefore, the functionality of SolidWorks Costing was related to each company's own existing cost estimations. The existing estimation methods were needed as a foundation for the implementation of SolidWorks Costing. When the input data was missing, the estimation process in SolidWorks Costing became difficult.

Improving the quality of existing cost estimations would not only facilitate the implementation of SolidWorks Costing, but also the company's overall profitability according to Astrada (Kihl, 2012), expert within profitability analysis. Making correct cost estimations is necessary to find the hidden costs and make profitable business.

The quality of input data can be improved by using well-known enterprise resource planning, clearer work structures and continuous documentation. To find the missing data, a stopwatch could be used to document the operational time of a machines, or an experienced machine operator could estimate the operational time. These data could be improved by continuous documentation after series of uniform orderings.

10.1.6. Missing Functions

SolidWorks Costing as a new cost estimation tool from 2012, still had a few functions to improve in order to fulfill the customers' requirements, see Table 13.

Regarding the missing operations in SolidWorks Costing, custom operations could be used. Although the custom operations were not as detailed and well-developed as cutting and bending operations, it enabled manual insertions and adjustments.

10.2. Customer Profile

Based on the functionality of SolidWorks Costing, see Chapter 9, a customer profile of SolidWorks Costing was created. The customers who could benefit from using SolidWorks Costing were divided into two areas; the company profile and the user profile, see Table 17.

Table 17. *Profile of the company and user who could benefit from using SolidWorks Costing*

Company profile	
Size	All sizes
Industry	Sheet metal
Main operations	• Cutting • Bending
Company properties	• In-house manufacturing • (Product design)

User profile	
Position	• Manager • Manufacturer • Designer
Tasks	• Calculates quotes • Designs products

The company should be in the sheet metal industry and their products should be able to be manufactured with mainly cutting and bending operations. Since the manufacturers were concerned about the accuracy of the estimates created in SolidWorks Costing small sized orders where less is to lose would be an area where the first users could be. The main area would be companies which have manufacturing in-house, but also designers could have use of SolidWorks Costing. In order for designers to benefit from SolidWorks Costing they would need cost values to insert into a SolidWorks Costing template. These values could be difficult to find if the company does not have in-house manufacturing.

The user of SolidWorks Costing would be someone which uses cost estimates for quotes or for design decisions, which also was presented by SolidWorks (2012a).

The difference in benefits between the different users; manufacturers and designers is important to realize. As is shown in Table 18, in the manufacturer case, the manufacturer saves time and the company gets better competitiveness by providing more cost effective products. But in the case where the designer is the user only the company will have benefits. The designer will instead have an increase of workload (also discussed in Chapter 5.1.1) and it is therefore important to make the companies benefits clear to the designer in order for the designer to accept the new tool.

Table 18. *The benefits and corresponding profits for a company which lets either manufacturers or designers use SolidWorks Costing*

User	Benefits	Profits	User Workload Savings	Company Competitiveness
Manufacturer	Faster, more quotes	More orders	+	+
Designer	Earlier cost based decisions	More cost effective products	-	+

10.1. Implementation Plan

An important condition of a functional implementation plan was to decide the scope of implementation at an early stage; which operation costs were about to be estimated in SolidWorks Costing, the system owners and maintainers, the expected accuracy and the needed resources. In this research, an implementation plan for SolidWorks Costing was created based on the implementation model at SolidEngineer; see Figure 11, and a project model described by Tonnqust (2008, pp. 358-375).

The implementation plan should be used as a guideline for SolidEngineer when implementing SolidWorks Costing at sheet metal design and manufacturing companies. The technical level of the contents was formed after the knowledge level of the technicians at SolidEngineer. In the implementation plan, the process and detailed description of each stage are presented, see Figure 26.

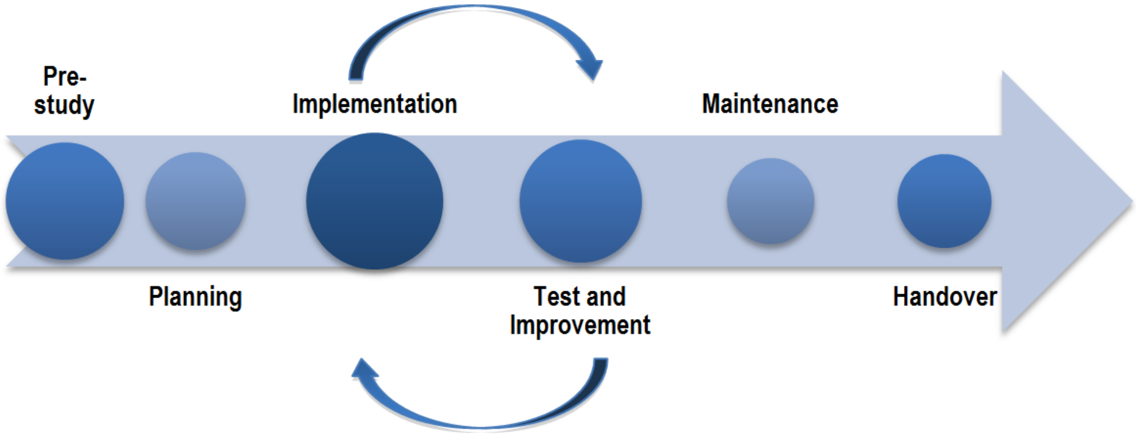


Figure 26. *The implementation process of SolidWorks Costing*

At the pre-study stage, the existing cost estimation methods are evaluated and implementation possibilities investigated. At the planning stage, the project's frames, goals and delimitations are set, and also the system owners and users are decided. Then SolidWorks Costing is about to be implemented and tested at the company. The whole implementation process is interactive, the stages Implementation and Testing & Improvement need to be repeated until the desired results are reached. The next stage in the implementation plan is to maintain the software. At this stage, a maintenance manager is responsible for the software's maintenance and well-functioning. At the last stage of the implementation plan, results of the implementation are handed over to the costumer company. For the complete implementation plan, see Appendix 7. Implementation Plan.

11. Discussion

The methodology used in this research has overall been sufficient to reach the aims. The interviews created a good base of knowledge. More understanding of the cost estimation process was obtained during the case study and finally the implementation plan could be created.

Interviews

The interviews' semi-structure worked in their context. All the interview questions have received an answer except for the questions regarding time and accuracy. The non-existent answers could have depended on the formulation of the question, but also more likely that the interviewees did not know the exact time spent on cost estimations or how accurate the current estimations were.

Also the interviews gave coherent answers, which might imply the questions were leading. However all questions were openly formed and should not have affected the interviewees' answers whereas the interview results could be regarded as true.

Case Study

The case study in this research was important in order to test both SolidWorks Costing and form an implementation plan. However more tests could have been performed. Recommendations of future study can be seen in Chapter 11.1.

11.1. Future Study

This research has been complete to fulfill the aims. However, following tasks can be performed as an extension of this research in the future.

Interviews

- Perform interviews with one or more larger company. Since the interviewees in the smaller companies in this research tended to have multiple tasks, it would be interesting to learn more about how cost estimations are made if and when treated by different departments, and also to see if the work and communication structure at the company could affect the cost estimation procedure.

Case study

- Perform a case study with designers as the cases in this research's case study only included manufacturers.
- Measure how much time is spent on cost estimations with the company's current method and compare it to SolidWorks Costing.
- Perform a case study with secure reference sources. The references should be based on measurements from the manufacturing of certain parts in order to test SolidWorks Costing's possible accuracy.
- Compare the company's actual cost estimations to both company's own cost estimations and estimation from SolidWorks Costing for more cases. The comparison is to find the possible difference in accuracy of different cost estimation methods.
- Perform a larger scale of implementation at a company in order to find possible unforeseen problems. Also measure the difference in implementation time for SolidWorks Costing between small and large scale implemetations.

- Collect more data during the cases to improve the accuracy of the results. However, there is a limit of how much data can be collected due to limit of time and resources. At a point, it will no longer be profitable to collect more data for accuracy improvement. Finding the relation between time and resource cost and accuracy improvement is also a future study point of this research.

Implementation

- Test the implementation plan with more cases to prove the reliability of the implementation plan and find areas of further development.
- Perform a test of the implementation plan over a longer period and follow up the results. The test can prove the durability of the implementation plan and the maintenance sections of the plan.

Other

- Check the possibility of combing SolidWorks Costing and other manufacturability evaluation software. During this research, the manufacturers claimed that the manufacturability also should be considered in industry. By integrating cost estimation and manufacturability, both designer and manufacturer can work closer to each other and more effectively.

12. Conclusions

The conclusions of this research are answers to the aims presented in Chapter 1.3. The conclusions are based on research in the sheet metal industry.

Cost estimation in industry

I. The current cost estimation procedure could be broken down into the steps shown in
Figure 27.

Figure 27. *The current cost estimation procedure in industry.*

II. The most important aspect during the current cost estimation process was to have good knowledge of the process, based on experience in sheet metal manufacturing.

Cost estimations in SolidWorks Costing

III. Sheet Metal Costing gives as good accuracy as existing methods regarding use for sheet metal parts, but Machining Costing needs development to be suited for industrial use.

IV. SolidWorks Costing is faster and more reliable than current used methods in industry. SolidWorks Costing fulfill many, but not all of the industry's requirements,
see Table 16.

Implementation of SolidWorks Costing

V. An implementation plan of SolidWorks Costing was developed and can be seen in Appendix 7. Implementation Plan.

VI. The common problems during the implementation and maintenance of SolidWorks Costing were;

- Acceptance issues, which depended on low trust in software, and also of the implementation time and cost.
- Short service life, which depended on the lack of maintenance and a bad implementation process.

To avoid the problems it is important to inform all users of the benefits and possibilities that will come from using SolidWorks Costing, and also to inform of problems that could occur and which precautions that are taken to avoid them. Implementation should be made in small steps.

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Appendix 1. Interview Guide

This is the interview guide which was used as a framework conducting interviews for the thesis Implementation of SolidWorks Costing.

- Please tell us something about your company. Within which industry do you work? How many work here and do you have your own manufacturing?
- Who usually do the estimations and who accepts them within your company?
- Do you have a method for doing cost estimations?
- When do you do cost estimations?
- How much time do you spend on calculating costs?
- How is the needed manpower calculated in a cost estimation?
- What do you base the calculations on? If it is experience, how do you store and pass the knowledge to the new coworkers?
- What do you think is the most difficult part of cost estimations?
- Do you have a standard price list for different operations? How often do you update the values in the list?
- Which accuracy does a cost estimation need to hold?
- What do you think about your existing way to estimate costs? Why?
- Have you tested other methods than the existing?
- If there is software to make cost estimations, what are the most important tasks it should manage?

Appendix 2. Case Study Protocol

This protocol was used as a conduction plan of the case study made in the thesis Implementation of SolidWorks Costing.

1. Background
    a) In order to perform this case study, a pre-study of frame of references and interviews were done to find the theories behind cost estimations and how it is done in Swedish sheet metal industry.
    b) The main research question of this case study is to find the hidden link between cost estimations in Swedish industry and SolidWorks Costing, and how to implement SolidWorks Costing in industry.

2. Design
    a) In this study, a multiple-case of two cases were be used. These two cases were done at partner companies with different backgrounds, to see if the implementation procedure of SolidWorks Costing would be similar or if there needed to be modifications.
    b) The object of this study is SolidWorks Costing.
    c) Besides how the implementation of SolidWorks Costing would be done in Swedish sheet metal industry, another research question of this study is to find the user profile of the software.

3. Case Selection
    a) The two cases needed to be done at two Swedish companies with operational area sheet metal.
    b) The two companies needed to act in sheet metal industry.
    c) The two companies needed to work with both design and manufacture.
    d) The products of these two companies needed to have cutting and bending as the most common operations.

4. Case Study Procedures and Roles
    a) During the cases, the partner companies would supply cost estimation information and costs of different operations.
    b) The researchers would analyze how the information could be transformed into required parameters in SolidWorks Costing and compare the results from the existing cost estimation method and SolidWorks Costing.

5. Data Collection
    a) The needed data of this research was:
        i. Cost data and dimensions of cutting and bending tools
        ii. Setup costs of the tools
        iii. Results from existing cost estimation methods
    b) The data will be collected and compared in Microsoft Office Excel sheets

6. Analysis

a) The collected data would be re-calculated to find out the relations between operation and cost
b) Different trend lines would be drawn to find if the operation cost was depended on a specific parameter, such as material type, thickness and so on.
c) Operation costs depended on material type and thickness would be used in SolidWorks Costing to find the manufacture costs.
d) The possible differences between costs from SolidWorks Costing and existing method would be compared.
e) Possible reasons behind the differences would be analyzed.

7. Study Limitations

Two cases would be performed in this study.

9. Reporting

The results and detailed analysis of this case study are shown in the report, Implementation of SolidWorks Costing, The Implementation process and Cost Estimation in Sheet Metal Industry.

Appendix 3. Case Study Results: Material

This appendix describes the percentage different between SolidWorks Costing and the company's own cost calculation in material cost. The results are presented for each of the test parts. Also, the average difference from the first comparison and the average difference after adjustments are shown. Table 1shows the results from Case 1 and Table 2 shows the results from Case 2. Some cells remain empty due to lack of data.

Table 1. *The first and adjusted difference between the company's cost estimations and results from SolidWorks Costing in Case 1*

Part Nr.	Original comparison		Comparison after adjustment	
	Percentage difference	Absolute value of percentage difference	Percentage difference	Absolute value of percentage difference
1	-67%	67%	-64%	64%
2	2%	2%	11%	11%
3	-13%	13%	-5%	5%
4	-9%	9%	-1%	1%
5	-11%	11%	-3%	3%
6	-72%	72%	-69%	69%
7	-1%	1%	8%	8%
8	-2%	2%	7%	7%
9	19%	19%	29%	29%
10	-12%	12%	-4%	4%
11	27%	27%	39%	39%
12	26%	26%	37%	37%
Average	-9%	22%	-1%	23%
Median	-6%	13%	3%	10%

Table 2. *The first and adjusted difference between the company's material cost estimations and results from SolidWorks Costing in Case 2*

Part Nr.	Original comparison		Comparison after adjustment	
	Percentage difference	Absolute value of percentage difference	Percentage difference	Absolute value of percentage difference
1	-8%	8%	-5%	5%
2				
3	-10%	10%	-6%	6%
4	-5%	5%	-1%	1%
5	-3%	3%	1%	1%
6	14%	14%	19%	19%
7	-11%	11%	-7%	7%
8	16%	16%	20%	20%
9	-21%	21%	-18%	18%
Average	-3%	11%	0%	10%
Median	-7%	10%	-3%	7%

Appendix 4. Case Study Results: Cutting

This appendix describes the percentage different between SolidWorks Costing and the company's own cost calculation in cutting cost. The results are presented for each of the test parts. Also, the average difference from the first comparison and the average difference after adjustments are shown. Table 1 shows the results from Case 1 and Table 2 shows the results from Case 2. Some cells remain empty due to lack of data.

Table 1. *The first and adjusted difference between the company's cutting actual cost calculations and results from SolidWorks Costing in Case 1*

Part Nr.	Original comparison		Comparison after adjustment	
	Percentage difference	Absolute value of percentage difference	Percentage difference	Absolute value of percentage difference
1	-41%	41%	-31%	31%
2	-17%	17%	-4%	4%
3	-67%	67%	-62%	62%
4	1%	1%	17%	17%
5	-28%	28%	-17%	17%
6	33%	33%	54%	54%
7	-13%	13%	0%	0%
8	-79%	79%	-75%	75%
9	-55%	55%	-47%	47%
10	9%	9%	27%	27%
11	57%	57%	83%	83%
12	8%	8%	25%	25%
Average	-16%	34%	-2%	37%
Median	-15%	30%	-2%	29%

Table 2. *The comparison between the company's laser cutting cost estimations and results from SolidWorks Costing in Case 2*

Part nr	Percentage difference	Absolute value of percentage difference
1	-17%	17%
3	-15%	15%
4	28%	28%
5	-14%	14%
6	-13%	13%
7	6%	6%
8	13%	13%
9	9%	9%
Average	0%	14%
Median	-3%	14%

Appendix 5. Case Study Results: Bending

This appendix describes the percentage different between SolidWorks Costing and the company's own cost calculation in bending cost. The results are presented for each of the test parts. Also, the average difference from the first comparison and the average difference after adjustments are shown. Table 1 shows the results from Case 1 and Table 2 shows the results from Case 2. Some cells remain empty due to lack of data.

Table 1. *The first and adjusted difference between the company's actual bending cost calculations and results from SolidWorks Costing in Case 1*

	Original comparison		Comparison after adjustment	
Part Nr.	**Percentage difference**	**Absolute value of percentage difference**	**Percentage difference**	**Absolute value of percentage difference**
1	15%	15%	10%	10%
2	-38%	38%	-40%	40%
3	12%	12%	8%	8%
4	-12%	12%	-16%	16%
5	19%	19%	14%	14%
6	25%	25%	20%	20%
7	38%	38%	33%	33%
8	8%	8%	4%	4%
9	-53%	53%	-55%	55%
10	79%	79%	72%	72%
11	-29%	29%	-32%	32%
12	-17%	17%	-20%	20%
Average	4%	29%	0%	27%
Median	10%	22%	6%	20%

Table 2. *The first and adjusted difference between the company's bending cost estimations and results from SolidWorks Costing in Case 2*

	Original comparison		Comparison after adjustment	
Part Nr.	**Percentage difference**	**Absolute value of percentage difference**	**Percentage difference**	**Absolute value of percentage difference**
1	12%	12%	14%	14%
2				
3	-3%	3%	-2%	2%
4				
5	45%	45%	47%	47%
6	-36%	36%	-35%	35%
7	-13%	13%	-12%	12%
8	13%	13%	14%	14%
9	-25%	25%	-24%	24%
Average	-1%	21%	0%	21%
Median	-3%	13%	-2%	14%

Appendix 6. Case Study Results: Combined Results

This appendix describes the percentage different between SolidWorks Costing and the company's own cost calculation combined in material, cutting and bending. The results are presented for each of the test parts. Also, the average difference from the first comparison and the average difference after adjustments are shown. Table 1 shows the results from Case 1 and Table 2 shows the results from Case 2. Some cells remain empty due to lack of data.

Table 1. *The comparison between the original estimation from SolidWorks Costing and the adjusted estimation from SolidWorks Costing and the company's actual cost calculation.*

Part Nr.	Original comparison		Comparison after adjustment	
	Percentage difference	Absolute value of percentage difference	Percentage difference	Absolute value of percentage difference
1	-19%	19%	-17%	17%
2	-29%	29%	-27%	27%
3	-39%	39%	-35%	35%
4	-9%	9%	-5%	5%
5	-7%	7%	-2%	2%
6	-9%	9%	-7%	7%
7	2%	2%	10%	10%
8	-64%	64%	-61%	61%
9	-33%	33%	-29%	29%
10	8%	8%	17%	17%
11	17%	17%	28%	28%
12	12%	12%	22%	22%
Average	-14%	21%	-9%	22%
Median	-9%	14%	-6%	19%

Table 2. *The comparison between the original estimation from SolidWorks Costing and the adjusted estimation from SolidWorks Costing and the company's cost estimations.*

Part Nr.	Original comparison		Comparison after adjustment	
	Percentage difference	Absolute value of percentage difference	Percentage difference	Absolute value of percentage difference
1	12%	12%	14%	14%
2				
3	-3%	3%	-2%	2%
4				
5	45%	45%	47%	47%
6	-36%	36%	-35%	35%
7	-13%	13%	-12%	12%
8	13%	13%	14%	14%
9	-25%	25%	-24%	24%
Average	-1%	21%	0%	21%
Median	-3%	13%	-2%	14%

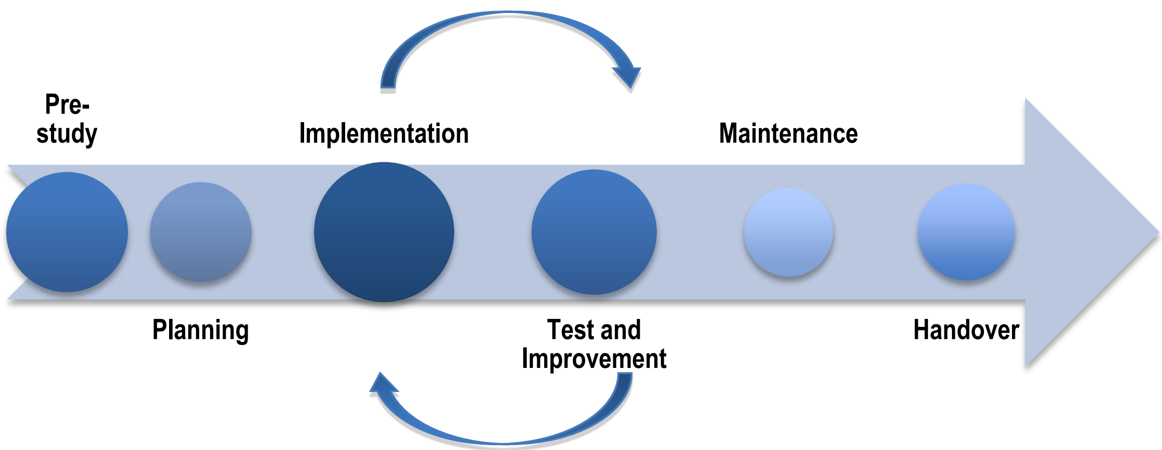
Appendix 7. Implementation Plan

This is an implementation plan for SolidWorks Costing, developed in the thesis Implementation of SolidWorks Costing.

Implementation

of

SolidWorks Costing



Abilities and Limitations in SolidWorks Costing

There are several advantages of using Costing. For designers it can help evaluation of design changes in an early stage, the comparison of different material as well as features and provide for a more precise estimation of manufacturing costs. For manufacturers on the other hand, Costing can make more specific quotes based on material and manufacturing processes.

Sheet metal Costing can do:

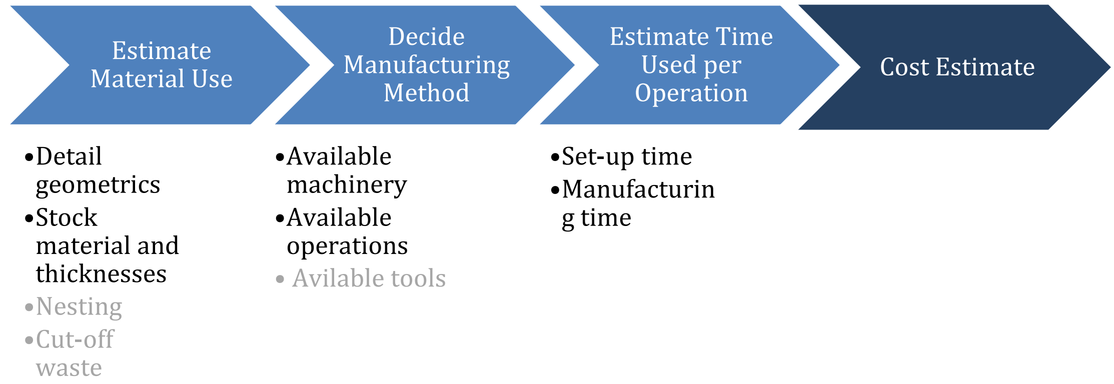
- Parts that can be converted to sheet metal
- Cutting
- Bending
- Library features
- Custom operations

Sheet metal Costing cannot do:

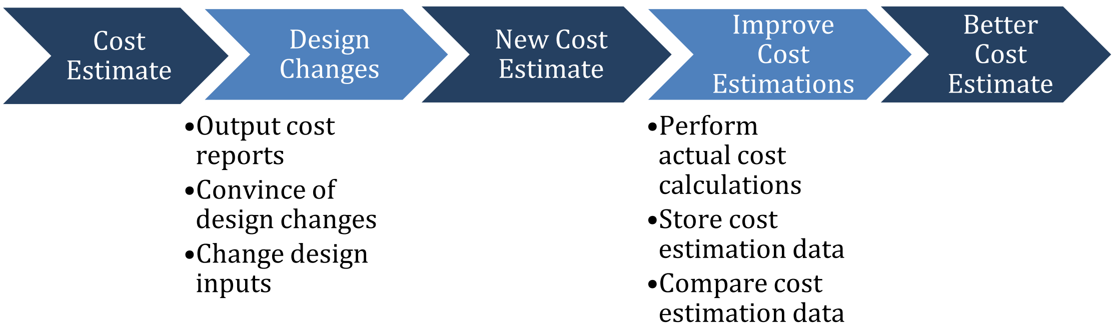
- Assemblies
- Drawing or PDF-file

The abilities and limitations of Costing during the cost estimation process are shown in the figures below. The black points are those Costing can do during the process, while the gray points are those included in the process but not yet supported in Costing.

Cost Estimation Procedure



Design Change and Cost Estimation Improvement



The customer profile of suitable company to implement SolidWorks Costing to reach good results is shown in the table below:

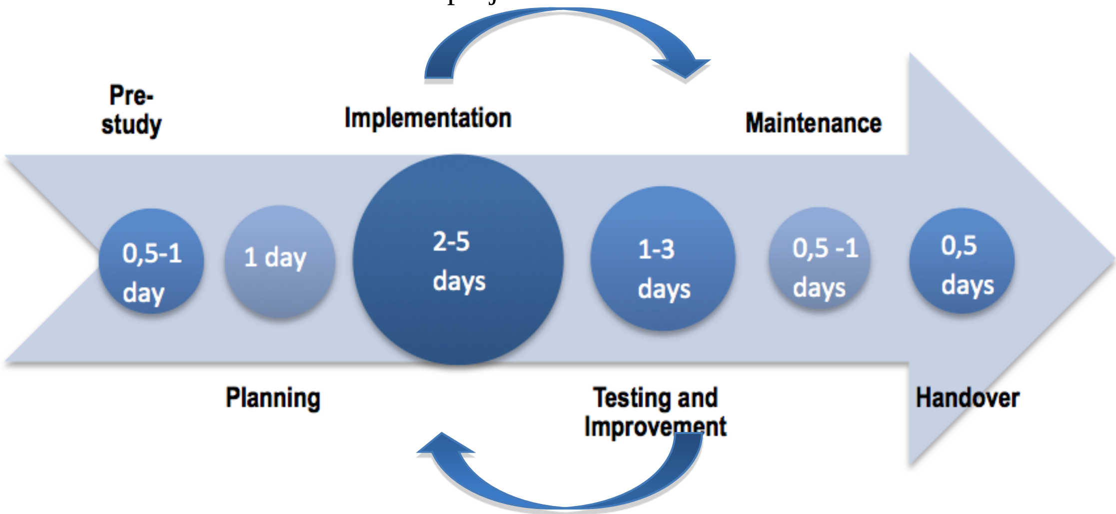
Company profile	
Size	All sizes
Industry	Sheet metal
Main operations	• Cutting • Bending
Company properties	• In-house manufacturing • (Product design)

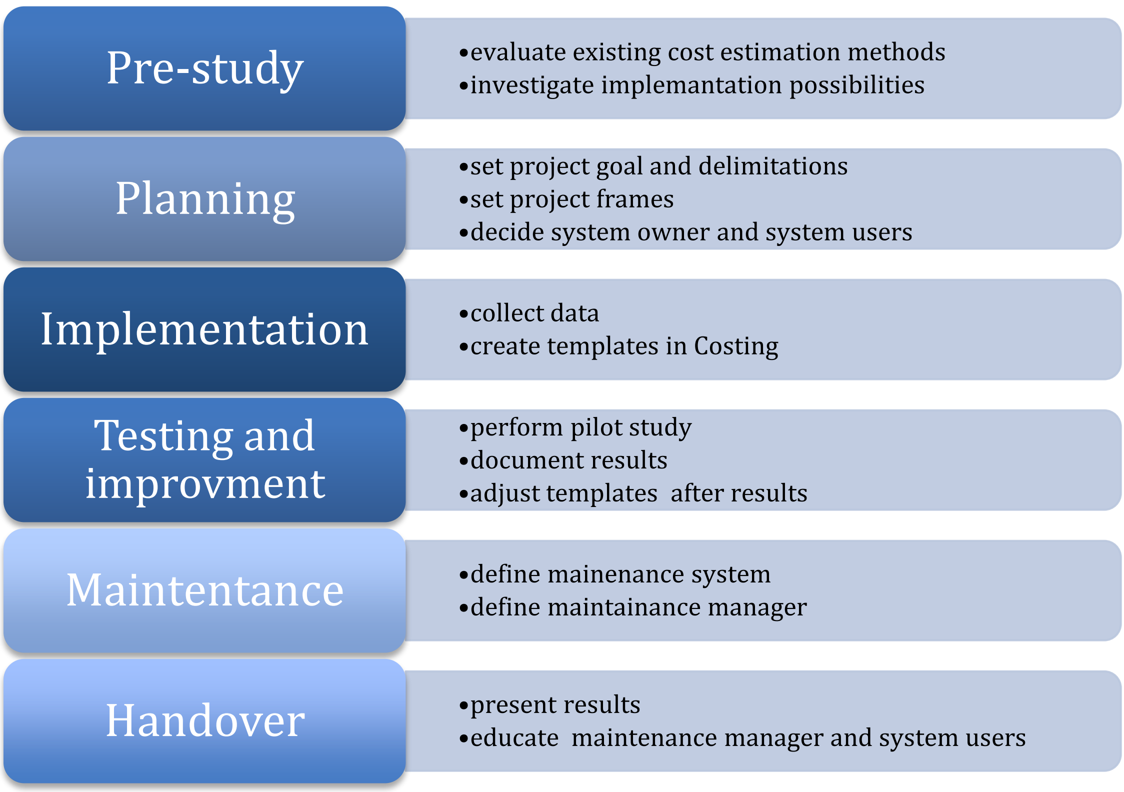
User profile	
Position	• Manager • Manufacturer • Designer
Tasks	• Calculates quotes • Designs products

Table of Contents

1. The Implementation Stages

The implementation stages were developed based on two earlier performed implementation experiments. In the first figure, the whole structure of the process is shown. The whole implementation process is interactive, the stages implementation and testing & Improvement need to be repeated until the desired results are reached. The needed time of each stage, shown in the process figure, is estimated based on the two experiments. The time varies due to the extent and condition of different projects.





2. Pre- study

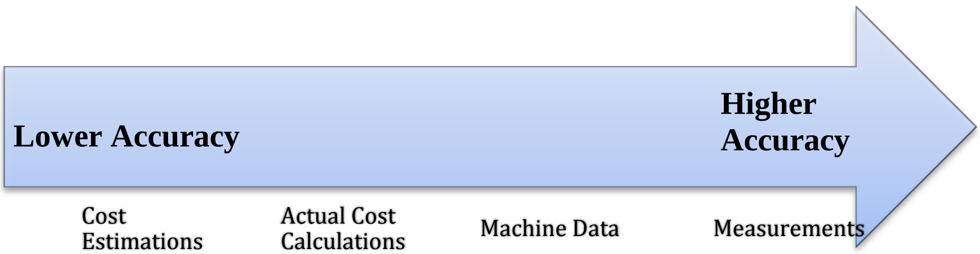
A pre-study is needed to find the possibilities and scope of the implementation. In this stage, the following need to be investigated:

- Evaluate the existing cost estimation methods
  - Which operations are performed and which of them are suitable to implement in SolidWorks Costing
  - The possibilities to combine existing methods and Costing
  - The accuracy and reliability of the existing methods

2.1. Evaluation of Existing Methods

The following tasks are important when evaluating the reliability of the existing methods

- The accuracy of SolidWorks Costing depends on the inserted data; see the figure below
- Clarify if setup costs already are included in the existing method to calculate the operational costs
- Double-check the reliability of data. The actual cost estimation could sometimes be incorrect.



3. Planning

At this stage of the project, the extent of the project should be defined. The following need to be decided:

- Define goals and limitations of the implementation
  - Included operations
  - Amount of templates to be implemented
  - Chosen data sources
  - Desired estimation accuracy with SolidWorks Costing
  - Amount of part files which should reach the desired accuracy
  - How many test parts will be used in the test and improvement stage

- Define the system owner and system maintainer

- The organization of the project
  - Responsibilities
  - Project budget
  - Communication and quality assurance
  - Risk analysis of the implementation
  - The time schedule of the project

- Handover plan

4. Implementation

At this stage of the implementation, the main tasks are:

- To collect data
- To create a template

4.1. Collect Data

Data needed to insert in a template:

- List of used material (find them in SolidWorks database or insert custom material in the database)
- Relevant thicknesses of the used materials
- Cost per kilo of the materials
- Setup costs for the chosen operations
- Cost per operation

Criteria of data collection:

- Data with minimal manual processing during the operations
- Representative data to assure the quality of data. For example data from typical and regular orderings
- Large series
- If there is both a pre-estimation and an actual cost calculation, data quality is considered good when the two estimations match each other well

Amount of suggested data (parts) for material and operations[1]:

Data source	Suggested amount
Material cost per part	20 parts
Own cost estimation/actual cost calculation	20 parts
Machine data from laser, plasma and water jet	Machine data sheet
Machine data from setup schedule, punching machine	10 data points per sheet thickness
Measured operation time	20 parts

[1] The suggested amount was based on two earlier performed implementation experiments. Lager amount of data provides better results, however data collection is a time-consuming activity.

4.2. Calculate Material and Operation Costs

Calculate cost of material and operations when the test parts are chosen.

How to calculate material costs:

(or use Appendix Template Data Collection with Excel-files)

- Insert the kilo cost per material in SolidWorks Costing, to find out material cost per part for the chosen test parts according to the table in the previous page
- Compare the material cost per part from SolidWorks with the material cost per part provided by the company
- Find the average percentage difference between SolidWorks Costing and the company's own material cost data
- Adjust material cost per kilo according to:
  - $$\boldsymbol{new\ cost\ per\ kilo = old\ cost\ per\ kilo * (1 - average\ difference)}$$
- Use the new cost per kilo to insert in SolidWorks Costing

How to calculate operation costs:

- If the reference values come from the company's own cost estimation or their actual cost calculation, calculate the needed values to insert in a Costing template according to Appendix: Template Data Collection, including instructions and Excel-files
- If the reference values come from machine data, for example, laser machine or water jet machine, calculate according to:

$$\boldsymbol{Cost\ per\ millimeter = \frac{laser\ machine\ hourly\ cost}{laser\ machine\ speed}}$$

- If the reference values come from machine data, for example a punching machine's setup schedules, calculate according to Appendix: Punching Operation Cost
- Measure data if neither of the options above are available or unreliable. Measure the machine operation time of a part with a stopwatch, as well as the machine setup time. From the machine's/operation's cost per hour, calculate the needed values to insert in Costing template according to Appendix: Template Data Collection

4.3. Create a Template and Estimation in SolidWorks Costing

Create a template, using material and operation costs calculated from the previous stage. Fill out the following in a template:

- Chose units
- Chose material types
- Enter thicknesses of the selected material
- Insert cutting costs
- Insert bending costs
- Insert other costs

For a more detailed description of each step, see Appendix: How to Fill out an Template

Finish the cost estimation in SolidWorks Costing by choosing relevant material, sheet thickness, lot size etc in the task pane. For a detailed description, see Appendix: Estimate Costs in SolidWorks Costing

5. Testing and Improvement

To test the accuracy of the created template, test on 10 representative parts that have not been used to create the template. Repeat this stage until the desired accuracy is reached according to Appendix: Accuracy Improvement, including instructions and Excel-sheets.

6. Maintenance

Define the maintenance plan of the project:

- What in the templates should be updated and how often
- How much time should be spent on maintenance
- Who is the maintenance manager and which are his/hers responsibilities

The templates should be updated continuously, at least once every six months according to the test and improvement phase. An update of the templates is recommended when the following happens:

- change of vendor
- change of prices
- change of machinery
- change of hourly wages
- or change in rent or investment costs

7. Handover

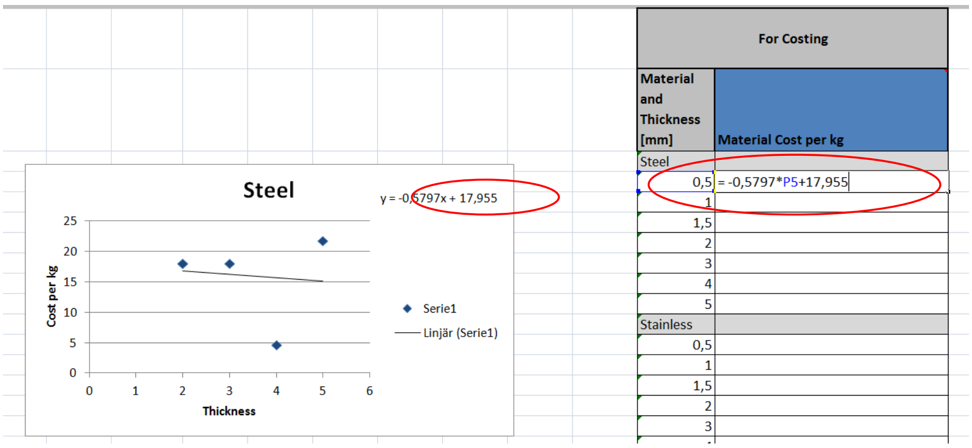
- Delivery of results and follow-up plan
- Analysis of existing cost estimation methods
- Education plan of the system users and maintenance manager
    - How Costing works
    - How to collect data
    - How to maintain the template and improve data from the templates

Appendix: Template Data Collection

The file [Template Data Collection] contains several sheets named [Part info], [...], and so on. Go through the sheets in the following order to collect the needed figures for creating a SolidWorks Costing template.

1. [Material Def] Fill in all materials and thicknesses
2. [Part Info] Fill in the needed information from:
    a. Part Files
    b. Cost information per part and operation
    c. Solid Works Costing
3. [Material Cost] Find the costs for different materials by:
    a. Analysing the data in the diagrams. (Remove ev. odd data.)
    b. Insert the equations from diagrams into the ”For Costing” square. Use one equation for every material. The variable should be changed into the thickness. See example below.

    -
    - Example of how to insert an equation
        i. Right click the diagram and insert a trendline, check the box show equation.
        ii. Enter the equation into the right table, see figure below.
        iii. Drag down holding the corner of the square to copy the equation for each thickness.



4. [Cutting Cost], [Bending Cost], [Custom Operating Cost] Repeat step 2 for the remaining operations.
5. [Costing Data]Insert the calculated data into a SolidWorks Costing Template.

Appendix: Punching Operation Cost

There are two ways to insert punching costs in SolidWorks Costing:

- Cost/hole
- Cost/mm

To calculate the two costs if the setup schedules from the punching machine data are used as reference:

1. From every schedule, find out the time spent to punch the whole sheet and amount of holes in the sheet, regardless of hole sizes and tool sizes
2. Calculate average time/hole = t
3. Find out the hourly cost of the punching machine = k
4. Cost per hole can be calculated according to:

$$cost/hole = k * t$$

5. Plot cost/hole as an exponential function of sheet thickness in a Excel-file.
6. Calculate the new average cost/hole to insert in SolidWorks Costing according to the exponential equation.
7. Find out the dimension of the punching tool. If the tool is 20 mm wide, then cost per millimeter is calculated according to:

$$cost/mm = \frac{cost/hole}{20}$$

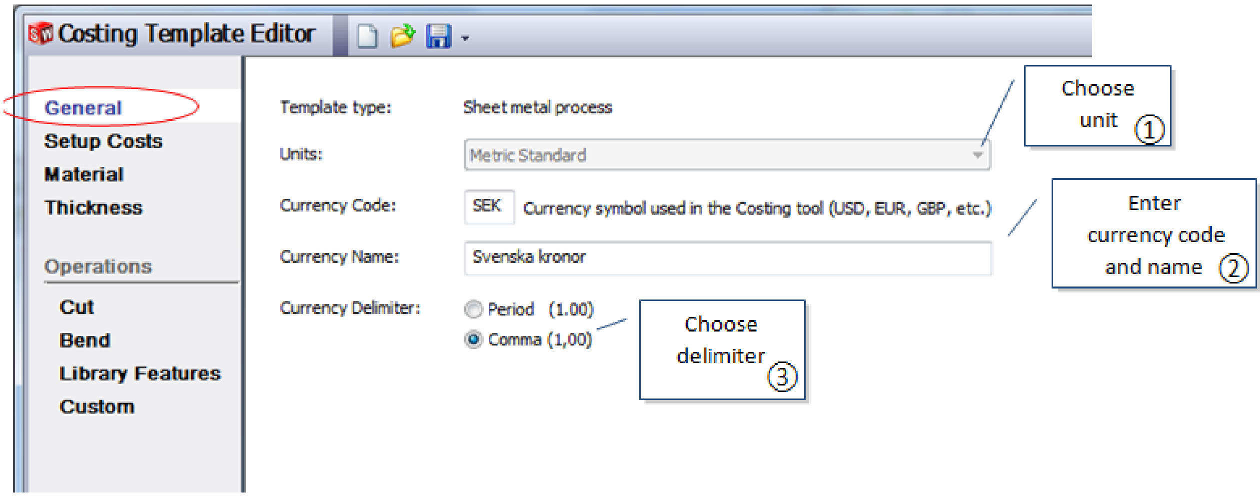
Appendix: How to Fill out an Template

There are several values to choose or enter in order to create a SolidWorks Costing template, see the steps below.

The Costing Template Editor is found under tools, SolidWorks Costing. Then click “Launch template editor” in the task pane.

First step: General

Set type of units and currency according to step ① to ③.

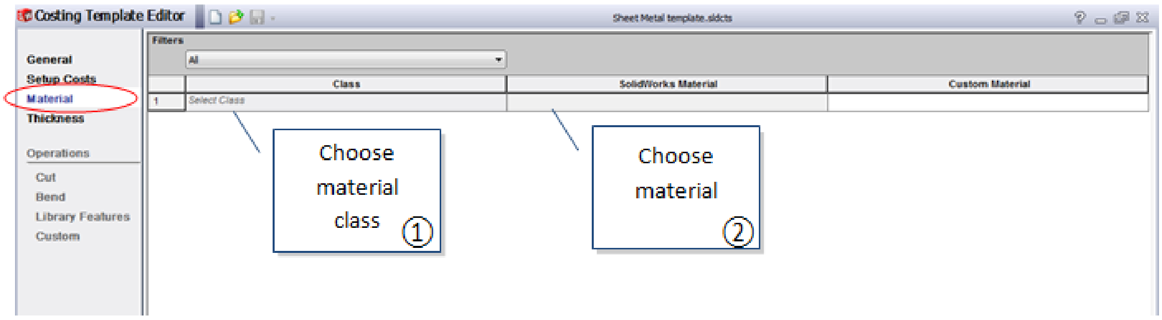


Second step: Material

Use Material data from the Excel-file, Template Data Collection.

Costing Data								
	Operation Costs					Set-up Costs		
Material and Thickness [mm]	Material Cost [cost/kg]	Cutting Cost [cost/mm]	Bending Cost [cost/bend]	Custom Operation Cost [cost/?]		Cutting	Bending	Custom Operation
Material 1						0	0	0
0.5	0	0	0	0				
1	0	0	0	0				
1.5	0	0	0	0				
Material 2								
0.5	0	0	0	0				
1	0	0	0	0				
1.5	0	0	0	0				

Enter material types according to step ① to ②. Repeat for all materials.

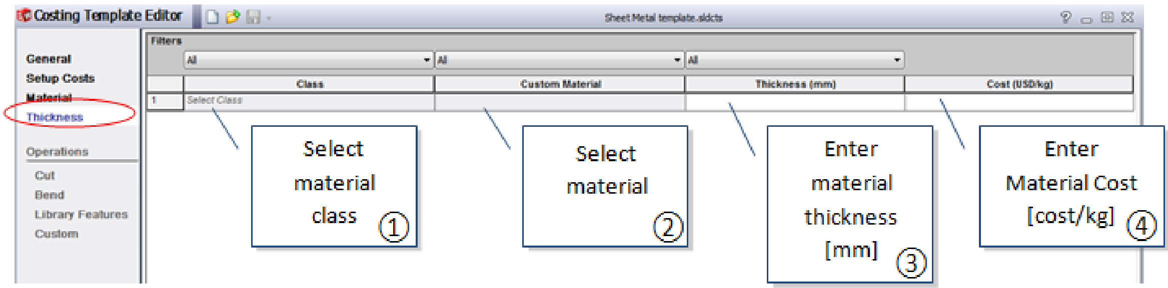


Third step: Thickness

Use Material cost data from the Excel file, Template Data Collection.

Costing Data								
	Operation Costs					Set-up Costs		
Material and Thickness [mm]	Material Cost [cost/kg]	Cutting Cost [cost/mm]	Bending Cost [cost/bend]	Custom Operation Cost [cost/?]		Cutting	Bending	Custom Operation
Material 1						0	0	0
0.5	0	0	0	0				
1	0	0	0	0				
1.5	0	0	0	0				
Material 2								
0.5	0	0	0	0				
1	0	0	0	0				
1.5	0	0	0	0				

Enter material thicknesses and costs according to step ① to ④. Repeat for all materials and thicknesses. Save the template.



Fourth step: Cut

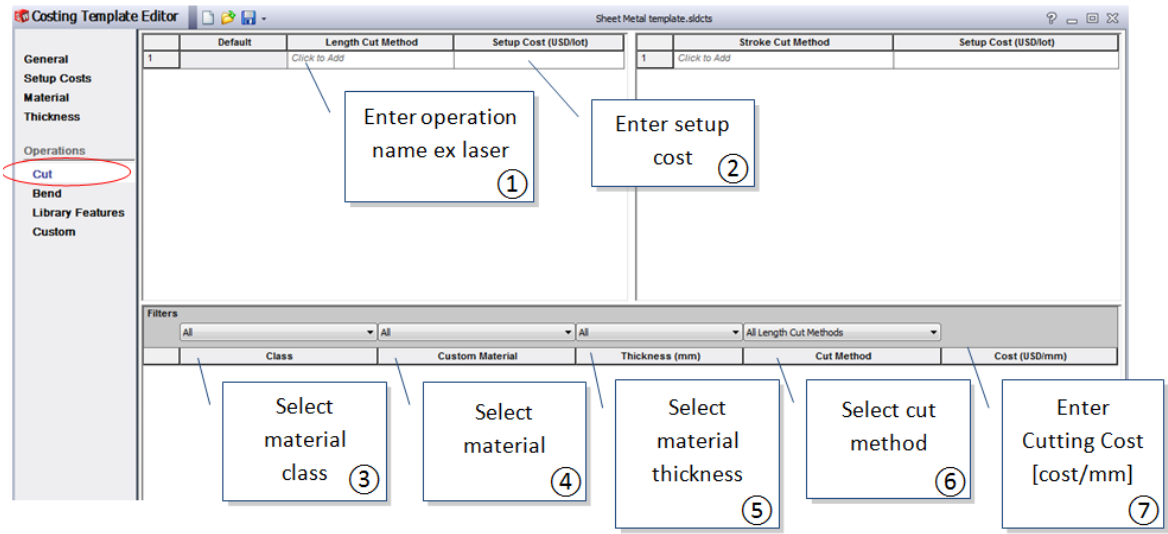
Use cutting cost data from the Excel file, Template Data Collection.

Costing Data

	Operation Costs			
Material and Thickness [mm]	Material Cost [cost/kg]	Cutting Cost [cost/mm]	Bending Cost [cost/bend]	Custom Operation Cost [cost/?]
Material 1				
0.5	0	0	0	0
1	0	0	0	0
1.5	0	0	0	0
Material 2				
0.5	0	0	0	0
1	0	0	0	0
1.5	0	0	0	0

Set-up Costs		
Cutting	Bending	Custom Operation
0	0	0

Enter cutting cost according to step ① to ⑦. Repeat for all materials and thicknesses. Save the template.



Fifth step: Bend

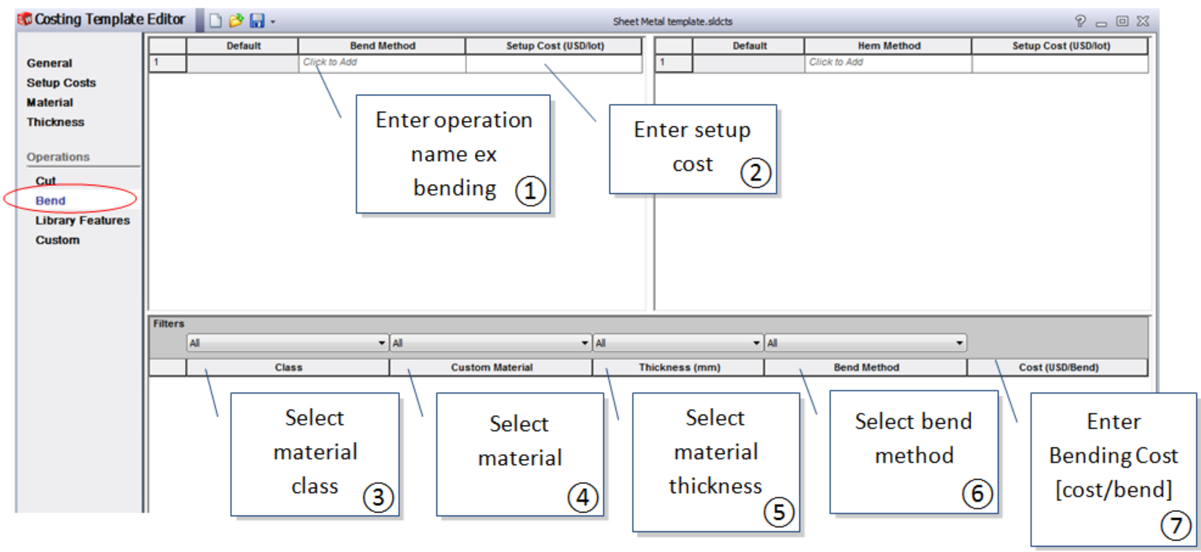
Use cutting cost data from the Excel file, Template Data Collection.

Costing Data

	Operation Costs			
Material and Thickness [mm]	Material Cost [cost/kg]	Cutting Cost [cost/mm]	Bending Cost [cost/bend]	Custom Operation Cost [cost/?]
Material 1				
0.5	0	0	0	0
1	0	0	0	0
1.5	0	0	0	0
Material 2				
0.5	0	0	0	0
1	0	0	0	0
1.5	0	0	0	0

Set-up Costs		
Cutting	Bending	Custom Operation
0	0	0

Enter bending costs according to step ① to ⑦. Repeat for all materials and thicknesses. Save the template.



Sixth step (optional):

Enter Setup costs, Library features costs and Custom operations costs similar to the other operational costs.

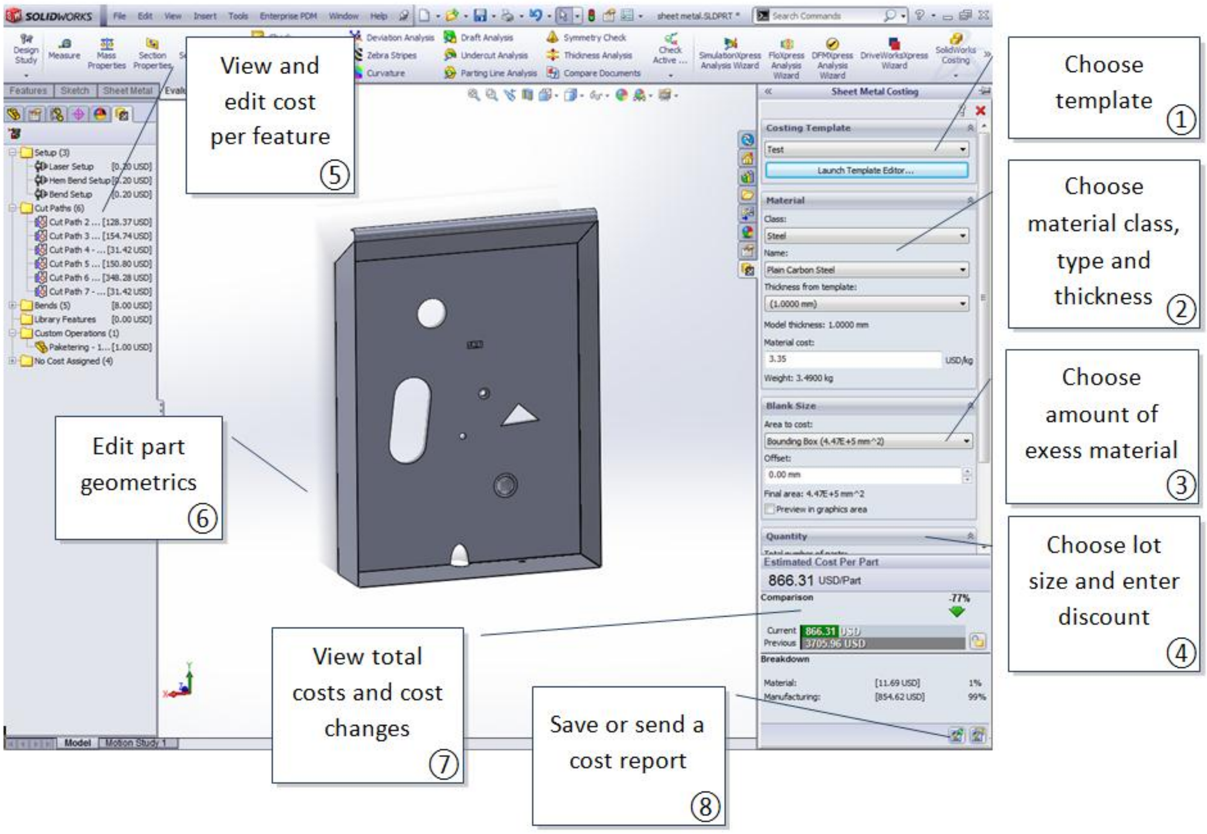
Save the template.

Appendix: Estimate Costs in SolidWorks Costing

Go to Tools, Costing, Sheet Metal Costing to start SolidWorks Costing. The cost estimating steps and abilities in Costing are shown in the figure below.

The cost estimating choices that precede a cost estimate are step ① to ④.

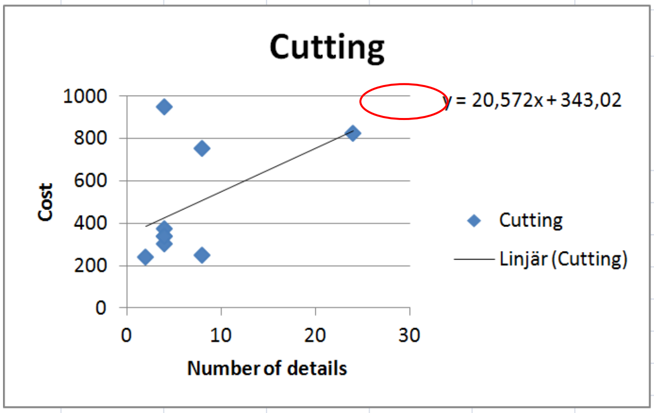
And the cost analysis steps are ⑤ to ⑧.



Appendix: Accuracy Improvement

The file [Accuracy Improvement] contains several sheets named [Data Collection], [...], and so on. Go through the sheets in the following order to test and improve SolidWorks Costing results.

1. [Costing Values] Fill in the original values from a SolidWorks Costing Template.
2. [Data Collection] Fill in the needed information from:
    a. Actual cost calculations
    b. Part Files
    c. SolidWorks Costing
3. [Test without setup] Analyze the operation costs.
    a. If the new Costing values gives better results, the Costing Template need to be updated.
    b. Updated Costing Template values are found in [Costing Values].
4. [Test with Setup] Analyze the part costs with setup.
    a. If the new values give better results, the Costing template needs to be updated.
5. [Setup Costs] Update the setup costs.
    a. The new setup cost equals the equation constant, see example below.
    - Example of where to find new setup cost values



    b. The "Additional Profit Margin" could be used to change setup cost to receive a different profit margin.
6. [Costing Values] View the new SolidWorks Costing Template values.
    a. Update the values in the Template for operations that were given a better result in step 3 and 4.