A PARAMETRIC PROCESS-BASED COST ESTIMATION FRAMEWORK TO SUPPORT CONCEPTUAL PRODUCT FAMILY DESIGN AND PRODUCTION

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ABSTRACT

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In today's globally competitive environment, production costs estimation is a challenging task. This competitive market has brought specific strategies in the manufacturing sector, such as introducing more new products into the market with lower prices. In order to have the most accurate production costs estimation, accurate production cost information in a useful and relevant form is needed. This study presents a cost estimation framework that integrates both activity and parametric cost estimation methods to increase the ease, accuracy, and speed of producing cost estimates for a family of products or services.

There is a need for an integrated production cost estimation model framework with three main characteristics. First, a model combining different costing methods that estimate product costs at the early stage of development in the product family. Secondly, a model with system description methods that can be more flexible and generic. Third, a costing model based on system analysis and computer models which support dynamic cost estimation. A production cost estimation model with these three characteristics can be an integrated, generic, and dynamic model providing cost information in a useful form which could be seen as a more accurate cost estimation method.

The study will discuss how process description capture methods can be used to identify the activities that drive cost. Also, a costing model based on the conceptual system description method will provide a more generic costing tool. The process description capture method (IDEF3) is used to support different production scenarios. Also, this study indicates the probability that precise and accurate cost estimation can be done by utilizing simulation before actual manufacturing production. Simulation-based cost estimation provides a powerful management tool for decision-making processes. In addition, simulation models are able to provide more details and also consider the variation of a dynamic manufacturing system. In order to highlight the important potential benefits of the new costing model, different applications of the new model are discussed. Finally, the model was tested based on a real case study of a small us-based manufacturer.

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List of Abbreviations

ABC	Activity Based Costing
ABM	Activity Based Management
IDEF3	Process Description Capture Method
PFA	Product Family Architecture
RFWN	Weld-Neck Flange
RFSO	Slip-On Flange

CHAPTER 1

INTRODUCTION

1.0. The Need For Better Costing

In today’s globally competitive environment, production costs estimation is a challenging task. This competitive market has brought specific strategies in the manufacturing sector, such as introducing more new products into the market with lower prices. In order to have the most accurate production costs estimation, accurate production cost information in a useful form is necessary. There are many different cost-modeling techniques based on qualitative or quantitative approaches that can be used. However, the actual cost estimation choice depends on the product, process, and the availability of information. Therefore, it would be difficult to select the most appropriate ones. An appropriate cost estimation model might provide more accurate information that leads to more successful business. However, it will nonetheless be a challenging decision.

In this chapter, some problems in available cost estimation models are presented. Then, approaches and tools for reducing or solving those aforementioned problems and the need for a new costing model are discussed. After that, the value and novelty of a new costing model will be explained. Finally, in order to highlight the important potential benefits of the new costing model, different applications of the new model are discussed.

1.1. Problem Statement

Production cost estimation is a challenging task. Some challenges during production cost assessments are cost estimation during the early stage of the design, as well as the total accurate cost estimation. Most of the traditional cost methods are applied after the design process when cost reduction possibilities have already been lost. Therefore, production cost estimation in the early stages of product design and development is one of the main challenges for cost assignment, especially in a product family design.

There are many studies evaluating the production cost estimation framework to support product family design at early stages of product development. Most researchers discuss the combination of different modern product cost modeling for the better result, rather than traditional cost methods. Among all different costing models, activity-based costing, the parametric costing model, and the combination of these two have been considered more during recent decades. However, these models are inefficient. First of all, there is not any flexible production cost estimation framework which can be used for different products with different manufacturing processes within the product family. A flexible framework or system description model that can define and evaluate production cost during the development stage in a product family is needed. In other words, a costing model, which is flexible with different production scenarios in a product family, would provide more accurate cost estimation at an early stage of product development. Secondly, most cost calculations are time-consuming, especially when combinations of different models are used. Therefore, some system analysis and computer-based models will provide more accurate estimation in a shorter timeframe.

To sum up, there is a need for an integrated production cost estimation model framework with three main characteristics. First, a model combining different costing methods that estimate product costs at the early stage of development in the product family. Secondly, a model with system description methods that can be more flexible and generic. Third, a costing model based on system analysis and computer models which support for a dynamic cost estimation. A production cost estimation model with these three characteristics can be an integrated, generic, and dynamic model providing cost information in a useful form which could be seen as a more accurate cost estimation method.

1.1.1. An Explanation Of Approaches To Solving The Problem

Current costing models have some deficiencies and are not able to respond to both customer and manufacturer needs accurately and quickly. One of these deficiencies is the cost estimation at the early stage of product development in the product family. Comparing traditional costing models with new costing ones, the combination of two or more new costing models can estimate production costs at the early stages of product development. For instance, the combination of two common costing models such as activity-based costing and the parametric costing model is recommended by many researchers.

Different studies indicate that there is a trade-off between the details that parametric representation provides and the cost estimation accuracy. Therefore, a detailed method like the parametric view, which provides information at an early stage of design and can be used later in the life cycle of the product, is needed. In addition, traditional costing models distort the cost information because they are using a single overhead rate. However, modern costing models such as activity-based costing are more accurate cost estimation methods. Therefore, there will be more advantages in combining ABC and the parametric cost representation of design and development activities. In other words, instead of regular manufacturing activities, parametric activities will be used for cost estimation. A parametric costing model uses the relationship between the physical part features and the cost, but with less physical relationship to the process. Therefore, an activity-based costing model, which is based on processes, improves the accuracy and provides cost information suitable for decision-making.

Furthermore, the use of product family architecture provides detailed useful product design information in advance, which increases the accuracy of the costing model. Product family design is mentioned as a cost-effective design strategy by many researchers that provide a variety of products for customers at a competitive price. In addition, shared components sometimes cause additional production costs. When the shared components lead to lack of specialty and a shared component in a product cannot meet the exact requirements of other products, it will cause additional costs. Therefore, it is critical to develop a product family design in terms of production costs. However, another concept in product family design is process sharing, whereby the same production processes will support the components for different products in a product family. Sometimes when the component-sharing concept is replaced with process sharing, there will be lower production costs. Finally, in order to have a more accurate cost estimation for product family design in the early development stages, a cost estimation framework should be defined.

Another missing part of current costing models is the lack of a generic costing model which can quickly respond to different product designs. A new costing model, which is a combination of activity-based costing, parametric costing, and process modeling, would be an effective tool for the evaluation of different design scenarios in advance. Decisions on product development are mainly based on the technical criteria more than relevant cost information. However, considering the important role of product designs in the total costs, the quality of cost information should be improved so it answers product designers’ needs better. The role of a process model in a new costing model is to provide the whole picture of what goes on in the company and how the money is spent. The combination of available costing methods with process description methods will provide the effects of different design options.

There are many different system description methods, such as Function models (SADT/IDEF0), Data Models (IDEF1), Process Models (IDEF3), and Ontology models (IDEF5). Considering system characteristics, costing methods, and system strategies, one or more of these description methods can be used as the system conceptual model in order to provide a more generic costing model.

Finally, a system analysis and computer-based model can create more dynamic costing models. Some of the system analysis models are Simulation, Optimization, Queuing, and Petri Net. Any of these models can be used in order to have a dynamic costing model. Therefore, a combination of different costing models for a product family, based on the conceptual model which is linked to the computer model, will create an accurate, generic, and dynamic production cost estimation framework.

1.2. Research objective

The primary objective of this research is to develop a cost estimation framework that integrates both activity and parametric cost estimation methods to increase the accuracy of cost estimates for a family of products. The proposed cost estimation framework will have the following characteristics:

- The framework must provide a method for collecting and organizing product, process, and cost information in an intuitive and usable form.
- The framework must be generic by providing cost estimates for a wide range of both physical and service products.
- The framework must be dynamic so that it can adapt to meet the cost estimation needs of an evolving product family.
- The framework must leverage this evolving product family costing knowledge to provide accurate product cost estimates for new products defined within the product family architecture.
- The framework should provide sufficient product cost knowledge to support: the development of future product design guidelines, resource acquisition decisions, and the establishment of operational policies.
- The framework must also provide product cost estimates that are more accurate than those obtained from traditional product costing techniques.

1.3. Significance And Value Of The Research

Modern manufacturing systems are facing a new trend in global market competitions. A new competitive market, which is working based on time, quality, cost, and variety, has been introduced all over the world. In order to have an advantage in such a competitive market, manufacturing plays a very important role. In fact, a manufacturing firm that is equipped with an accurate estimate of product design and development costs has a greater chance of being successful in a globally competitive market.

Besides potential competitive advantages in production cost assessment, estimation of production costs is the most important factor in determining the new product development process performance. The earlier the production cost information is defined in a production process, the more efficiently-managed the decisions between cost and product performance will be. Finally, product cost estimation is a critical decision-making tool. It is necessary for managers to know their production costs in order to make more sensible decisions regarding the products and their market. Cost estimation and profitability of the product will affect product design and new product development decisions. The marketing process for a given product or product line will also be impacted and controlled by the product cost estimation.

To sum up, an appropriate generic and dynamic product-costing model with the ability to determine cost estimation at the early stages of the design and development phase of the production process is of great value in order to compete within a global market. In addition, it can be used as a measure of new product development performance. Finally, a cost estimation model is needed as a decision-making tool in different areas such as product design, new product development, product marketing, and production location.

1.3.1. Novelty Of The Approach

Different studies indicate that designing production cost methods out of the product's components and processes is the most effective way to control costs and profits (Tang et al., 2014; Qian and Ben-Arieh, 2008; Park and Simpson 2005; Tornberg et al., 2002). However, most of the time production cost information is not available for product designers in an accurate and usable form at the early stage of design. In order to achieve useful cost information for product designers, different researchers have developed the activity-based costing, parametric cost modeling, and process modeling. However, an integrated cost estimation model combining various cost-estimation approaches (such as a parametric cost estimation model based on activity-based costing and process modeling for product family design) is addressed as a possible future piece of research.

There are some studies focusing on multi-use and multi-tool models to meet the challenges of the competitive market. One of those approaches is Integrated Modeling & Analysis Generator Environment (IMAGE) which is represented the combination of system description methods such as process model (IDEF3) and system analysis models such as the simulation model (Delen and Benjamin, 1998). The future plans for IMAGE include adding more tools such as cost analysis modules. Furthermore, recent studies address a new conceptual modeling technique, named IDEF-SIM (Integrated Definition Methods-Simulation). This approach uses IDEF logic in a way that is similar to the logic of simulation projects. Information generated by conceptual modeling will merge with the information needed for computer modeling and necessary information for computer modeling would be available through conceptual modeling. As a future piece of research, the IDEF_SIM technique might be used when costs are associated with simulation models.

Considering the above-recommendedresearch, a cost module is the missing part of those multi-tool models. The novelty of this research is an integrated cost management tool focusing on the combination of conceptual models or system descriptions methods with computer-based models or system analysis models as a cost analysis tool.

The new costing model that is being developed by this research contains a system description method in order to have a generic costing model for different production scenarios. Among the system description methods, the Process Description Capture Method (IDEF3) is going to be used, because different products and their processes can be defined by different scenarios in a family architecture, providing a generic product family based on those processes. Secondly, using the combination of product family architecture (PFA) and (IDEF3) process models supports the concept of process sharing. Using the concept of process sharing with activity-based costing and developing this model into a process-based costing model is the technical approach that will provide more accurate costing models. Cost information will also be represented and available in a more usable form.

The aim of this study is to investigate the development of a parametric cost estimation tool based on activity and process based costing methods. Conceptual process models, constructed using the (IDEF3) Process Description Capture Method, will be used to identify to costs associated with product families that utilize the concept of process shearing. The combination of a conceptual process model, with costing models (such as activity-based costing and parametric based costing) will provide a generic and dynamic cost estimation framework at the early stages of product design in a product family. A new costing model, with all the above characteristics, will provide an integrated cost management tool which has an advantage for manufacturing, service industries, and academic communities.

1.4. Research Application

Costing and cost management provide various forms of information for different decision makers. For example, a marketing agent needs cost information in order to negotiate with customers, or an operations manager can use cost information as a processes improvement tool. A company can also use cost information as a competitive advantage in a global or local market. Therefore, cost estimation and cost management have different applications in an enterprise. Some of these applications will be discussed in this section.

1.4.1. Cost Estimation For Mass Customization Designs

The main goal of mass customization is to design and deliver customized products that meet all customer requirements. The main advantage of mass production is to make the product at lower costs so that the customers can afford the customized products. Accurate cost estimates are crucial to successful mass customization. Therefore, a generic parametric costing model, which is based on product features, can estimate product cost as a function of customer requirements.

A prospective mass customization customer needs answers to three fundamental questions before committing to the purchase of a custom product. These questions are simply:

1. Can the producer make it?
2. How much will it cost?
3. When will it be delivered?

All three of these questions must be answered before the potential customer will commit to the purchase. This research will positively impact the ability to accurately and rapidly answer the last two questions. More accurate cost estimation reduces the risk on the part of the producer by ensuring that the custom product is not underbid. More accurate cost estimates also increase the likelihood of a successful sale because they reduce the chance that the producer's offer will not be underbid by competitors with a better understanding of their true costs.

Literature indicates that the speed with which the producers can accurately answer these fundamental questions also increases the likelihood of a successful order. Having systems that allow the producer to confidently answer these questions during the customer's first contact when inquiring about the product has proven to be much more successful in securing the work than competitors that require several days or weeks to respond to the customer's inquiries.

The new costing model, which is both parametric and process-based, can respond to the customer's needs more quickly. In the first stage of personalized mass production, customers' needs are recognized, and appropriate production design is then provided based on the new parameters and new processes for customized products. Despite knowing this production design information, it is still difficult to obtain accurate cost estimation for those products. A generic, dynamic process-based costing model like the one developed in this research can use the customers' needs as the input. Said needs can then be translated to the new parameters or resources in the costing model and an accurate cost for the product will be available for both manufacturers and customers.

1.4.2. New Product Development In The Product Family

The new product cost estimation method can be applied to support decisions in product family design. These strategic decisions affect many areas within an organization such as product pricing, optimal platform selection and production process selection within the product family tree.

A new product in the product family can be different from available products in two aspects; these are the process aspect and the features aspect. Most modeling methods proposed for use in cost estimation efforts do not formally support multiple alternative views or definitions of a process. The IDEF3 process description capture method specifies the scenario construct within the method that supports the specification of multiple variations within a process specification. A process description method like IDEF3 can define both aspects. New production processes and new parameters for a new product in the product family can be illustrated by the IDEF3 model. New processes can be generated and defined as a new scenario in the process description. If the new product differs from other members of the product family based on its features, then the elaborations in the process description models can illustrate product parameters. Finally, those parameters and processes from description models can be used in a costing model, which is the combination of both processes and parametric costing models.

To sum up, this research provides a cost estimation model for new products within a product family. Using this model, designers are equipped with a production costing system for new products, which estimates production costs by connecting products within a family tree and using product taxonomy to analyze both features and processes for different product design options.

1.4.3. Offshoring And Re-Shoring Of Product Families

The Development of a competitive manufacturing strategy is needed for all companies. Product cost estimation methods can thus be considered as a useful decision tool. Different studies show that for make-or-buy decisions the comparative production costs are the strongest predictor, among other factors such as supplier market competition or volume uncertainty.

One of the applications of make-or-buy decisions is a company’s offshoring and re-shoring strategy. The decision to re-shore is affected by some of the economic strategic tools such as the make-or-buy decision. An appropriate cost estimation model can be used as a decision-making tool for “make” or “buy” decision and the re-shoring of products.

1.4.4. Decisions On Different Product Design Options

At the early stage of product family development, production costs can be estimated based on a set of production processes or components. It would be difficult to have an accurate cost estimation since the costs ultimately depend on decisions made on what processes or components are included in production. Therefore, the components and processes required for a product should be defined at an early stage of the design process. However, design decisions on processes or components nevertheless influence the production costs and it would be a good approach if at the early stage of product design (when designers evaluating different design options pay attention to the processes and components) which required for each design. The costs associated with those processes and components for different design options can then be estimated. Finally, considering the costs evaluation, the best design option can be chosen.

1.4.5. Other Applications

Different applications and advantages of integrated cost estimation framework were mentioned so far. However, there are more applications and advantages of cost management. An integrated cost management tool will improve business performance and sustain this improvement constantly. Most of the time cost estimation as a primary goal is followed by cost sustaining and cost management. In other words, costs information can be used for management strategies too. This is where the concept of activity-based management and cost sustaining play important roles.

Activity-Based Costing/Management (ABC/M) is an information system developed to improve management systems and strategic decision-making. It can be used as a useful information system, helping effective operations processes. ABM has different managerial applications in operations management. Some of the operations decisions that can be managed by cost management are decisions related to quality and control, inventory control, capacity management, human resources, product planning, and product design.

1.5. Proposal Outline

This dissertation is structured as follows:

Chapter 2 provides the literature review of cost estimation. In this chapter, the literature on the subject of the study will be reviewed and classified, and the contribution of previous works towards this study will be presented. This chapter also addresses what kinds of solutions are needed, and provides the basis for designing the new model framework. This study uses a systematic literature review. At the first stage of review, most of the available production cost estimation models and their advantages are evaluated. The most useful and popular combinations of these costing models are then selected. In the second stage of the review, other related topics to the production costing models and their significance are found. Finally, considering selected costing models and other related topics and their interactions, the gaps in the research that can reduce research problems are recognized and will be developed in the methodology chapter.

Chapter 3 describes the research methodology and technical approaches. In this chapter, the research methodologies and theoretical framework of the study will be developed. The tools and techniques used for analysis are determined, and a new costing model as an integrated cost management tool with all properties will be constructed and represented in this chapter. In a chapter 4 the proposed methodology is employed in small manufacturing. It will be clear to what extent the proposed methodology can obtain research objectives and answer research questions. It can be shown as a feasible solution for research questions and problems. Finally, in Chapter 5, major conclusions and recommendations are presented.

CHAPTER 2

LITERATURE REVIEW

2.0. Introduction

This chapter provides the literature review of cost estimation. In this chapter, the literature on the subject of the study will be reviewed and classified and the contribution of previous works towards this study will be presented. This chapter also addresses what kinds of solutions are needed and provides the basis for designing the new model framework. This study uses a systematic literature review. At the first stage of review, most of the available production cost estimation models and their advantages are evaluated. Then the most useful and popular combinations of these costing models are selected. In the second stage of the review, other related topics to the production costing models and their significance are presented. Finally, considering selected costing models and other related topics and their interactions, the gaps in the research that can reduce research problems are recognized and will be developed in the methodology chapter.

2.1. Product Cost Justification And Management

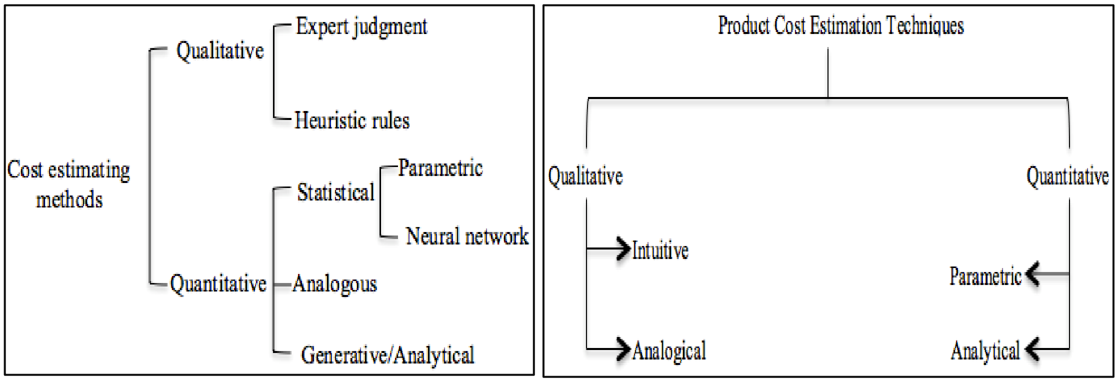
In the last two decades, global competition has increased greatly in both manufacturing and service environments. One of the best ways to survive and compete in such environments is to maintain profit margins. Therefore, cost management techniques and tools are improved constantly (Morrow, 1993; Spedding and Sun, 1999). However, the main issue is how cost technology can be transferred to the industrial environment effectively (Zuk et al., 1990).

Cost justification based on product development is the most effective product cost management strategy. Combinations of cost justification and product development will lead to the design of products with the most accurate total costs and consideration of important design criteria. Product designers are the main users of cost information because decisions made in product design brought total product costs down. However, this strategy requires a usable form of cost information to be provided for product designers, which is rarely available. The problem with cost information includes both the content and the form of information (Tornberg, 2002). Therefore, accurate cost information plays an important role as a decision-making tool (Spedding & Sun, 1999).

In addition, if business process design activities are combined with cost justification and join product development then there will be more advantages. Accounting professionals, who produce cost information and designers as cost information users, accept the advantages and opportunities when the combination of cost information, product structure and business process activities are used. A cost information base on product structure will provide more reliable information for designers in order to estimate total product costs (Uusi-Rauva and Paranko, 1998).

2.2. Classification Of Cost Estimation Techniques

There are several cost modelling techniques that may be based on qualitative or quantitative approaches (Caputo et al., 2008; Niazi et al., 2006). Figure 2-1 illustrates the classification of cost modelling methods. Considering a qualitative class, they work based on judgment and rules. These models evaluate cost alternatives to see whether it is better or worse, without specifying any values (Layer et al., 2002; Asiedu et al., 2000). However, quantitative analysis evaluates product costs based on specific values.



(a) (b)

Figure 2-1 Cost Modeling Techniques. (a) Caputo et al. (2008) and (b) Niazi et al. (2006)

The parametric cost model is one of the statistical models, used to identify the relation between causal links, costs and product characteristics in order to design a parametric costing model (Foussier, 2006). Another class of statistical model is a neural network. This model uses product characteristics as inputs and product costs as the output (Caputo et al., 2008). Analogous methods use product family and component sharing concepts in order to estimate product costs. In this model, similar products are identified and historical cost information is reused to estimate the cost by analogy, through cost adjusting for the differences between the products. Therefore, analogous models use the similarity in the cost structure from the geometrical similarity of product features (Layer et al., 2002; Shields and Young, 1991).

A generative-analytical method as a final category is the most accurate one because the actual product creation process is involved with cost estimation. An analysis of the production process is done and then, those defined process are decomposed to the single operation. Then a specific analytical model estimates the cost of each process (Caputo et al., 2008). Also, a detailed model can be used to estimate a labour rate and material processes as direct costs, and then an allocation rate is utilized for indirect or overhead costs (Shields and Young, 1991). In fact, an analytical method forms the basis of design-to-cost or design-for-manufacturing cost estimation (Boothroyd et al., 2001; Eversheim et al., 1998; Kristsis et al., 1999; Kiritsis and Xirouchaksi, 2000; Poli, 2001).

2.3. Traditional Cost Methods Vs. Modern Cost Estimation Methods

In the last two decades,research and practices have been largely focused on cost accounting as a management tool. Traditional cost accounting is not able to respond to the changing information that is required in manufacturing management. On the other hand, modern costing models such as activity-based costing provide cost accounting as a management tool. Activity Based Costing/Management (ABC/M) systems improve the deficiencies of the traditional cost systems. This method focuses on a list of activities and coststhe number of resources spent on each activity (Spedding and Sun, 1999).

Today managers use cost accounting as a decision-making tool in costing, however, traditional costing methods are unable to support decision-making activities. Many practices indicate that traditional accounting methods are “too late, too aggregated and too distorted” to use and support decision-making processes in costing (Johnson and Kaplan, 1987). Traditional methods use traditional single overhead allocation methods, on the other hand, in activity-based costing overhead rates are allocated to individual products. Therefore, ABC system explains the causes of cost increase and a decrease of the individual products. This cause and effect relationship allows management to distinguish value-added activities from non-value added ones. That is how the ABC system can be considered as a strategic decision-making tool for various applications such as process redesign or continuous process improvement (Hanson and Mowen, 1997).

As mentioned, one of the differences between traditional and modern costing methods is overhead rate allocation. Total manufacturing costs include the cost of materials and labour rates as direct costs and apply overheads as indirect costs. If overhead costs were a little portion of total product cost, then it would not be a concern. However, high technology manufacturing causes the overhead cost to be a large percentage of the total manufacturing cost. If the overhead rate as part of manufacturing costs increased, then the manufacturing cost increased consequently. Therefore, overhead rate plays an important role in total manufacturing costs and it should be recognized based on a more accurate cost estimation and calculation method (Ruhl and Bailey, 1994; Takakuwa, 1997).

Furthermore, traditional cost estimation methods are volume-based cost systems, which are inaccurate in the modern competitive manufacturing environment. Many of the significant costs in production processes are not volume related, for example, quality control, order processes or planning are not volume based. However, the ABC method focuses on the costs incurred at the activity level and then allocate the cost to the products based on the activities and resources consumed (Spedding and Sun, 1999).

To sum up, many industries have implemented a successful ABC system since the late 1980s in order to improve operational performance. Activity-based costing provides more relevant and accurate cost information in a usable form for both cost estimation and cost management. In addition, Activity-based costing methods prevent distorted product cost information that occurs when using the traditional costing system, because the ABC system focuses on activities instead of products (Cooper and Kaplan, 1991; Gunasekaran and Singh, 1999; Lee and Koa, 2001).

Suzhou et al., 2012, proposed a new process-based model with higher estimation accuracy than the traditional and basic activity-based costing (ABC) model. As they mentioned the complexity of the manufacturing environment and the limitation of the traditional (ABC) are the main reasons for proposing the new approach. Recently, better customer satisfaction and competitive advantages can be achieved through accurate cost estimation. Suzhou et al., concluded that the accuracy of cost estimation wouldbe increased if the traditional analytical model was replaced with the process-based analytical model. This new model can analyze the manufacturing processes and cost consumption of the product in more details.

2.3.1. Applications Of Cost Estimation Methods

Cost estimation and cost management have different applications in an enterprise. Some of these applications will be discussed in this section. One of the main advantages of new costing models is their management ability. There is much research which indicates modern costing methods as a cost management tool (Niazi and Dai, 2006; Gupta and Galloway, 2003; Lee and Kao, 2001; Speding and Sun, 1999;Gunasekaran and Sarhadi, 1998).

Activity-based costing has become one of the most important factors in the international markets for manufacturing and service organizations. Many companies are interested in more accurate cost estimation with the objective to integrate marketing and manufacturing strategies together (Gunasekaran and Sarhadi, 1998). New manufacturing strategies such as productivity and quality improvement increase the awareness of ABC as an appropriate framework for management decision making. There are some technological advances in manufacturing productivity and quality such as JIT, TQM, kaizen and CIM. However, many researchers pay attention and focus on reducing product cost to support managerial initiatives. In recent years, manufacturing systems have considered the combination of non-financial concepts and ABC. New concepts such as design for quality, design for production, and design for distribution are based on ABC and advanced manufacturing concepts as a management tool. The analysis of the ABC system indicates that it is a management tool with four related aspects, which are: costs, quality, time and innovation (Cooper, 1990; Berliner and Brimson, 1988; Kaplan, 1983).

Lee and Kao (2001) mentioned activity-based costing as a tool that improves cost management by providing accurate and relevant cost information. In addition, one of the main competitive advantages of ABC is productivity improvement by eliminating non-productive activities and managing the operational costs through analysis processes. Accurate cost information is critical for each company, as it not only affects pricing policies; it also affects product designs and performance. Therefore, new accounting systems have been accepted all over the world, called Activity-Based Costing/Management (ABC/M) systems (Keegan and Eiler, 1994). In fact, ABC/M system considers whole system perspective, from both a financial and a non-financial perspective. Activity-Based Costing /Management (ABC/M) is an information system developed to improve the management system and strategic decision-making. It can be used as an information system helping affective operations processes. The

ABC/M system has different managerial applications in operations management. Some of the operations decisions that can be managed by cost management systems are decisions related to quality control, inventory control, capacity management, human resources, product planning and product design (Gupta and Galloway, 2003).

Another application of modern cost accounting that has been mentioned by several researchers and adopted by many companies is the use of cost justification in the early stage of product design (Qian and Ben-Arieh, 2008; Tornberg and Jamsen et al., 2002; Gunasekaran and Sarhadi, 1998; Cooper and Slagmulder, 1997). The final product cost depends on design decisions that are made in the early product development stage. Therefore, a framework should be provided for designers in order to estimate the manufacturing cost of different design options. Then the lowest cost design alternative would be selected among a set of design choices. Without accurate cost information, a designer may add more features that are not necessary for the product, which might increase the manufacturing costs (Gunasekaran and Sarhadi, 1998).

Product designers are key customers of cost information (Tronberg et al., 2002). However, product cost justification in the early stages of design and development is not an easy job. Recently, industrial and manufacturing sectors have experienced more competitive environments. This competitive environment leads to manufacturers focusing on a variety of products with a shorter life cycle and of better quality at the lowest possible cost. In order to achieve such financial success and shorter lifespans, an accurate design and development costs estimation is needed especially in the design and development stages (Qian and Ben-Arieh, 2008).Jean Loup et al. (2016) compares different statistical models for manufacturing cost estimation during the early design phase. In the early stage of design and cost estimation, the interests and requirements of the customer should be considered. However, it is difficult to cost different designs. Therefore, there is a need to develop a relatively accurate cost estimation at an early stage of design.

Modern product cost estimation methods can also be applied to support product family design decisions. These strategic decisions are from different areas within an organization, such as price decisions, and optimal platform selection for the product family based on product parameters and production processes within the product family tree. In addition, one of the advantages of defining a product family architecture is mass customization production. However, the main goal of mass customization is to design and deliver customized products that meet all customer requirements. The main advantage of mass production is the ability to make the product at the lower costs so that the customers can afford the customized products. In other words, cost elements are crucial for successful mass customization (Tseng et al., 2014). Many studies have been focused on the advantages of modern cost estimation in product family and mass customization production (Tseng et al., 2014; Yarlagadda et al., 2013; Johnson and Kirchain, 2010; Qian et al., 2007; Chen and Wang, 2007; Park and Simpson, 2005; Fixson, 2004).

Park and Simpson (2005) developed a production cost estimation framework in order to support product family design. The main responsibility of a product family designer is to select the appropriate components, design variables and production processes. The main task is to maintain economies of scale while all the product's requirements and performance are met. There are several criteria that help designers with those decisions, but production cost is a primary concern. Production cost estimation based on the product family includes two types of costs. First, estimating the production cost of each product in the family and secondly, the costs of common components, designs and processes in the family. Therefore, the production cost estimation framework is needed to support both types of costs in the product family design.

Product cost estimation methods are useful tools supporting decisions in the product family design. Cost justification as a decision tool in the product family architecture will support price decision and optimal platform selection (Qian et al., 2007). In addition, production cost estimation for a product family provides useful design information for designers. Designers use cost information as a decision-making process as there is a link between costs and production activities (Bars and Emblemsvag, 1995; Yamashina and Kubo, 2002). Understanding design activities and the resource consumption for each activity is a significant factor in production cost estimation. Activity-based costing systems have been introduced to recognized hierarchical activities in the product family based on different levels. Activities in the product family range from unit-level through batch-level and product-sustaining level to facility-sustaining level (Cooper and Kaplan, 1991b; Hundal, 1997; Ben-Arieh and Qian, 2003a).

One of the advantages of product families is the cost-competitive role of it in today's competitive global economy. Such a competitive market asks the firm to deliver more new products to the market in a shorter time. The determination of which components should be shared and which should be unique for the new product development is very important. The commonality metrics are indicated and the main advantage of them is their ability to reduce costs in the product family (Johnson and Kirchain, 2010). Therefore, there will be a link between commonality metrics and cost modelling that leads to cost reduction in the product family architecture.

Sebastian and Dieter (2017) introduced a new approach to quantify the cost effects of using product family structures. The variety of products is increasing due to globalization and customized customer demands. However, there is a negative cost effects of variety. Product variety is fulfilling customer requirements and increasing the competitive advantages, but meanwhile, it causes additional costs which is known as the complexity cost. One strategy to cope with the variety and resulting cost challenges is the use of product family structures. Modular product family structure realized the commonality and it benefits. For instance, there are cost savings in the product development stage due to the need for less design effort when using a product family structure.

Another application of cost estimation is process-based and component-based cost modelling that is mentioned by several researchers (Tang et al., 2014; Kirchain and Field, 2001; Fisher et al., 1999). One of the managerial challenges for most firms is product variety. The main goal is to provide a high degree of variety for competitive success while keeping the cost low. The approaches companies use to cope with this challenge are process-based or product based strategies (Fisher, 1999). In process-based models processes with sufficient flexibility are defined in order to provide a variety of products at reasonable cost. Product-based models define product designs to increase product variety in the marketplace.

One of the product-based models is a component-sharing strategy that is based on product family designs in which families of products have similar components. One of the key drivers of component sharing and decision to share a component is the cost issue. The cost issue is useful as the investment for new products includes the cost of product development and the fixed costs of production. New products with unique components must be designed and tested, however, component sharing can reduce the cost of product development. Also, component sharing may reduce the fixed costs of production, as a new component also requires fixed costs such as tooling (Fisher, 1999).

Kirchain and Field (2001) used process-based cost modelling in order to recognize the economics scales of different technical decisions. Mathematical models based on parameters allow designers to define product physical properties based on their geometry and material, then manufacturing engineers control operating conditions based on physical characteristics of process outputs by the use of the parametric mathematical models (Ashby, 1992).

Applying design specifications or process operating conditions affect both product performance and production costs. Then, this cost information must be used when evaluating changes to product or process for different design options.

Integration of cost estimation methods and the theory of constraints (TOC), have been suggested by many researchers (Zubi and Khamees, 2014; Kuma, 2013; Tsai and Lai et al., 2008; Huang, 1999; Kee, 1995). The integration of activity-based costing (ABC) and the theory of constraints (TOC) is an approach for modelling production structure. The resulting model evaluates the relationship between the cost, resources and production capacity. Finally, the best production mix can be selected based on cost information and the attributes of the production process at the same time (Kee, 1995). A combination of ABC and TOC help a bottleneck distinction. Also, the economic consequences of production related decisions can be clearly recognized.

Kuma (2013) mentioned the integration of activity-based costing (ABC) and TOC as a profitability improvement model. These models improve cost management systems in many respects such as product costing, cycle-time management and product-mix decisions. Finally, allocating unused capacity in costing the product is one of the advantages of those integrated models. The ABC system identifies the unused capacity costs and considers this cost on total production costs in order to provide more accurate cost information (Baxendale and Gupta, 1998).

There are other applications of cost estimation that few researchers have mentioned. The integration of activity-based costing (ABC) techniques with enterprise modelling can be used for reengineering (Tatsiopoulos and Panayiotous, 2000). In addition, joint product decisions and outsourcing or capacity expansions are other applications of cost estimation methods (Tsai and Lai, 2007).

2.4. Combination Of Various Cost Estimation Methods

There are some researchers that have mentioned combining two or more cost estimation approaches as a faster and more accurate methods for cost justification (Tang et al., 2014; Qian and Ben-Arieh, 2008; Niazi et al., 2006; Tornberg et al., 2002).

Tornberg et al. (2002) mentioned the development of a cost estimation framework that defines the parametric cost estimation model based on activity-based costing as a future challenge of their study. Qian and Ben-Arieh (2008) also presented a combined model using parametric and activity-based costing methods. In their study, a list of parameters was determined at the product design stage. Then, cost rates in a parametric cost estimation model are defined by the use of activity-based costing in order to have an early cost justification. The parametric costing model evaluates the costs based on physical characteristics of the part but it does not consider the costs that are related to the process. However, an activity-based costing model determines all costs incurred with the activities and processes required for product production. The integration of parametric cost analysis with the ABC model provides an accurate and easy-to-compute cost estimation framework. In activity-based costing systems the cost of each activity is proportional to the activity’s cost driver rate. Therefore, if the activity drivers used within ABC become parameters in a parametric costing model the user can use cost information in a more relevant form.

As mentioned in section 2.2, qualitative and quantitative approaches are the two main categories of cost modelling techniques. The ABC system uses predetermined activity rates to calculate the total amount of activities consumed for a product with little or no need for detailed design and manufacturing information. A combination of qualitative and quantitative costing models could help develop an integrated cost estimation system that provides cost information in a more useful form in various stages of design and development (Niazi et al., 2006).

Another research focuses on the combination of different cost estimation methods in order to develop a relatively accurate cost estimation at an early stage of design done by Jean Loup et al. (2016).In their research they developed the parametric feature-based model that belongs to the family of parametric models. The simplest statistical models share elements with the analogous method, and the more complex element of their work use analytical methods. Finally, they conclude that Data Mining and Machine Learning methods can increase the performance of the statistical models.

2.4.1. Parametric Costing Model

The quantitative parametric costing method is a commonly used costing model in both industrial and service sectors (Tang et al., 2014; Qian et al., 2008; Caputo and Pelagagge, 2008; Cavalieri et al., 2004). There are many advantages to using a parametric view in cost estimation. For instance, there is a direct relation between details of parametric information and cost estimation accuracy. Parametric models use the relationship between the physical characteristics of a part and its cost. Also, these models are fast and accurate for well-defined parts within a product family architecture. In addition, a parametric costing approach is useful during the product design stage, where there is no detailed information about manufacturing processes (Qian et al., 2008). Different parametric cost estimation models are more accurate and are based on detailed information. In addition, they can be used in early stage of product development utilizing geometric parameters defining in the product design stage (Ben-Arieh et al., 2003b).

Tang et al. (2014) developed a parametric model for rapid and precise cost estimations. The product design parameters are listed to define production processes in more detail. For example, in machine-based processes, the change of design parameters for different design options would determine the selection of machining parameters in order to define the operation processes. Despite all the advantages of a parametric costing model, there are some disadvantages as well. These models have little or no physical relationship to the process. All different parametric cost models have cost estimation errors and they might not be accurate for some parts. There are two main reasons for these errors. First of all, usually simple linear mathematical relationships are considered between parameters and cost. Secondly, normally only some of the important parameters are considered in the cost function. The limitation on parameters will cause cost overestimation or underestimation. However, one possible solution for using only a limited number of parameters is to use a product family architecture. Different parts can be categorized into thedifferent family branchs and different parameters can be defined in the parametric cost model for each family branch or group (Qian et al., 2008).

2.4.2. Activity Based Costing Models

The activity-based costing method has been in use since the 1980s by Cooper and Kaplan, as a better alternative to traditional costing methods (Cooper and Kaplan, 1988). ABC can be defined as "a method for accumulating product costs by determining all costs associated with the activities required to produce the output." (Lewis, 1995). As mentioned in the previous section, a key missing component of parametric models is the lack of a physical relationship with the production processes. Activity-based costing methods might overcome this problem, by providing more links between processes and the cost information. This method gathers cost information from each of the production processes in the company, therefore; costs of different designs can be compared easily (Cooper and Turney, 1990).

There are many advantages in using activity-based costing methods. Many researches state that ABC as a more accurate costing model than traditional cost accounting. Most of the time designers have information on direct costs only. However, product design decisions affect indirect costs, not only direct costs. One of the main advantages of ABC is that indirect costs for the different products are more accurately considered in cost evaluations (Ben-Arieh et al., 2003a; Uusi-Rauva and Paranko, 1997; Park and Kim, 1995).

Improvement of product costing accuracy and more detailed indirect costs are not the only advantages of the ABC method. Other advantages of the ABC method is its ability to provide timely cost information and suitable cost information for decision-making processes (Qian et al., 2008; Cooper et al., 1992). The activity-based costing method also tends itself to supporting new manufacturing and service initiatives like mass customization as well as design for production and distribution efforts (Qian et al., 2008).

2.4.3. Combination Of Parametric And ABC Costing Methods

There are several studies focusing on the combination of different costing methods and its advantages, Qian et al. (2008) conducted one of them. The novelty of their research was the combination of parametric costing with ABC methods. In their research, a parametric cost model based on ABC is mentioned as a more accurate and easy-to-compute cost estimation method for use in product design and development activities. Parametric cost estimation methods evaluate the costs based on physical characteristics of product and parameters without describing it in detail or with little or no relation to the operational processes. However, the activity-based costing method overcomes this shortage as it focuses on activities and processes in more detail. In the ABC system the cost of each activity within a processes is proportional to the activity's cost driver rate. Therefore, if these activity drivers become parameters in a linear parametric cost model, it will make the physical relation between product parameters and activities, which will lead to more accurate cost justification.

Different cost justification methods can be used at different product life cycle phases. However, costing models that provide more details at the later phase of the product development lifecycle typically are more accurate. While costing models used at the early stage of design do not have the benefit detailed product configuration information. In order to reduce cost estimation errors at the design stage, a model considering the overhead allocation and indirect cost of design activities would be a good option. Therefore, a parametric costing model based on the ABC model that includes overhead and indirect costs will help generate a more accurate cost estimation during the design and development phase.

Park and Simpson (2005) developed a production cost estimation framework to support product family design based on ABC that consists of three stages: allocation, estimation and analysis. In the allocation stage, production activities and required resources are identified. Then, in the estimation stage production costs are estimated. Finally, in the analysis phase products and design parameters for product family design are investigated. The product data used at the estimation stage has three categories, which are engineering, process, and production parameters. The engineering parameters are a specification list for the products such as design specifications. The process parameters indicate the specification of the processes such as process speeds. The production parameters show the overall information of the operation. In this framework, a set of product data is transforming into the cost information through production activities in the product family design, which lead to the more accurate cost estimation methods.

Another cost estimation framework uses the combination of different cost estimation methods such as parametric and activity based costing as a process based parametric model (Tang et al., 2014). In this model, the production activities are defined and the main activity cost rates are analyzed with the activity-based costing method. Then, the relationship between product parameters such as design parameters and the usage of production activities is established. For the new product development, the critical design parameters are defined, then the detailed cost estimation in the manufacturing process can be estimated from these parameters. For process based parametric model development, first the production activities and their cost rates are obtained, then the relationship between product parameters and activity usage is determined and finally a cost estimation is obtained by determining the quantity of resources consumed as a result of performing the product realization activities.

Many studies have been carried out on the integration of different costing methods. The combination of a parametric costing model and an activity-based costing model is the most common one. However, as future work, many researchers suggest the combination of different cost methods with other management tools to construct an integrated cost management framework. Tonberg et al. (2002) proposed that future research focus on the combination of parametric cost estimation, activity-based costing and process modelling. Qian et al. (2008) state the need for a quick and accurate cost justification model that can estimate costs over the early stage of product design.

Considering above models, the first stages of most of them are activities and resource data classification. However, production data and resource information are usually not known at the early design stage for designers and engineers. Park and Simpson (2005) mentioned the use of more information on the higher-level activities in order to solve the problem. Therefore, future research could focus on addressing higher-level activities more thoroughly. In addition, system description models such as the process description capture method (IDEF3) is a useful tool for providing production data at the early design stage for designers, engineers and accountants. Finally, design strategies and product data help designers make better decisions during product family design.

Some researchers have attempted to combine ABC method with feature-based costing method not only for cost estimation also to find the better production (Tseng and Jiang, 2000; Suzhou et al., 2012). In Suzhou modeling, the cost estimation was based on the complex consumption relationships and activities. Therefore, it has higher estimation accuracy and can be applied to the decision-making process. The manufacturing system contains both direct and indirect consumption, which makes cost estimation more complex. Traditional process-based analytical methods such as ABC only consider regular consumption within a manufacturing process, feature-based methods however, can provide more details for complex environments.

Even with a set of historical data, it is difficult to have accurate cost estimation. There are many considerable types of research on cost estimation for the manufacturing processes, such as turning, milling and welding cost estimation. However, process costs have not been consistently defined, and analytical cost estimation can be a useful tool for complex processes and products. In the analytical cost estimation manufacturing processes are decomposed into the cost factors such as operations methods, features and process parameters. Therefore, to manage the cost elements efficiently and meanwhileincreasing the cost estimation accuracy, analytical analysis can be improved by a feature-based approach (Narges and Yongshen, 2015).

2.5. Production Cost Estimation Based On Conceptual Process Methods

Several studies use one or more system descriptions methods to improve the cost estimation framework (Qian et al., at 2008; Tronberg and Miika et al., 2002). Tronberg and Miika et al. (2002) investigate the effectiveness of activity-based costing and process modelling as a useful tool for alternative design evaluation. In their research, they try to provide a more useful and suitable form of cost information for product designers using activity-based costing and the modelling of different processes in a company such as design, purchasing and the manufacturing process. The study presents the usefulness of activity-based costing and process modelling as an effective tool for more cost-conscious design. In this model, the designers track the relationship between different activities and their costs, which emerge from different decisions made in product design phase.

Narges and Yongshen (2015) applied feature-based engineering models for cost estimation using the ERP system. According to their research, a practical procedure for obtaining more accurate cost estimations can be achieved by using manufacturing process data. They mentioned that complexity, changes of the production processes and the lack of data collection as the main reasons for having less accurate manufacturing costs. As an alternative, they suggest the development of a generic and comprehensive process that is supporting by a data model for manufacturing processes. Their approach is limited, however, due to the fact that ERP models fail define the variations that can exist in production process.

The most important component of the ABC method is activity identification. Aderoba (1997), classified manufacturing activities into four main classes: machine-based activities, labor-intensive activities, technical services, and administrative activities. Other researchers have proposed using the IDEF0 methodology to support activity identification (Ang& Gay, 1996; Ben-Arieh&Qian, 2003).

The first and most important phase of the activity-based costing method is the classification and identification of the production activities, resources and a production flow. The combination of activity-based costing methods and process description methods facilitate information gathering during this first stage. The use of a process description method in activity-based costing systems allows management to focus on activities. The conceptual description method allows managers to understand the horizontal flow of services, products and activities in an organization (Symons and Jacobs, 1997). The conceptual process methods are descriptive, rather than normative, and the main purpose of them is to describe the process as it actually happens rather than how it has been documented. Process modeling is a way to specify activities occurring within an existing process. Therefore, the combination of process modelling and an activity-based costing system provides cost information in a more usable form for product designers.

Finally, predefinition of manufacturing features is difficult. However the combination of an analytical cost estimation method with process models such as IDEF0, IDEF3, and the product family architecture provids a generic manufacturing process data that can be managed and analyzed to improve coat estimation accuracy.

2.6. The Integration Of Simulation With Production Costing Methods

In today’s complex systems, direct costs production or service deelivery make up only a small portion of a product’s total cost. Indirect costs must also be considered in cost evaluations (Kaplan, 1984). Zuk et al. (1990) state that simulation models can define indirect costs as the product moves through the system. These indirect costs may include set-up transactions, material or product handling, and any other detailed cost information that can be attributed to the product can be traced by a simulation model.

Takakuwa (1997) designed a simulation model in order to implement activity-based costing for flexible manufacturing systems. Their study shows that a simulation model based on production costing can be used as a prediction model before actual manufacturing activities are performed to reduce the variance between predicted and actual costs. Current cost methods cannot consider all costs in the production processes because it is a difficult job tracking the parts through the entire production operation. Simulation can be a tool tracking parts through all processes, which provide acomplete summary of all production activities for a production costing model such as activity-based costing.

Spedding and Sun (1999) show how ABC of a system might be evaluating by discrete event simulation and present the flexibility and potential advantages of simulation-based ABC models. According to their study, the time-consuming activity based calculation is the main reason for using a computer-based model such as simulation in the cost estimation framework. Most of the time in activity-based costing models, different combinations of activities lead to the different production scenarios and cost item variations. Therefore, an activity-based costing model without an appropriate computer model would be time-consuming and costly which makes the implementation of activity-based costing models and cost estimation difficult (Troxel, 1989).

Also, a dynamic modelling framework such as discrete-event simulation needs to be developed for activity-based costing models. Another advantage of using simulation models in the cost estimation framework is the ability of these models to record accurate running costs and expenditures associated with the activities performed by the system. Finally, some outputs and features in simulation models such as reports and information summaries can facilitate the modelling and error checking steps within the production cost model building process.

Von Beck and Nowak (2000) try to link production costing models such as activity-based costing with discrete-event simulation to provide better costing, planning and forecasting tools. The discrete-event simulation indicates the behaviour of a physical system using the statistical and stochastic nature of the processes. A combination of the physical system and the cost structure provide a range of costs based on the variation of process conditions. This combination will improve cost estimates and support operational and strategic decision making as well.

Combining activity-based costing models with the concepts of discrete-event simulation demonstrates how activity drivers can be used for modelling in a discrete-event simulation. First of all, activity cost drivers are available as simulation output and they are ideal for simulation. Secondly, running the simulation repeatedly can define variation in cost drivers. Activity-based costing present two key factors in the system, the costs and activities. Then, the simulation can be used to model the stochastic nature of those activities. One of the main problems during cost estimation is the numerous number of production scenarios. When there are different production scenarios same costing models have to build a base for a new scenario to get a cost estimation, which can be time-consuming. Therefore, the integration of the costing model and simulation software can save time. A production costing model based on discrete-event simulation analysis illustrates the dynamic nature of a product costing system.

Lee and Kao (2001) used the combination of the activity-based costing (ABC) and simulation modeling to estimate operational costs. One of the main applications of the simulation technique in product costing processes is to design a model for a real system. The simulation technique can make dynamic relationships between different variables in a dynamic system, creating the ability to design a model for a real system.

Another application of a simulation model is the ability of system bottlenecks detection for future improvement. Knowing system bottlenecks mean a logical balance can be created between system inputs and outputs, which has a direct effect on production costs (Lee and Kao, 1999; Chiu, 1997; Chen et al., 1997). Finally, the simulation technique can be used as a decision-making tool for capacity and capability analysis. Karim (1998) mentioned simulation as a decision-making tool provides a balance between costs and benefits under various situations. When the simulation results are implemented in the ABC model, there are more accurate allocations of cost, especially for resources costs. First step operational simulation models are created to model the real world, then simulation results that are resources usage and operational time can be implemented in ABC model. By using simulation results in the activity based costing calculations, resource costs are more accurate.

To sum up, there are several advantages of using a simulation-based cost estimation framework. It is easier to learn and use simulation models than activity-based costing (ABC) software (Jorgnson and Enkerlin, 1992). Recent editions of simulation software have costing modules that support activity-based costing without the need for custom programming (Kelton et al., 2013). Furthermore, simulation models are flexible and validate both operational and financial aspects of the system. Simulation software provides a good graphical representation of the system. This provides a powerful visualization tool that aids in the decision-making process (Spedding and Sun, 1999).

2.7. Combination Of System Analysis And System Description Models

There are many studies focused on designing and implementing multi-use and multi-tool models of manufacturing systems (Mize et al., 1992; Kamath et al., 1995; Delen et al., 1996). The main concept of those approaches is a generic, persistent “base model” of the system. The base model provides a current, accurate, and detailed system representation that supports multiple forms of system analysis (Duse et al., 1993).

Delen et al. (1998) provide an approach, which is integrated modelling and analysis environment. In their study one or more system description models such as function model (IDEF0) or process model (IDEF3) utilizing with system analysis models such as simulation or optimization model. In this approach modelling methods are viewed as an ongoing process in order to have the reusable and multi-tool modelling. In traditional enterprise approaches a model is developed for a specific problem and after solving the problem there is no more use for the model. On the other hand, new approaches such as Integrated Modelling and Analysis Generator Environment (IMAGE) by Delen et al. (1998) improve traditional modelling to the reusable and multi-tool modelling, which supports the decision-making process. Using such models provide a variety of analysis models base on the system description models.

For example, simulation models as one of the system analysis models used for the study of stochastic behaviour. Using the new framework, a simulation model can be created from the information obtained in the system description models. Therefore, simulation specific information is available at the early stage of modelling which makes the model construction easier. Finally, based on the simulation and analysis results, the decision maker has the opportunity to reuse the model and process by changing the parameters, goal or scope. As future plans for IMAGE, adding more tools such as cost analysis modules, is suggested.

Montevechi et al. (2010) introduced new conceptual modelling named IDEF-SIM (Integrated Definition Methods-Simulation). The new approach adapted IDEF logic elements, but in a way that the process interpretation logic in techniques such as IDEF0 and IDEF3 is similar to the logic used in the simulation model. The combination of conceptual and computer models increases the conceptual model's utility, in order to facilitate the simulation modelling, model verification and validation and different scenarios creation. There are many studies emphasising the interconnection between the conceptual processes tools and simulation models. They believe that computer simulation uses the conceptual modelling of processes in some phases (Perera and Liyanage, 2000; Ryan and Heavey, 2006; Greasley, 2006; Chwif et al., 2006).

In fact, the conceptual modelling improves the computational models in different ways. First of all, conceptual modelling increases the quality of simulation models. Also, by use of conceptual modelling the construction time of computational models reduces (Perera and Liyanage, 2000). The main objective of integrated conceptual modelling with computer modelling is creating a conceptual model for the process that defines required data for the computational modelling in order to make the computational modelling easier. One of the models with integrated conceptual modelling with computer modelling is IDEF-SIM (Integrated Definition Methods-Simulation). Costa et al. (2010) mentioned the ability and probability of IDEF-SIM in costs estimation when costs are associated with simulation models, as a further research.

2.8. Process Knowledge Capture Based On Simulation As A Cost Model

The literature review on product cost estimation shows that there are many studies which consider different applications of cost estimation and methods applied in order to improve cost estimation. The combination of different costing models, simulation-based cost estimation and the use of process description capture methods have been used or mentioned as future research by several different researchers. Therefore, the literature review indicates that there is a need for an integrated production cost estimation and management model with three main characteristics. First, a model combining different costing methods that estimate product costs at the early stage of development in the product family. Secondly, a model with a system description method that can be more flexible and generic. Third, a costing model based on system analysis and computer models, which make a dynamic cost estimation. A production cost estimation model with these three characteristics can be an integrated, generic, and dynamic model providing more accurate cost information in a useful form.

Many studies indicate that there are more advantages in using modern costing methods such as activity-based costing than traditional cost methods. However, modern costing models also have some deficiencies and cannot answer all product costing questions. Production cost accuracy depends on many factors even using modern cost estimation models. For example, inactivity-based costing model activities, classification and identification, cost pools and cost drivers are factors that can affect cost estimation accuracy. Among those factors, cost drivers are the most important one that changes the cost accuracy a lot. Therefore, it is very important to increase the accuracy of those factors especially the cost driver as much as possible (Spedding and Sun, 1999).

In this study, a combination of different cost models and the use of modern cost methods are considered as the approach that provides more accurate cost estimation in the early stage of product development in order to improve the accuracy of modern cost estimation such as activity-based costing method, parametric cost estimation is integrated with ABC system. In next chapter taxonomy of product cost estimation techniques that use in this study will be presented.

Furthermore, the use of a product family architecture provides detailed useful product design information in advance, which increases the accuracy of the costing model. Product family design is mentioned as a cost-effective design strategy by many researchers that provide a variety of products for customers at a competitive price. In addition, sometimes shared components cause additional production costs. When the shared components lead to lack of speciality and a shared component in a product cannot meet the exact requirement of other products it will cause additional costs. Therefore, it is critical to develop a product family design in terms of production costs. However, another concept in the product family design is the process sharing. Where the same production processes will do the components for different products in a product family. Sometimes when the component-sharing concept is replaced with process sharing there will be fewer production costs.

One of the critical stages during their research is to specify the qualitative cost information. For this purpose, activity-based costing approach using to make efforts for processes quantifiable. This approach provides a detailed understanding of the product cost structures. Activity-based costing method for product families is used to predict the cost savings using a platform commonality in the product family structure. Finally, according to Sebastian and Dieter (2017) the cost management is a useful tool to predicting and reducing the cost complexity of product family structure to support decision making processes in operations, designs, quality, and other production activities. The new model that integrates product family structure and activity-based costing/management system integrates the product, process and cost structure to solve the negative cost effects of product variety.

Another missing part of integrated cost estimation framework is lack of the system analysis and computer model for cost estimation. There are several researches who have mentioned the use of simulation in production costing methods. Production cost estimation methods such as activity-based costing are not able to respond to the sensitivity of product costs to process variation (Von Beck and Nowak, 2000). The results of simulation-based cost estimation are useful for both engineers and accountants in making better decisions about operational procedures and enterprise strategies. There is an important question when simulation based cost estimation is used, "When the costs should be determined, during or after the simulation?" The cost determination should be after simulation, because during cost estimation processes, there are some unallocated costs, which are not known during the simulation. Therefore, total cost estimation should be done after simulation modelling and results (Takakuwa, 1997).

This study indicates the probability that precise and accurate cost estimation can be done by utilizing simulation before actual manufacturing production. The simulation model can describe and analyses manufacturing activities before actual production performance. Therefore, production details can be simulated and potential production problems can be identified and considered in the cost estimation before manufacturing is performed. A simulation model can improve productivity and production time, however, when it integrates with a cost estimation method it can be a decision-making tool as well. Therefore, simulation-based cost estimation provides a powerful management tool for decision-making processes. In addition, simulation models are able to provide more details and also consider the variation of a dynamic manufacturing systems.

Another application of simulation models in this study is the ability of unutilized capacity recognition. The results of statistical reports indicate the unutilized capacity of different elements in the system. Analyzing the report production volume and the number of new orders can be identified. Also, the manufacturing scheduling and delivery time for a new order is predictable by use of simulation analysis.

After simulation based cost accounting, an activity-based costing integrated with process modelling is mentioned as a useful tool for the evaluation of different design options (Tronberg and Miika et al., 2002). This model is an effective tool for more cost-conscious design. Designers can track the relationship between different activities and their costs, which come from different decisions made in product design. Also, the combination of activity-based costing and process description methods facilitate the classification and identification of activities in the ABC system (Symons and Jacobs, 1997). Process capturing is a way to specify activities occurring within an existing process. That is how process modelling improves the first stage of activity-based costing system in activity identification and classification. Therefore, the combination of process modelling and activity-based costing method provides cost information in a more usable form for product designers. In addition, process modelling makes the cost estimation framework simple with more detailed information.

Most modelling methods proposed for use in cost estimation efforts do not formally support multiple alternative views or definitions of a process. In this study the IDEF3 process description capture method use, which specifies the scenario construct within the method that supports the specification of multiple variations within a process specification. New production processes and new parameters for a new product in a product family can be illustrated by an IDEF3 model. New processes can be generated and defined as a new scenario in the process description model. However, if the new product differs from other products based on features then the elaborations in the process description models illustrate product parameters. Finally, parameters and processes from description models can be used in a costing model, which is the combination of both processes and parametric costing models.

CHAPTER 3

RESEARCH METHODOLOGY

3.0. Methodology Steps

This chapter discusses the methods, tools, and approaches adopted to achieve the research objective. This includes the identification of the best model for an integrated cost estimation and cost management tool. First, relevant and useful cost information is collected via suggested tools and approaches such as system description models and system analysis models. Secondly, an accurate cost estimation model based on relevant cost information is developed. Finally, the proposed model is tested in order to obtain an accurate cost estimation and an integrated cost management tool. Figure 3-1 illustrates the methodology steps.

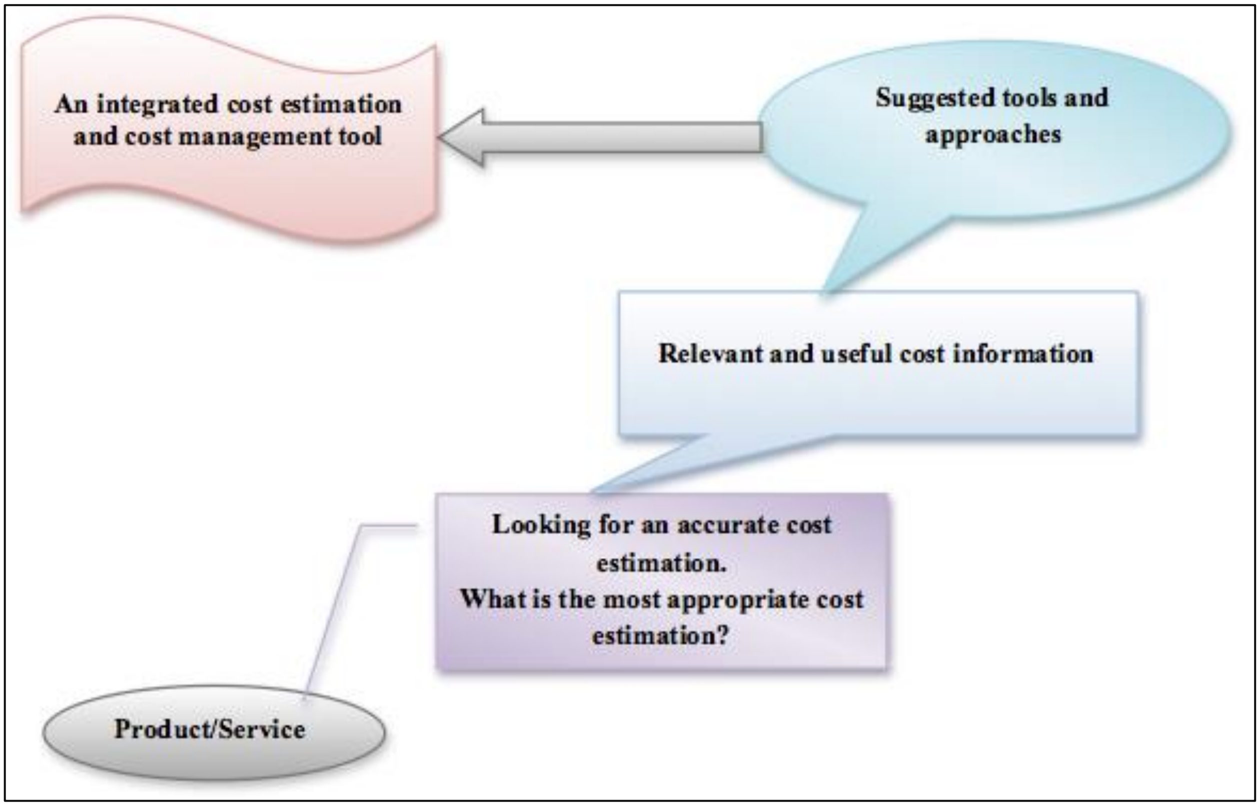


Figure 3-1 Methodology Steps

3.1. Research Framework

The first step of the research framework is to develop a problem statement and define the research questions (Figure 3-2). An accurate cost estimation model is one of the most important approaches in today's Global competitive environment, and has brought up new questions. For example, "What is the most appropriate cost estimation method?" or "Is a new costing model necessary?". Then, a systematic literature review is performed in order to find the different cost justification methods. Considering selected costing models and other related topics and their interactions, the gaps in the research that can reduce research problems are recognized and will be thus developed in the methodology. Using the technical approaches for appropriate and accurate cost estimation based on relevant and useful cost information lead to an integrated cost estimation and cost management tool. Finally, the new costing model is implemented in a real case study for evaluation.

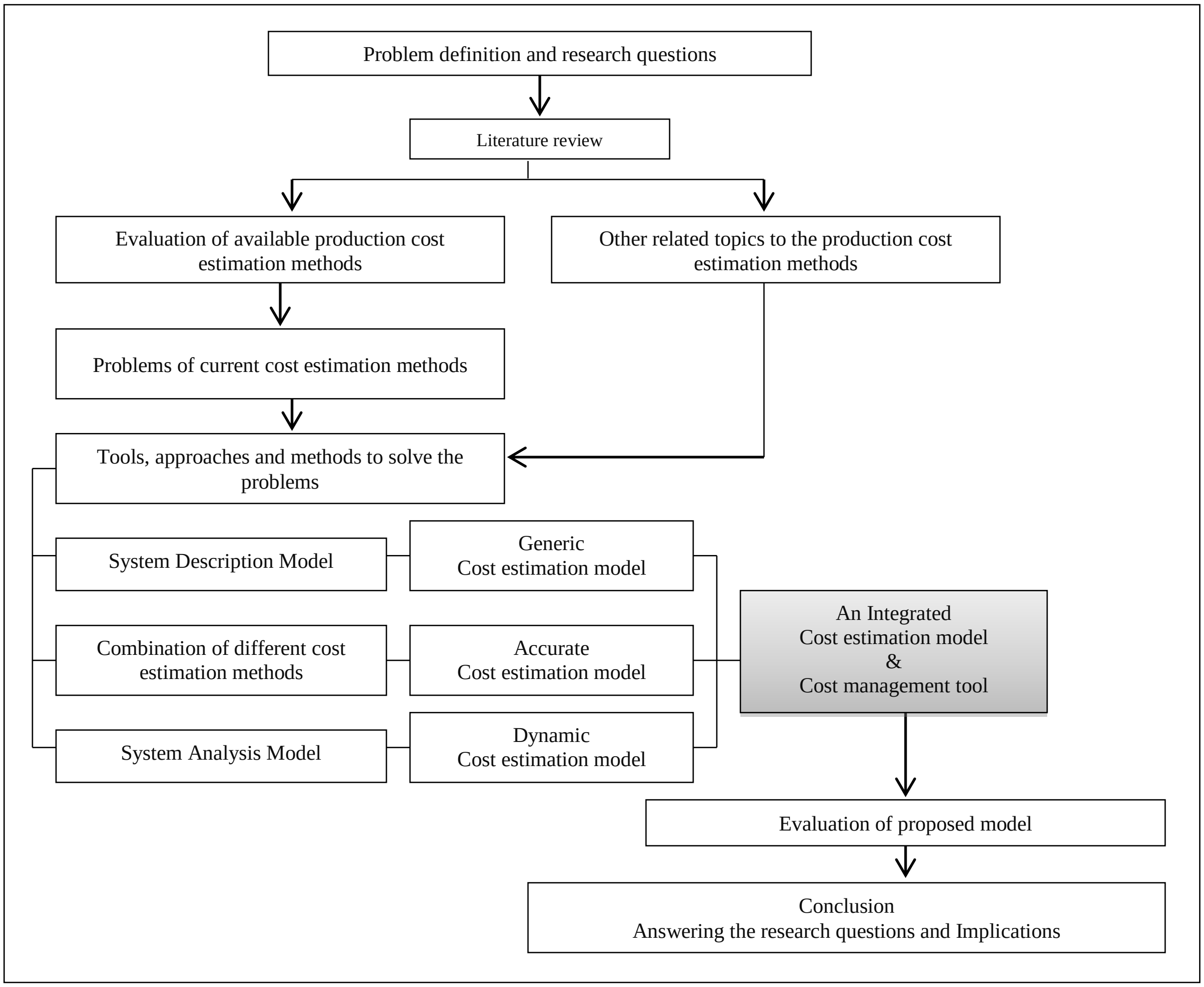


Figure 3-2 Research Framework

3.2. Technical Approaches

Regarding the literature review in the previous chapter, current costing models have some deficiencies and are not able to respond to both customer and manufacturer needs accurately and quickly. One of these deficiencies is the cost estimation at the early stage of product development in the product family. Another missing part of current costing models is the lack of a generic costing model which can respond to the different product designs more quickly. Finally, there is a lack of a system analysis and computer-based model, which creates more dynamic costing models. Therefore, a multi-tool approach is required in order to answer all the questions and problems.

Delen et al. (1998) provide an approach which is integrated modeling and analysis environment. In their study, one or more system description models such as function model (IDEF0) or process model (IDEF3) are utilized with system analysis models such as simulation or optimization model. This new approach improves traditional modelingto the reusable and multi-tool modeling, which supports the decision-making process. Also, Montevechi et al. (2010) introduced new conceptual modeling. The new approach adapted IDEF logic elements, but in a way that the process interpretation logic in techniques such as IDEF0 and IDEF3 is similar to the logic used in the simulation model. The combination of conceptual and computer models increases the conceptual model's utility in order to facilitate the simulation modeling, model verification and validation, and the creation different scenarios.

To sum up, The combination of different costing models, simulation-based cost estimation, and the use of description processes captured are used in some studies or mentioned as a future avenue of research by different researchers (Qian et al., at 2008; Tronberg and Miika et al., 2002; Spedding and Sun 1999). Therefore, using an integrated model that combines the system description methods and system analysis models can be used as an integrated cost estimation and cost management tool.

3.2.1. Combination Of Different Cost Estimation Methods

Comparing traditional costing models with new ones, the combination of two or more new costing models can estimate production costs at the early stages of product development. For instance, the combination of two common costing models such as activity-based costing and the parametric costing is recommended by many pieces of research (Tang et al., 2014; Qian and Ben-Arieh, 2008; Park and Simpson, 2005; Tornberg et al., 2002).

Different studies indicate that there is a trade-off between the details that parametric representation provides and cost estimation accuracy. Therefore, a detailed method like the parametric view, which provides information at an early stage of design and can be used later in the life cycle of the product, is needed. In addition, traditional costing models distort the cost information because they use a single overhead rate. However, modern costing models such as activity-based costing are more accurate cost estimation methods. Therefore, there will be more advantages in combining ABC and the parametric cost representation of design and development activities. In other words, instead of regular manufacturing activities, parametric activities will be used for cost estimation. A parametric costing model uses the relationship between the parts physical features and the cost, but with less physical relation to the process. Therefore, an activity-based costing model, which is based on processes, improves the accuracy and provides the cost information suitable for decision-making.

In this study, a combination of different cost models and the use of modern cost methods is considered as the approach that provides an accurate cost estimation in the early stage of product development in order to improve the accuracy of modern cost estimations such as the activity-based costing method, for instance when the parametric cost estimation is integrated with ABC system. Figure 3-3 illustrates the different quantitative and qualitative cost estimation methods that have been used in this study.

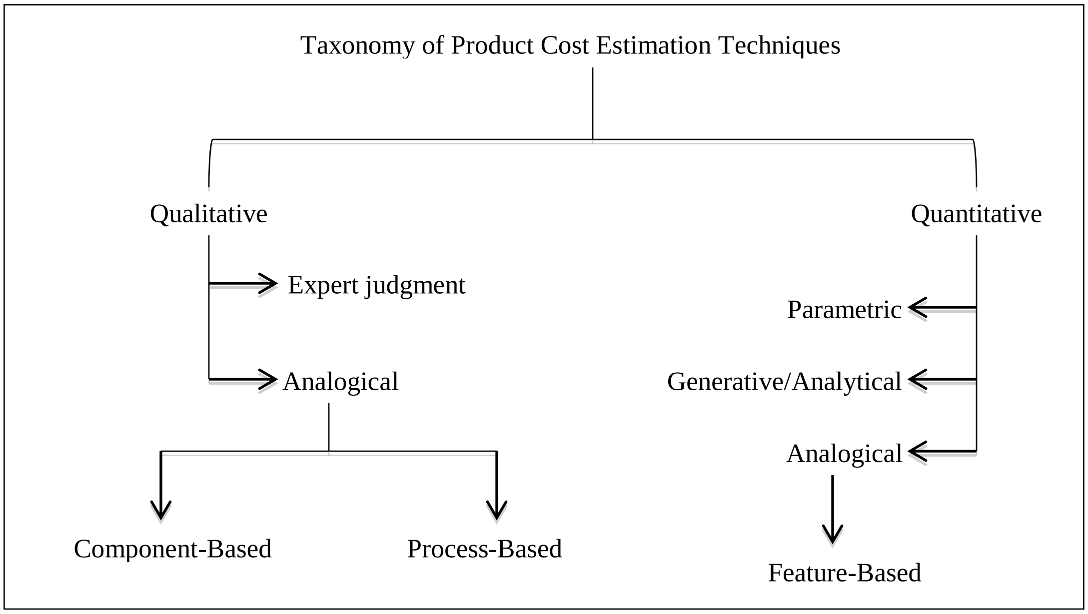


Figure 3-3 Taxonomy Of Quantitative And Qualitative Cost Estimation Techniques

There is an improvement in the new taxonomy of the product cost estimation techniques. Analogous methods use product family and component sharing concepts in order to estimate product costs. In this model, similar products are identified and historical cost information is reused to estimate the cost by analogy via cost adjusting for the differences between the products. Therefore, analogous models use the similarity in the cost structure from the geometrical similarity of product features. An analogous method is considered as quantitative classification by some researchers (Caputo et al., 2008) on the other hand, there are also some studies that consider analogous methods as well as qualitative ones (Niazi et al., 2006).

In this study and within the new taxonomy of product cost estimation techniques, the analogous method is considered as a quantitative and qualitative classification. When products in the family differ from each other based on components and production processes they can be categorized as a qualitative analogical. However, if the differences between the products in the family are based on product geometry and features (but they have the same processes and components) then they can be categorized as quantitative analogical methods.

3.2.2. Process Description Capture Method (IDEF3)

A new costing model, which is a combination of activity-based costing, parametric costing and process modeling would be an effective tool for the evaluation of different design scenarios. Decisions on product development are mainly based on the technical criteria more than relevant cost information. However, considering the important role product design plays is determining the total cost, the quality of cost information should be improved so it answers the product designers' needs better. The role of the process model in a new costing model is to provide the whole picture of what goes on in the company and how the money is spent. The combination of available costing methods with process description methods will provide the effects of different design options.

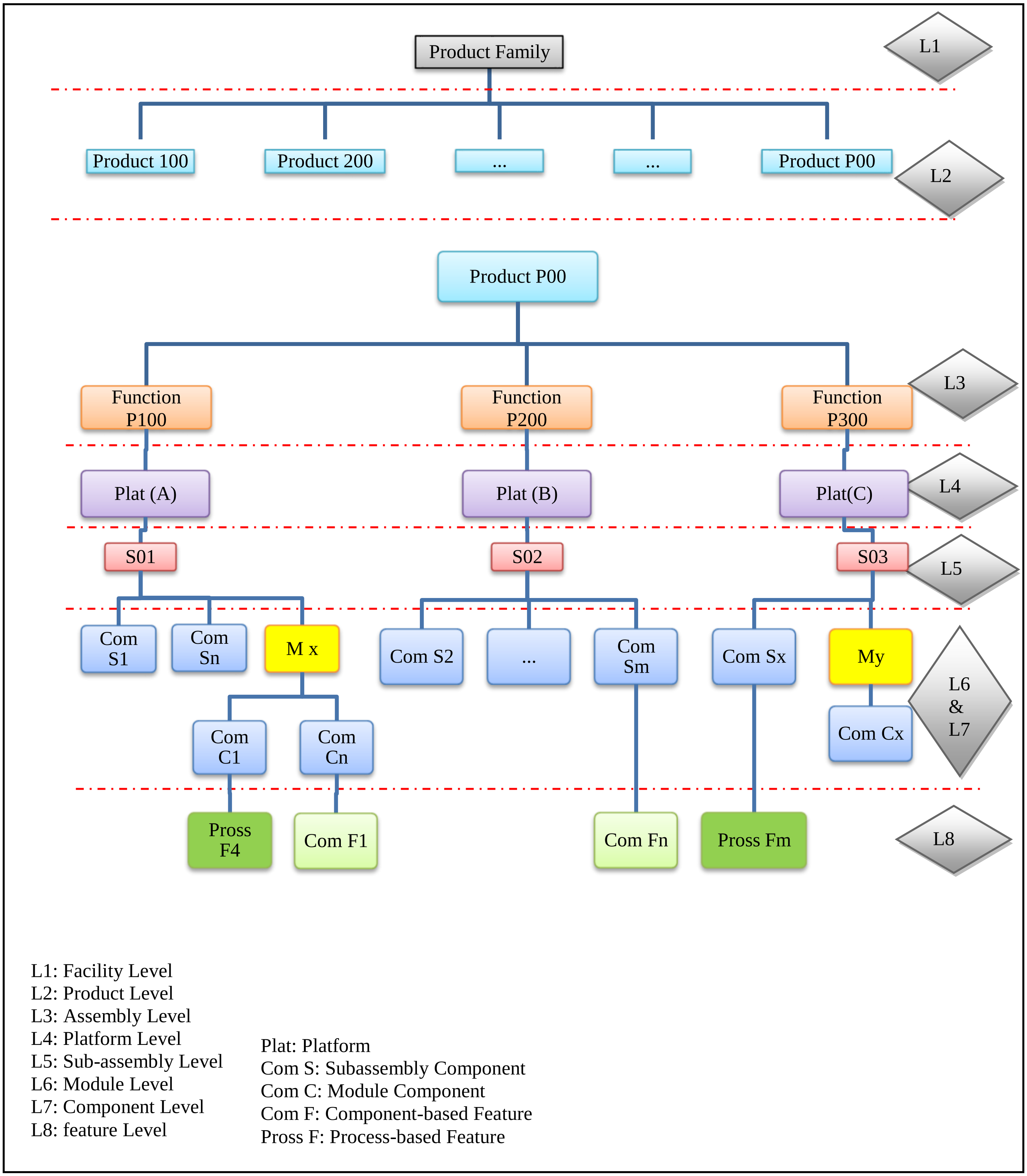
Most modeling methods proposed for use in cost estimation efforts do not formally support multiple alternative views or definitions of a process. In this study, the IDEF3 process description capture method is used, which specifies the scenario construct within the method that supports the specification of multiple variations within a process specification. New production processes and new parameters for a new product in the product family can be illustrated by the IDEF3 model. New processes can be generated and defined as a new scenario in the process description model. However, if the new product differs from other products based on features, then the elaborations in the process description models illustrate such product parameters. Finally, parameters and processes from description models can be used in a costing model, which is the combination of both process and parametric costing models.

3.2.3. Product Family Architecture (PFA)

The use of a product family architecture provides detailed and useful product design information in advance, which increases the accuracy of the costing model. Product family design is mentioned as a cost-effective design strategy by many researchers that provide a variety of products for customers at a competitive price. In addition, sometimes shared components cause additional production costs too. When the shared components lead to the lack of specialty and a shared component in a product cannot meet the exact requirements of other products, it will cause additional costs. Therefore, it is critical to develop a product family design in terms of production costs. However, another concept in the product family design is process sharing, whereby the same production processes will make the components for different products in a product family. Sometimes when the component-sharing concept is replaced with process-sharing there will be fewer production costs.

In this study a new product family architecture is developed based on two different product family structures. Park and Simpson (2005) developed a production cost estimation framework to support product family design. The proposed product family structure consists of facility, product, assembly, platform, component, and feature levels. In (2012) a new product family architecture is introduced by AlGeddawy. This new model has a more deep architecture hierarchy of sub-assemblies and modules which defines more levels of detailed description.

In this study, a new product family architecture is developed based on the two previous structures. This model consists of the facility, product, assembly, platform, sub-assembly, module, component and feature levels. The main advantage of the new model is the better commonality both in component and process shearing. The platform and module levels increase the commonality in the product family structure. Also, the new model is developed based on the new cost estimation model, and it provides cost information in a more usable form. For instance, one of the cost estimation methods is an analogical method which can be based on process-based features or component-based features. Figure 3-4 illustrates the new proposed product family architecture.



L1: Facility Level
L2: Product Level
L3: Assembly Level
L4: Platform Level
L5: Sub-assembly Level
L6: Module Level
L7: Component Level
L8: feature Level

Plat: Platform
Com S: Subassembly Component
Com C: Module Component
Com F: Component-based Feature
Pross F: Process-based Feature

Figure 3-4 Proposed Product Family Architecture (PFA)

3.2.4. Dynamic Simulation Modeling

This study indicates the probability that precise and accurate cost estimation can be achieved by utilizing simulation before actual manufacturing production. The simulation model can describe and analyze the manufacturing activities. Every production detail can be simulated and potential production problems can be identified and considered in the cost estimation before actual manufacturing takes place. A simulation model can improve productivity and production time; however, when it integrates with a cost estimation method it can be a decision-making tool as well. Therefore, simulation-based cost estimation provides a powerful management tool for decision-making processes. In addition, simulation models are able to provide more details and also consider the variation of a dynamic manufacturing system.

Another application of simulation models in this study is the ability of unutilized capacity recognition. The results of statistical reports indicate the unutilized capacity of different elements in the system. Analyzing the report, production volume and the number of new orders can thus be identified. Also, the manufacturing scheduling and delivery time for a new order are predictable via simulation analysis.

3.3. Case Study And Data Collection

XXX International, Inc. is a small manufacturing company with two branches in the US and Canada. This company specializes in the fabrication and design of heat transfer equipment for different industries such as petrochemical or food industries. This manufacturing company producesshell, tube heat exchangers, pressure vessels and recirculation pump systems. One of the significant characteristics of these products is that they are all custom-engineered in order to meet all customer requirements. The high fabrication capabilities of manufacturing allow the producer to use various materials, from carbon steel or stainless steel grades to titanium, which provide different applications and qualities respectively. All products will be customized and designed based on customer needs.

Some of the products offered by the company that are:

- Pressure vessels: Oil Separators, Intercoolers, Scrubbers, and Receivers.
- Shell and Tube heat exchangers: DX Chillers, Evaporators, and Oil Coolers.
- Plate and Frame heat exchangers: Flooded Evaporators, Direct Expansion Evaporators, and Condensers.
- Systems: Pump Recirculators and Scrubber Skids.

(a) (b)

Figure 3-5 Company Products. (a) Shell and Tube heat exchangers and (b) Plate and Frame heat exchangers

At first, this company started as a small manufacturing enterprise (SME). It is a member of the International Institute of Ammonia Refrigeration (IIAR). It is American Society of Mechanical Engineers (ASME) and National Board certified. A sample of its products can be seen in Figure 3-5.

3.3.1. Problems In Product Cost Estimation

One of the main challenges in the company is early stage cost estimation at the design and development phase. As mentioned before, this company produces custom-engineered products in order to meet all customer requirements. Products are customized for each order and customer. Therefore, there is a need for product cost estimation at an early stage of design. Another, problem that the company faces is the lack of cost management. Sometimes, accurate cost estimations are provided. However, in some cases, final costs exceed the estimations due to a lack of cost management and operations management. These problems highlight the importance of this research and the need for an integrated cost estimation and cost management tool.

The following company objectives serve as the primary motivation to adopt a new product cost estimation system:

- Improvement of product cost estimation
- Improvement of cost management
- Better analysis of production processes
- Capacity management
- Increased flexibility and productivity
- Increased product quality
- Increased efficiency (economic, mechanical, energy)

CHAPTER 4

RESULTS ANALYSIS AND DISCUSSION

4.0. Introduction

This chapter presents the application of the proposed product cost estimation methodology in a small manufacturing. It will be clear to what extent the proposed methodology can obtain research objectives and answer research questions. It can be shown as a feasible solution for research questions and problems.

First, a proposed framework is presented for cost estimation. Figure 4-1 illustrates the proposed cost estimation framework used in this study. Then, all cost estimations and their combinations are defined, and the tools or methods for cost information collection are presented. Useful and relevant cost information is collected by use of the different tools and methods. Finally, in the evaluation section, the cost analysis and results are presented for all parts produced in the machine shop.

The combination and integration of two or more cost estimation approaches provides faster and more accurate cost justification. As mentioned in the previous chapter, the new taxonomy of product cost estimation techniques was developed which includes the combination of both quantitative and qualitative cost estimation methods. Expert judgment and analogical methods are the qualitative methods used in this study. In expert judgment, cost information is collected via face-to-face interviews. There are several people on the board of the expert judgment committee. The manufacturing president and operations manager are the first two people responsible for providing general information about manufacturing and the current costing methods. They also discussed potential costing problems. The production manager and the vice president also joined the committee. The production manager has been working in the company since it started running, and therefore has good production information. The vice president is the leader of the design department. He is one of the main designers and provides valuable design information.

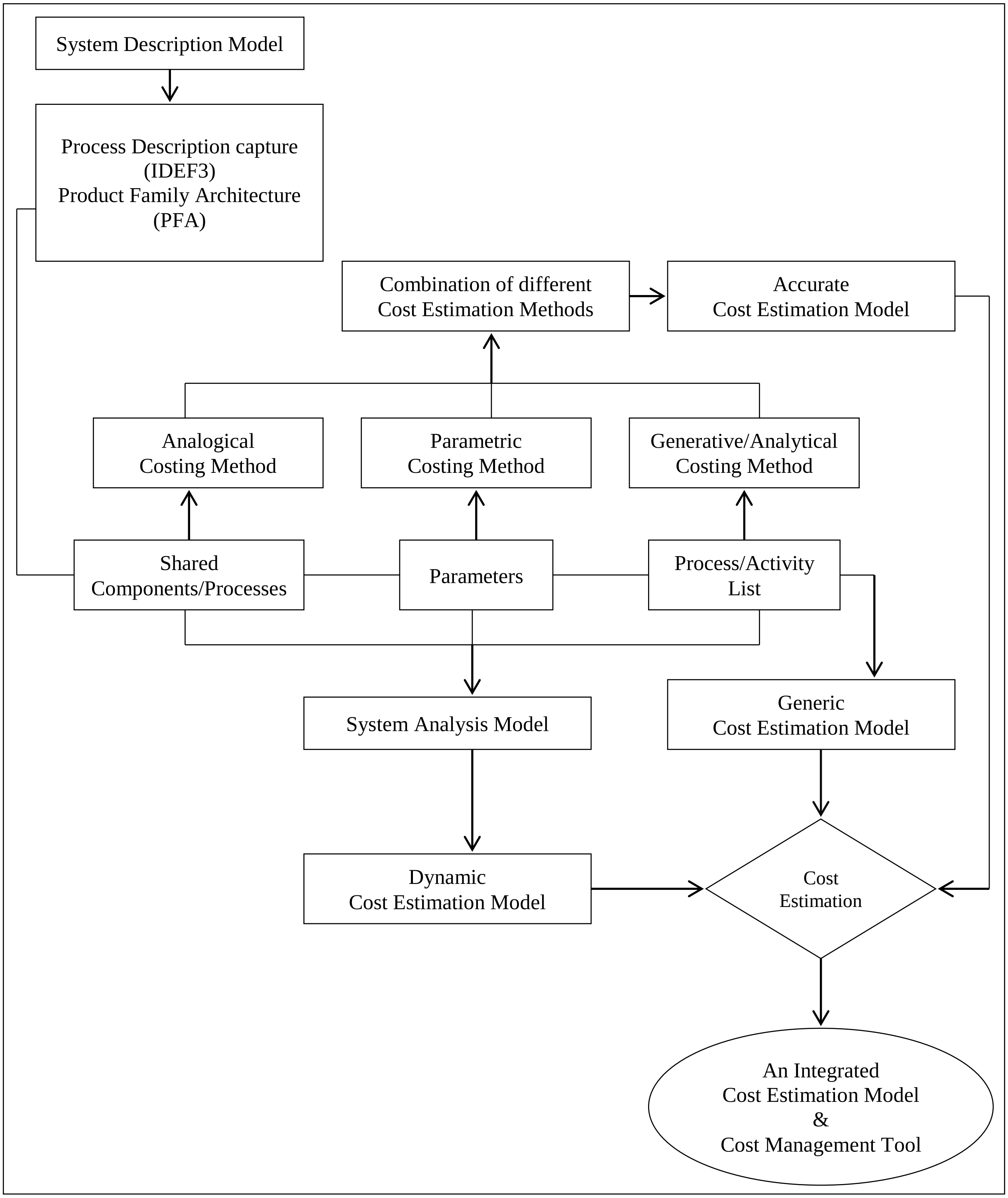


Figure 4-1 Proposed Cost Estimation Framework

The qualitative analogical method is another cost estimation technique used in this study. When products in the family differ from each other based on components and production processes, the cost model can be categorized as a qualitative analogical method. When a new products shears components and processes with existing products, historical cost information related to these sheared components and processes can be used for the new product's cost estimation at the early stage of product development. A product family architecture (PFA) and the processes capture description method (IDEF3) are the tools and methods used to identify shared components and processes in the product family.

There are three quantitative techniques used in the new cost estimation framework. The first one is the activity-based costing method. The activity-based costing method provides more links between processes and cost information. This model gathers cost information from each of the production processes in the company, and therefore the costs of different designs can be compared easily. The identification and definition of activities and processes are the first and the most important steps in activity-based costing. In this study, the process description capture method (IDEF3) is used to identify the production processes and activities.

The second quantitative cost estimation technique is the parametric costing model. Parametric models use the relationship between the physical characteristics of the part and the cost. Also, those models are fast and accurate for well-defined parts within a product family architecture. In addition, a parametric costing approach is useful during the product design stage where there is no detailed information about manufacturing processes. The combination of process description capture method (IDEF3) and product family architecture (PFA) techniques provide relevant and useful cost information. Finally, the third quantitative cost estimation technique is the feature-based analogous costing method. If the differences between the products in the family are based on a product's geometry and features (but they have the same processes or components) then quantitative analogical cost estimation methods are effective. The product family architecture (PFA) tool is the tool used to gather cost information at this step.

4.1. Process Description Capture Method (IDEF3)

One of the applications of the IDEF3 process description capture method in this study is the ability to collect relevant and useful cost information. First, the ability of the process description capture method (IDEF3) to describe what is happening in the system provides useful cost information. A big question before any analysis is that “How is the money spent in the enterprise?” and the main purpose of the process description capture method (IDEF3) is to describe the process as it happens, rather than how it is supposed to be.

The IDEF3 method can collect cost information considering the cost estimation model. One of the cost estimation techniques in this study is the analytical and activity-based costing. In this technique, the important step is the classification and identification of the production activities, resources, and production flow. The combination of the analytical cost estimation method and process models facilitate the information gathering in the first step, which is activity definition. Using the IDEF3 method allows management to focus on activities. The IDEF3 process descriptions allows managers to understand the horizontal flow of services, products,and activities in an organization. Figure 4-2 indicates the process flow of the TUBESHEET as an example.

Process capturing is a method for specifying activities within an existing process. That is how process modeling improves the first step of an activity-based costing system in activities identification and classification. The IDEF3 method also collects cost information for the parameters defined in the feature-based costing model. Within the (IDEF3) method construction, an elaboration form can be assigned to each process or activity. Within the elaboration form, there is a section called “Description” which is where related parametric cost information can be identified and gathered for further cost evaluation. Figure 4-3 is a sample of the UOB elaboration form which shows product and process parameters.

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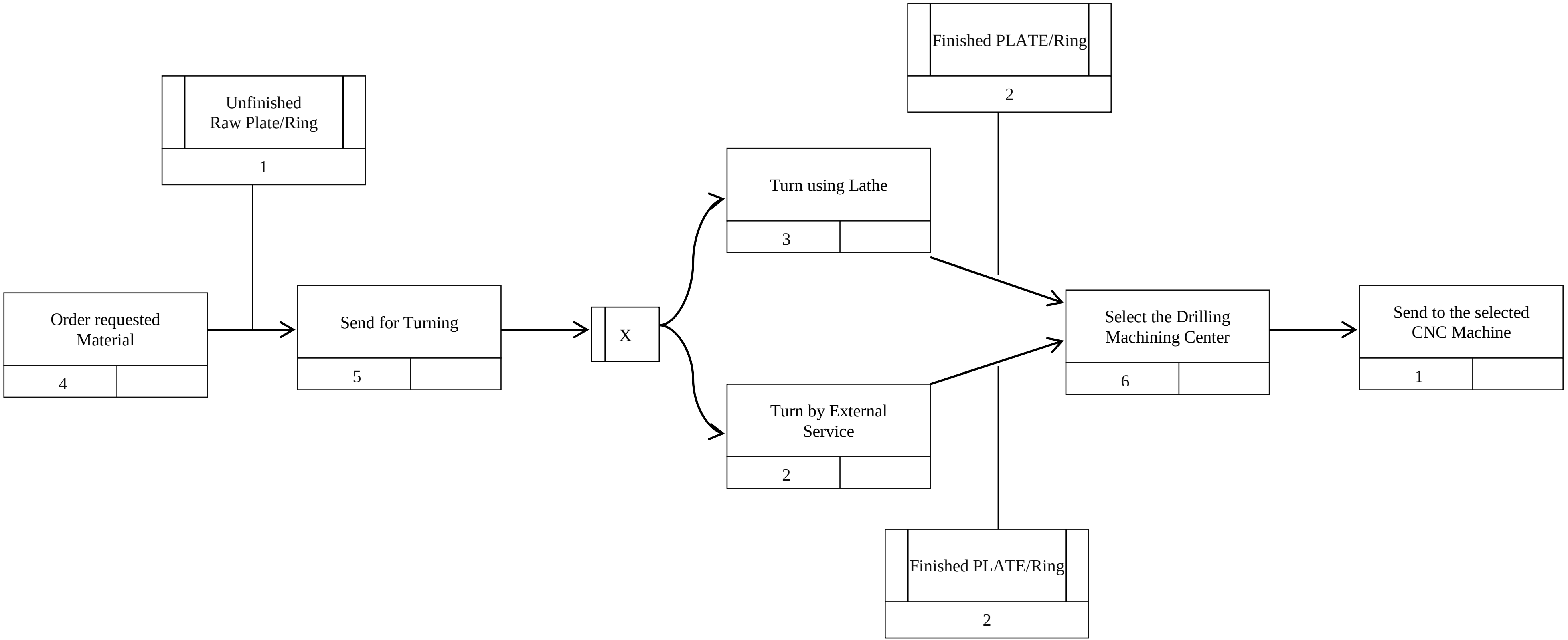

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: PRODUCE A PART IN MACHIN SHOP	FORM TYPE:

Figure 4-2 TUBESHEET Production Processes Description

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UOB No. UOB6	UOB Name:	Select Machining Center	UOB Label:	Select Machining Center
	Objects:	TUBESHEET		
	Constraints:	Outer Diameter and Material		
	Description:	If the outer diameter (OD) of the plate is less than 30 or if the (OD) equal to 30 and the material is (SS) the selected CNC machine is QuickMill, Otherwise CNC machine center is FADAL		
UOB No. UOB12	UOB Name:	Drilling Tube Hole	UOB Label:	Drilling Tube Hole
	Objects:	TUBESHEET		
	Constraints:	NA		
	Description:	Plate Thickness = 2 inch , Number of Tube Holes = 1952 , Feeding Rate (SA, 0.6330) = 12 inch/min		

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Drilling Tube Hole UOB	FORM TYPE:

Figure 4-3 UOB Elaboration for the TUBESHEET

Also, another costing method used in this study is analogical and feature based costing model. As mentioned in chapter 3 one of the categories of the analogical model is the process feature-based model. In process feature-based model a different processed production scenario for a single product is based on products' features. Considering Figure 4-2 and Figure 4-3 for the TUBESHEET production in turning process, if the outer diameter (OD) of the plate is less than 32 inches, CNC machine LATHE runs the turning processes. Otherwise the part sends out to the vendor for turning processes. Therefore, based on the outer diameter as a feature the production processes and production costs would be different. Using conceptual description capture method (IDEF3) provides cost information for the analogical method.

4.1.1. Different Production Scenarios Defined By IDEF3

Another useful application of the IDEF3 method in the new purposed model is the ability of the processes model to describe and indicate the different scenarios for a production process. Using this aspect of (IDEF3) provide useful cost information based on process and resource shearing concept in a family of product. In this research conceptual description capture method (IDEF3) is used to describe different production scenarios for all the parts produced in the machine shop. The core processes for all parts produced in the machine shop can be defined and according to this information, the conceptual description capture method (IDEF3) for different scenario production in the machine center can be developed.

The core processes in the machine center are explained in the first level of (IDEF3) in Figure 4-2, in the second level the core processes based on the machines operate them explain in more detailed that shown in Figure 4-4 and Figure 4-5. For instance, in Figure 4-4, the UOB "Lathe Turning Machining" (3) indicates the turning process expansion. Two main components turned with this machine based on different activities, which are the ring and plate. The UOB for each component are "Ring Turning Process" (3.1) and "Plate Turning Process" (3.2) respectively. Figure 4-5, indicates the next level of the UOB "Machining Centre" (1), this UOB considered all the other core processes except turning such as drilling, grooving, burnishing which are done by the FADAL or QUICKMILL machines. Therefore, the UOB "Machining Centre" is divided into two main categories based on the type of the machines, which are "Fadal CNC Machining" (1.1.) and "Quickmill CNC Machining" (1.2).

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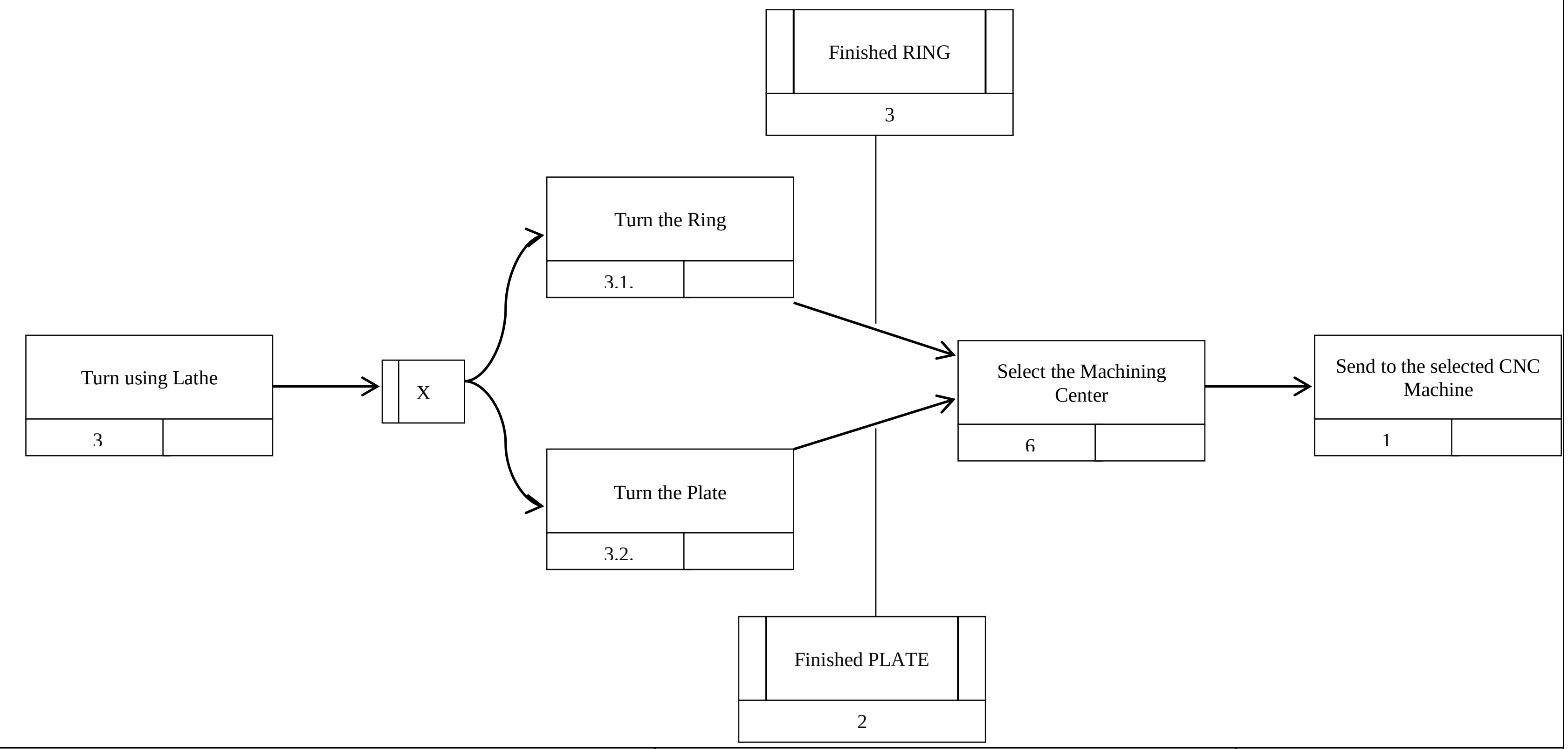

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Turning Process	FORM TYPE:

Figure 4-4 Turning Process Description

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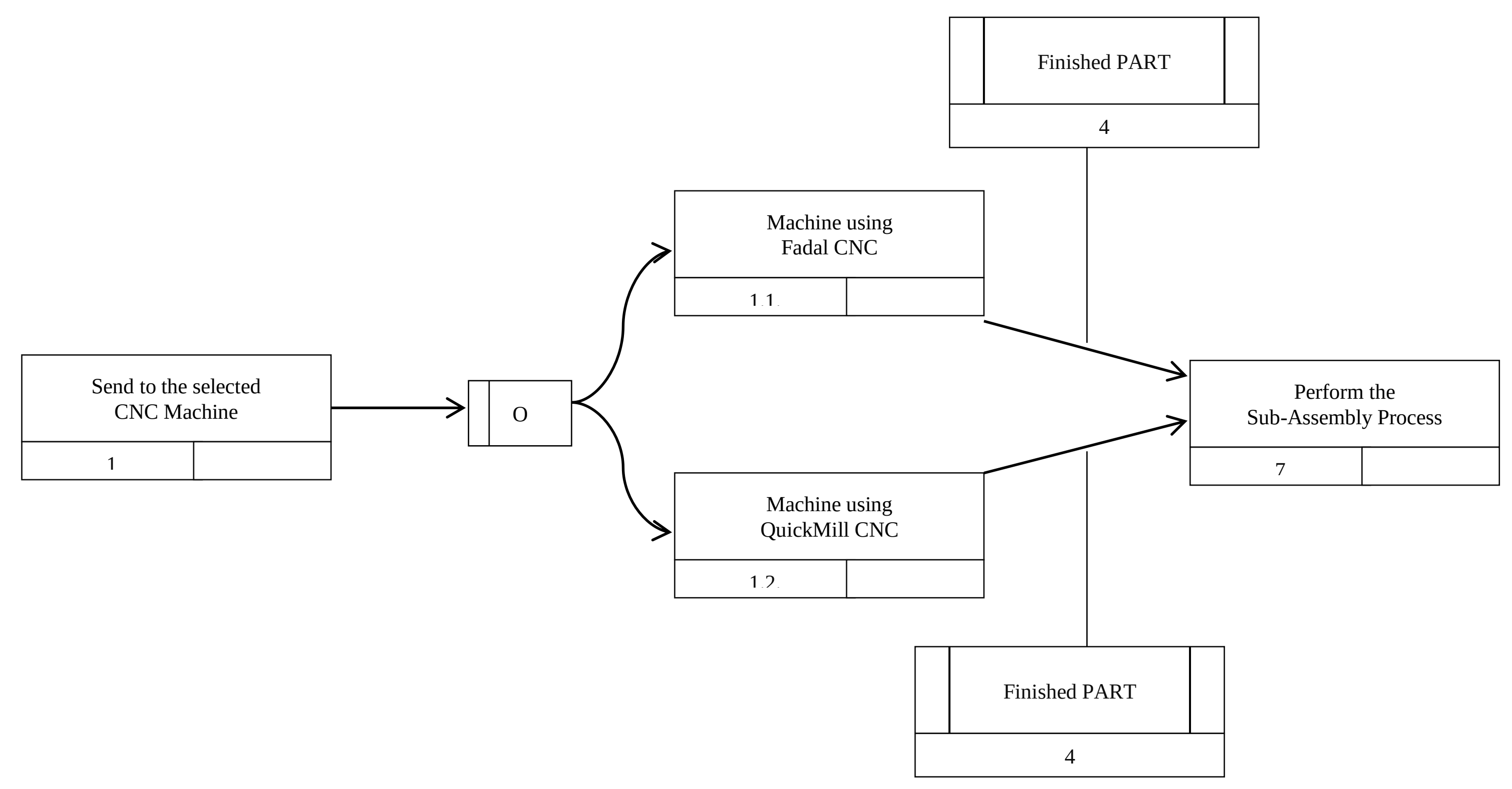

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Machine Centre Processes	FORM TYPE:

Figure 4-5 Drilling, Burnishing, Grooving, Chamfering Process Description Based on the CNC Machines

In the next level of the IDEF3 model, different production scenarios for all the parts produced in the machine shop using the QUICKMILL are shown in Figure 4-6 and Figure 4-7 for the TUBESHEET and BAFFLE respectively. For example, one activity in the TUBESHEET production scenario is “Tube Hole Drilling” (1.2.4.) UOB or one of the activities for BAFFEL production is “Tie Rod Holes Drilling” (1.2.11.). Also, there are common activities for both TUBESHEET and BAFFLE production such as “Programming” (1.2.1.) or “Setup” (12.2.). To explain the parent and child relations, (1.2.4.) as an example shows that the part passes “Machining Centre” (1) as a parent in the first level then goes through QUICKMILL machine by “Quickmill CNC Machining” (1.2.) processes as a child, and finally it pass drilling process through “Tube Holes Drilling” (1.2.4.) as a child decomposition. (See Appendix A for production scenarios of other parts produced in the machine shop). Finally, Figure 4-8 lists the activity and process pool to record the activities found in the machine shop processes.

To sum up, predefinition of manufacturing features is difficult, however, the combination of analytical cost estimation method with the process models such as conceptual description capture method IDEF3 provide a generic manufacturing process data that can be managed and analyzed to improve coat estimation accuracy. Also, as shown in this section IDEF3 provides useful cost information for different cost estimation methods.

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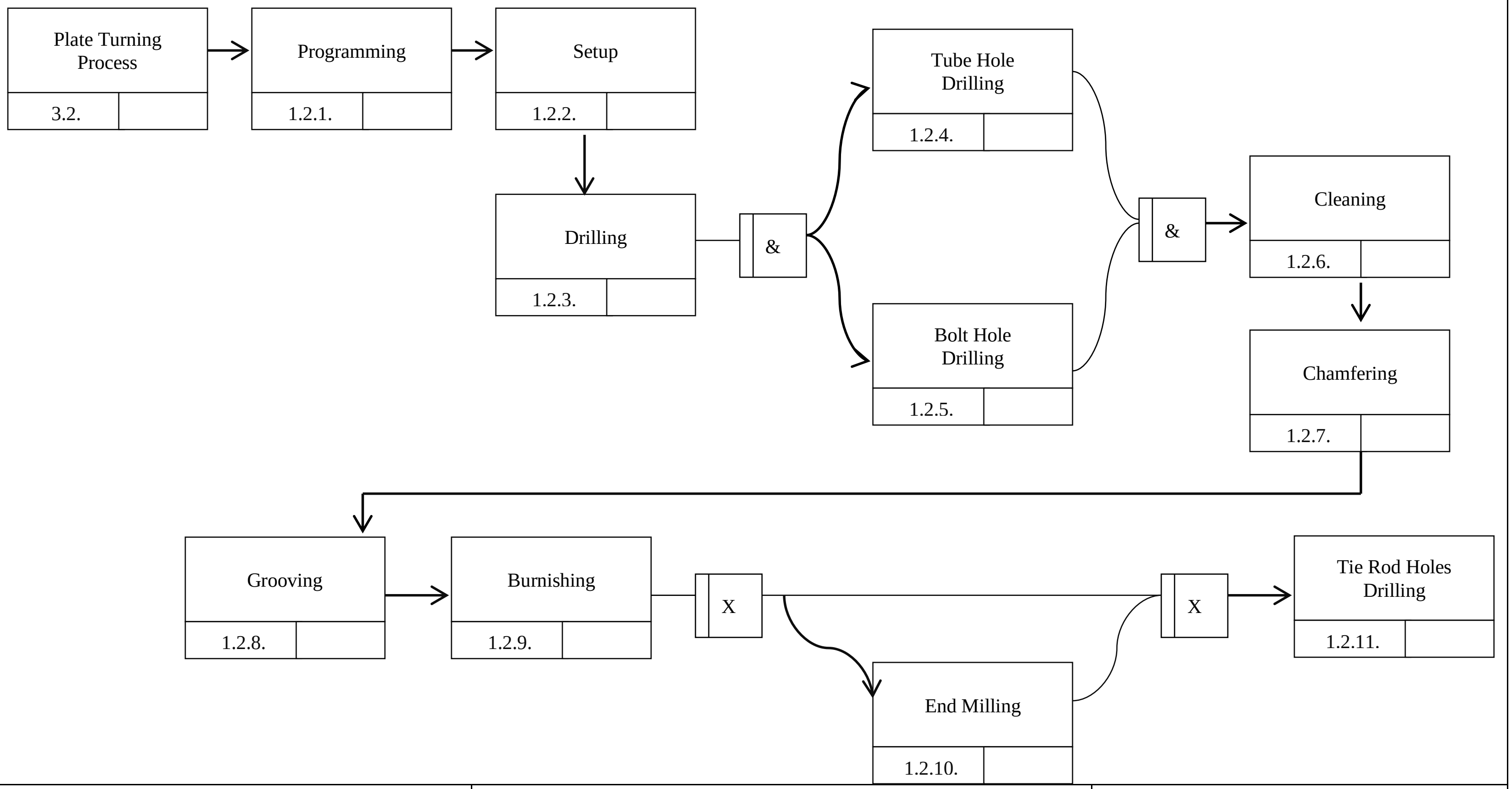

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Quickmill Machine, TUBESHEET Production Scenario	FORM TYPE:

Figure 4-6 TUBESHEET Production Scenario

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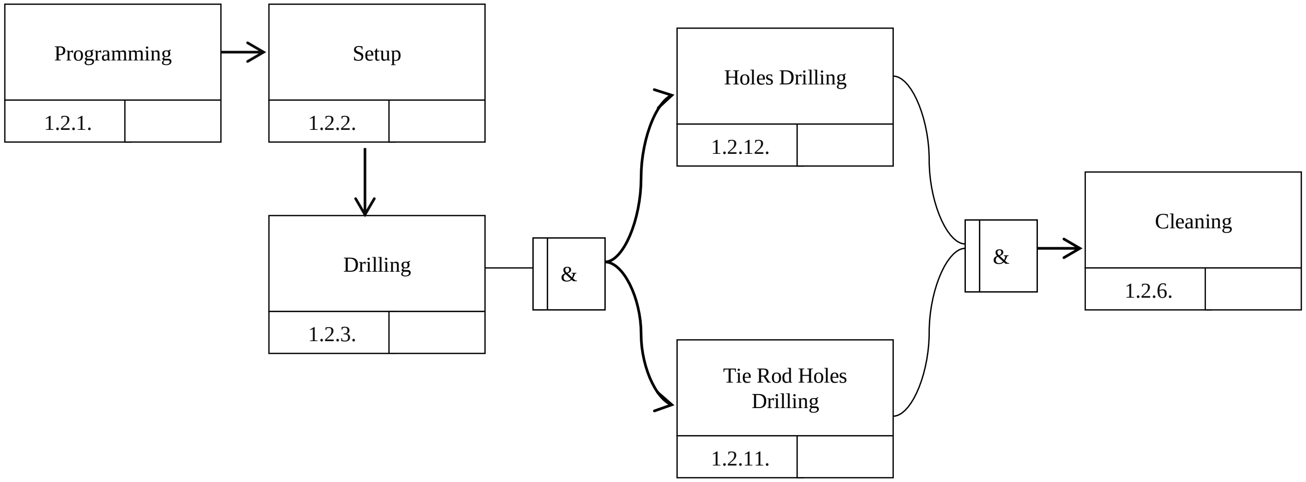

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Quickmill Machine, BAFFLE Production Scenario	FORM TYPE:

Figure 4-7 BAFFLE Production Scenario

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				DRAFT		
	PROJECT: Project Description Capture			RECOMMENDED		
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Object		Source Material No.	Object		Source Material No.
ID No.	Name		ID No.	Name	
01	Machining Centre		023	Holes Drilling	
02	Vendor Turning		024	Insert CLAD Tool	
03	Lath Turning Machining		025	CLAD Bolt Hole Drilling	
04	Order Requested Material		026	Insert Drilling Tool	
05	Sent for Turning				
06	Select Machining Centre				
07	Machining Centre				
08	Ring Turning Process				
09	Plate Turning Process				
010	Fadal CNC Machining				
011	Quickmill CNC Machining				
012	Programming				
013	Setup				
014	Drilling				
015	Tube Hole Drilling				
016	Bolt Hole Drilling				
017	Cleaning				
018	Chamfering				
019	Grooving				
020	Burnishing				
021	End Milling				
022	Tie Rod Holes Drilling				

CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: UOB Process POOL	FORM TYPE:

Figure 4-8 UOB Process Pool

4.2. Product Family Architecture (PFA)

In this section, the product family structure is developed to improve the new cost estimation model. Chapter three, identified analogous cost estimation as one of the costing techniques to be used in this study (See Figure 3-3). The basis of analogous methods are the product family, component sharing, and process shearing concepts. In this study, the product family architecture was used to gather cost information for the analogous method in a more useful form.

In the new cost estimation framework, similar products are identifiedand cost information used to estimate the cost by analogy, through cost adjusting for the differences between the products. Analogous models use the similarity in the cost structure from the geometrical similarity of component and process features. The product family architecture (PFA) method provides the cost information for the analogous cost estimation model. A PFA model shows the component and process shearing in the family tree, and at the detailed levels, features are identified.

4.2.1. Product Family Structure and Developments

The levels of the product family structure to support the new cost estimation framework are: facility, product, assembly, platform, sub-assembly, module, component and feature level (See Figure 3-4).

At the facility level, the XXX International Inc. product family is defined. The product level is divided into two main categories. Products with the single chamber (Pressure vessels), in this category there is one vessel with no channels or stationary. In the second category, multi chambers (Heat exchanger), there are one main vessel and different channels. The pressures vessels can be dividedinto three classes based on the position of the vessel. The vessel can be horizontal, vertical, or spherical. The most common pressure vessel in this study is the horizontal type after used for oil separators. The oil separator is one of the standard jobs which has the mass production, for example, one the customer’s order 15 oil separator yearly with no changes in the product. Therefore, there is mass production for this category.

On the other hand, for the heat exchangers, there is a mass customization production. There are over ten types of heat exchangers. However, in this company, there is a production capacity only for three types which are: shell and tube, plate and frame, and plate and shell heat exchangers. The shell and tube type is the most commonly demanded product representing 99% of the heat exchangers ordered. Based on the shape of the tube the shell and tube heat exchangers can be divided into two main categories, u-tube and straight-tube heat exchangers. The variety and function of heat exchangers are high, and there are many designs base on the application. Figure 4-9 illustrates the product family architecture (PFA) for facility and product level and Table 4-1summarize the product categories.

Table 4-1 Different Product Categories

ABC International Inc. Product Family	Single Chamber (17F)	Pressure Vessels	Horizontal (H)	
			Vertical (V)	
			Spherical (S)	
	Multi Chambers (17R)	Heat Exchanger	Shell and Tube	U-Tube Heat Exchanger
				Straight-Tube Heat Exchanger
			Plate and Frame	
			Plate and Shell	

So far the two top levels of the product family, facility and product levels are developed for all products. For the purpose of this study only the chiller product line (BKU) was analized. This product was selected due to its high demand according to the last year’s data. Also, the company has cost and cycle time estimation problems for this specific product. The next level in the product family is the assembly line. The important task in the assembly level is to define different functions of the product and based on the function a different platform can be chosen for the product. There are three main assembly portions for chiller heat exchangers, which are: the front end head, the shell, and the rear end head. The front head is the portion where the fluid enters the tubeside; the rear head is the portion where the tubeside fluid leaves the heat exchanger, or it may return to the front head if the heat exchanger has multiple tubeside passes. The shell is the portion that contains the tube bundle. The tube bundle is where the fluid passes through the heat exchanger and is transferred between the front and rear heads.

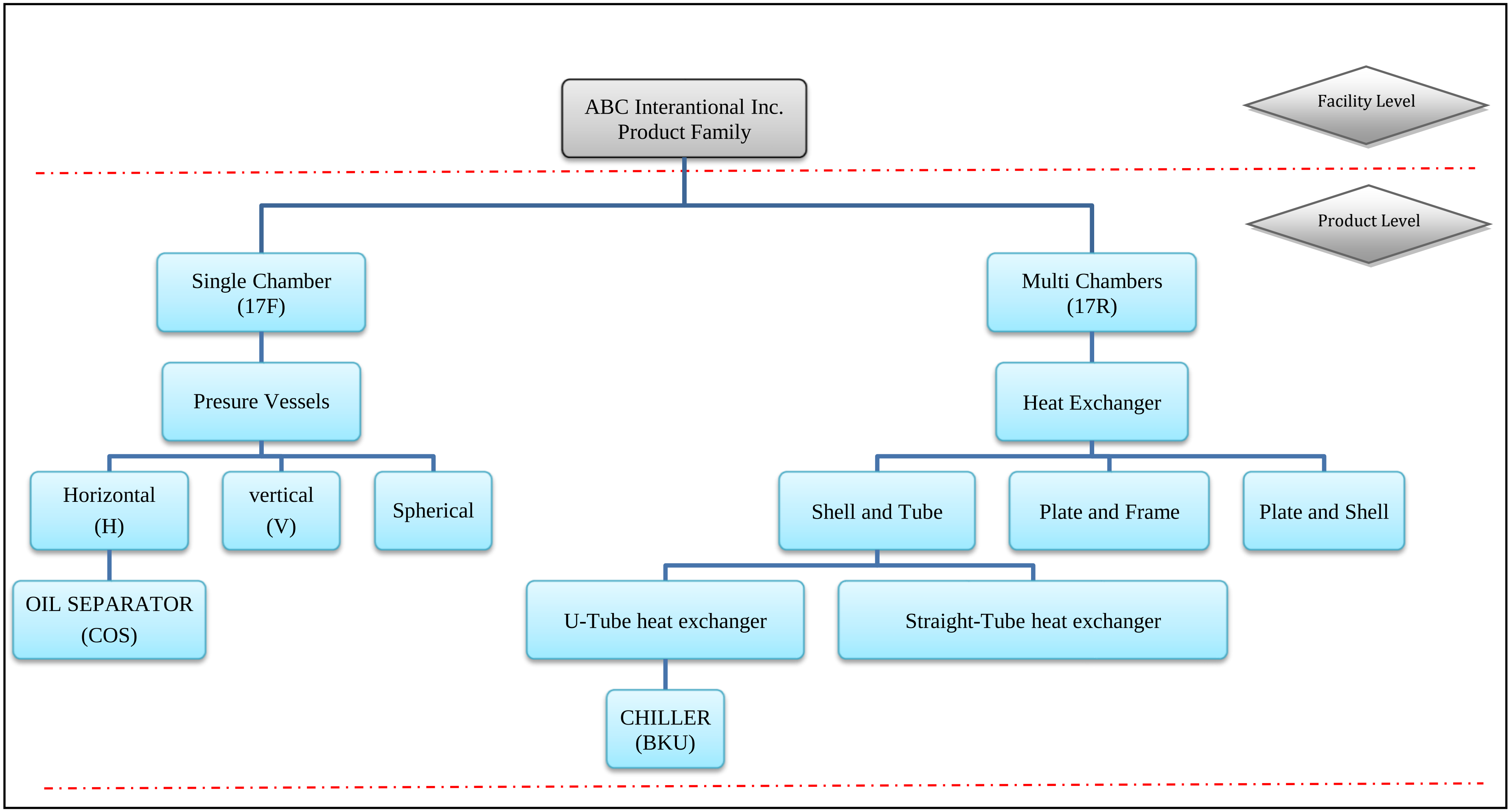


Figure 4-9 Facility and Product Level PFA

To design the heat exchanger the standards from TEMA, Tubular Exchanger Manufacturers Association can be used. This standard nomenclature design was developed based on the popularity of shell and tube exchangers. The standard consists of the diagrams, which are specified with a letter. Each heat exchanger consists of three letters. The first letter shows the type of the front end head, the second letter is the shell type, and the third letter stands for the rear end head type. Figure 4-10 shows examples of a BKU exchanger like chiller and Figure 4-11 illustrates all standard possible combinations for heat exchangers based on the TEMA nomenclature. The different functions of the product are defined in the assembly level. The product function determines which front head, shell, and head type is selected from the TEMA nomenclature.

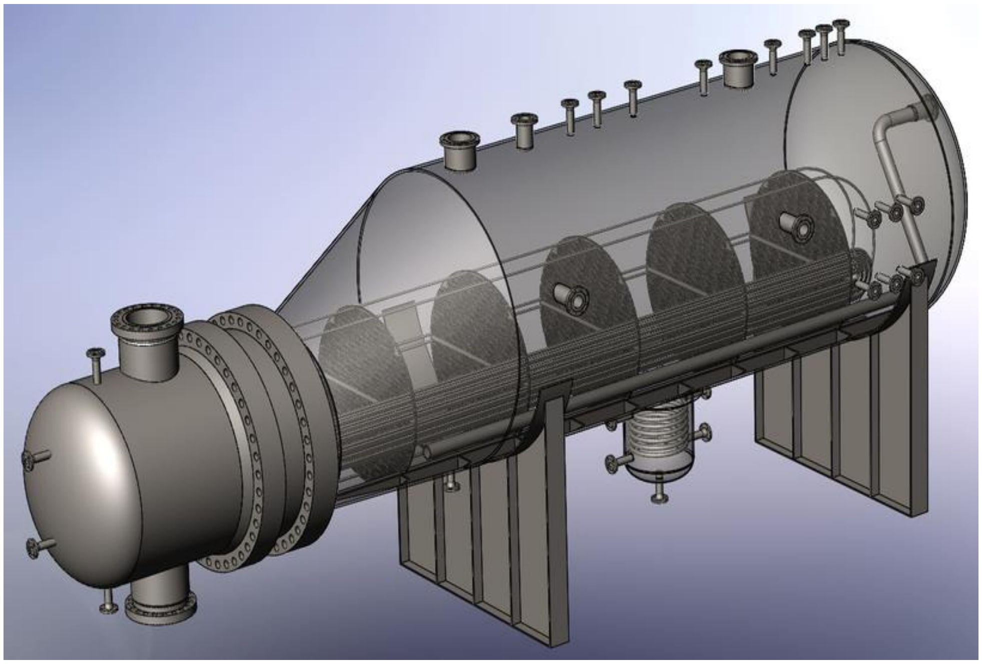


Figure 4-10 Sample of a BKU Exchanger, Chiller

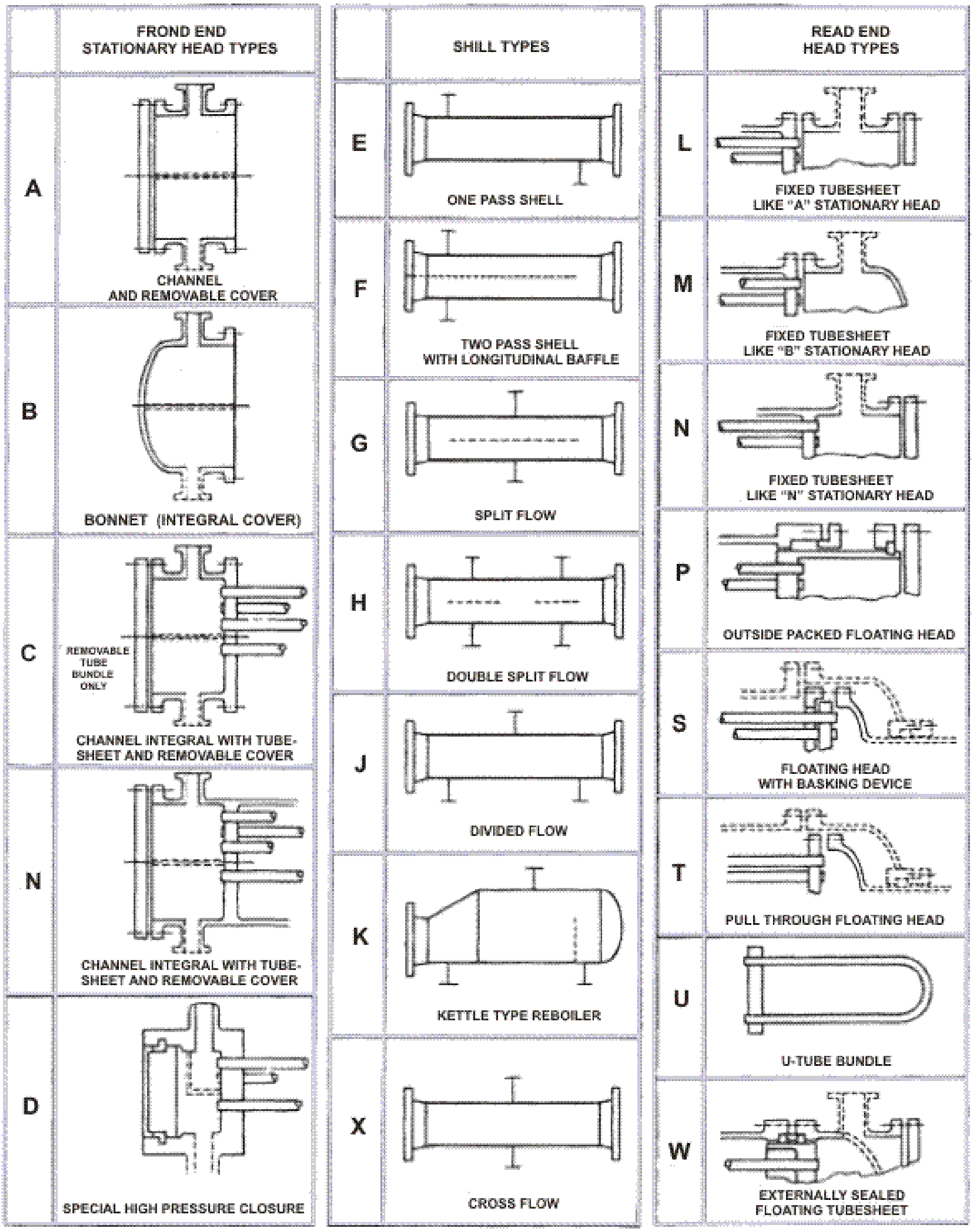


Figure 4-11 TEMA nomenclature. © 1988 by Tubulare Exchanger Manufacturers Association

For example, for the chiller (BKU) one of the main expected functions is to be able to work under high pressure which can be achieved by using the proper front head type. Also, for the chiller, the function of the shell is to cool the tube side fluid, and the final function of chiller is to have unlimited thermal expansion which can be achieved by using the proper rear head type. At the platform level, based on the required functions, the appropriate platform can be selected.

The platform level is one of the most important levels in the product family architecture. The commonality between different products can be defined at this level. Products differ from each other in the levels above and below the platform level. In the platform level, all products use different combinations of the same platforms based on the product functions. In this study, the platforms are defined based on the TEMA nomenclature types. Table 4-2 shows the different platforms for the front head types and their application. For instance, for the chiller front head, a designer would select front head Type B because it is suitable for high-pressure applications.

Table 4-2 Front Head Types Platforms

FRONT END STATIONARY HEAD TYPES	**PLATFORM Functions and Properties**
A	Easy to repair and replace. It gives easy access to the tubes for cleaning and repair. However, this type of front head has two seals and this increases the risk of leakage. Therefore, it cannot be used under high pressure.
B	This type of the head can work under **high-pressure conditions** because it has one seal. It is the cheapest type of front head. However it is difficult to gain access to the tubes therefore it is difficult to repair and maintenance.
C	This type of the head can work under higher pressure than type B. It is for **high-pressure applications (>100 bar)**. There is good access to the tubes but maintenance is not easy because the tube bundle is an integral part of the header.
N	This type of head provides very easy access to the tubes and it is cheaper than Type A. Maintenance is difficult because the header and tube sheet are an integral part of the shell.
D	It is suitable for **very high pressures (>150 bar)**. It is the most expensive front head. There is good access to the tubes but maintenance is not easy because the tube bundle is an integral part of the header.

The second assembly portion of the heat exchanger is the shell. Chillers use the Type K shell. The main process and function of a chiller is to boil a fluid on the shell side and cool the tube side fluid. All the shell type platforms and their functions are summarized in Table 4-3. One of the functions of a chiller is to work under high pressure with unlimited thermal expansion. A U-tube bundle which is the Type (U) rear head permits unlimited thermal expansion. Therefore, it is the most appropriate rear head for the chiller. Table 4-4 shows different platforms for rear head types and their application.

Table 4-3 Shell Types Platforms

SHELL TYPES	**PLATFORM Functions and Properties**
E ONE PASS SHELL	This type is the most common shell. It is suitable for most **general duties and applications**.
F TWO PASS SHELL WITH LONGITUDINAL BAFFLE	This type is useful when **pure countercurrent flow** is needed. There is a problem with thermal and hydraulic leakage in this type.
G SPLIT FLOW	This type of shell used when the **shell side pressure drop is small**. Splitting the shell side flow provides this property. The most common product with this type of shell is the horizontal THERMOSYPHON REBOILER.
H DOUBLE SPLIT FLOW	The application of this type is when the **shell side pressure drop should be small**. This type is preferred over the G-type when a **larger shell** is needed.
J DIVIDED FLOW	When the **design exceeds the maximum allowable pressure drop** this type should be used. Also, when there is tube vibration it is better to use this type. The divided flow reduces the flow velocities and causes less pressure drop and **reduces tube vibration**.
K KETTLE TYPE REBOILER	This type **provides a large space to minimize liquid carry over**. It is used for REBOILERS. It is also used for CHILLERS when the main application is to boil a fluid on the shell side in order to cool the tube side fluid.
X CROSS FLOW	This type provides the **maximum shell side pressure**. The main products using this type are CONDENSERS and GAS COOLERS.

Table 4-4 Rear End Head Types Platforms

REAR END HEAD TYPES	**PLATFORM Functions and Properties**
L FIXED TUBESHEET LIKE (A) STATIONARY HEAD	This type is only used with **fixed tubesheets**. It is easy to access the inside of the tubes. There is a limitation on operating temperature and pressure due to the roll expansion.
M FIXED TUBESHEET LIKE (B) STATIONARY HEAD	This type is similar but less expensive than the type -L. It **does not have easy access** to the inside of the tubes. It has operating temperature and pressure limitations.
N FIXED TUBESHEET LIKE (N) STATIONARY HEAD	This type of rear head provides **easy access**, but the header is integrated with tube sheet and is difficult to replace.
P OUTSIDE PACKED FLOATING HEAD	It is a low cost floating head with **easy access** to the inside of the tubes. Limited **to low pressure fluids** due to leaking possibilities. It has a **small thermal expansion**. The shell has to be rolled to small tolerances which increases the cost.
S FLOATING HEAD WITH BASKING DEVICE	The bundle can be removed in this type and it has **unlimited thermal expansion**. However, it is the **most expensive** floating head type.
T PULL THROUGH FLOATING HEAD	This type has **unlimited thermal expansion** and it is easier to remove the bundle. It is **cheaper** than the type-S, but is more expensive than a fixed header.
U U-TUBE BUNDLE	This type of rear head permits **unlimited thermal expansion** and the **bundle can be removed**. It has a **simple design** and it is the cheapest removable bundle design. **Normally it cannot have pure counter flow** unless combined with the F-type shell.
W EXTERNALLY SEALED FLOATING TUBESHEET	It has **unlimited thermal expansion** and a removable bundle. This type is **limited to low pressure fluids.** There is a possibility that the shell and tube side fluids can mix.

The next level in the product family architecture is the sub-assembly level. In XXX International Inc., first the sub-assembly processes are completed and then all three assembly portions are assembled together. Each platform has a specific sub-assembly as the components and modules of each platform are different from each other. The first sub-assembly, (S1), is for the front head. The second sub-assembly, (S2), is for the shell preparation. The final sub-assembly, (S3), is the tube bundle assembly. Figure 4-12 shows the assembly, platform, and sub-assembly levels for the chiller (BKU).

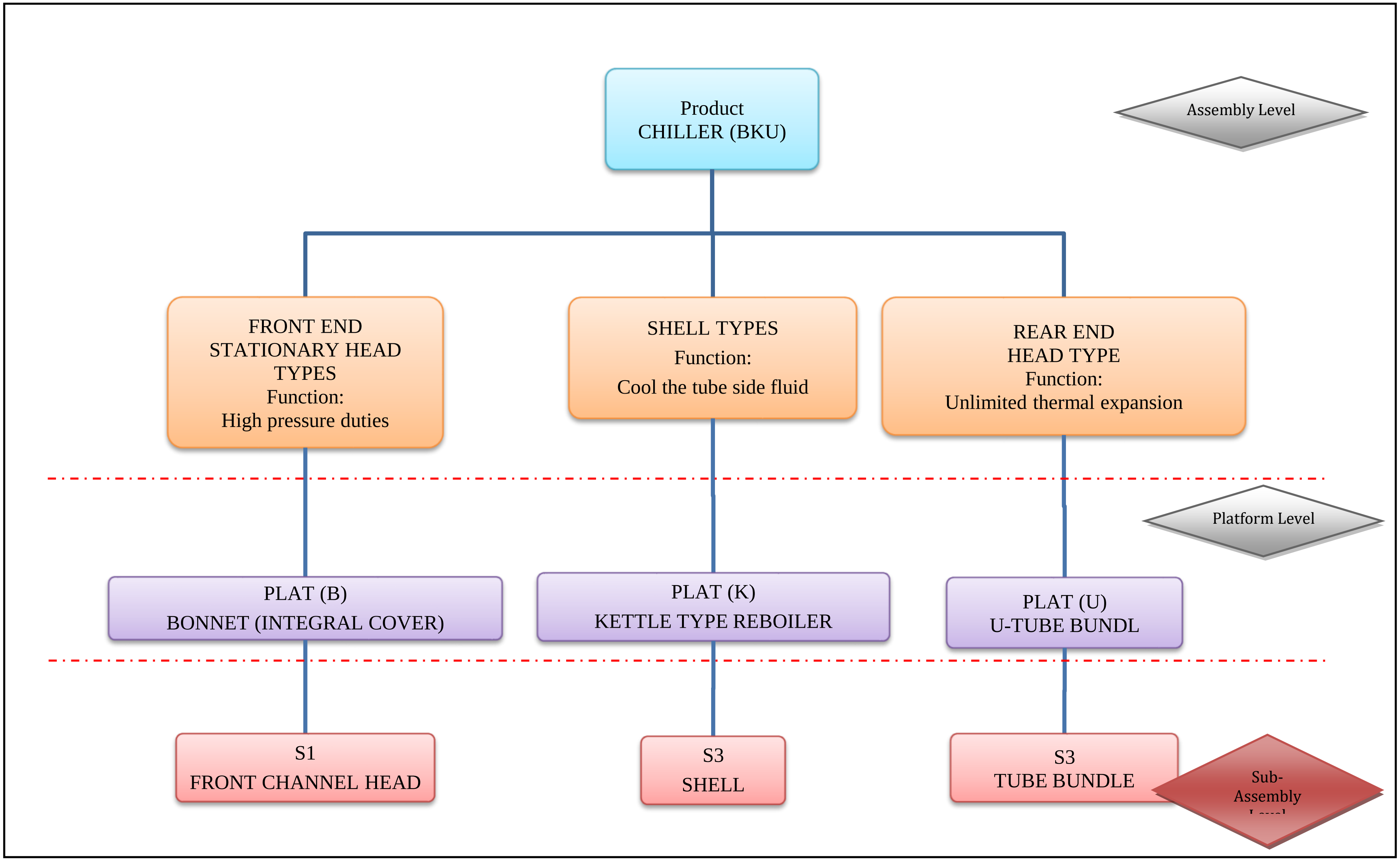


Figure 4-12 Product, Assembly, Platform, Subassembly PFA

Each sub-assembly level consists of components, modules, or both. Therefore, the next level in the PFA after sub-assembly is Modules & Components. A module is a combination of different components. Two main modules in the product family are connections (nozzles) and the support saddle. These modules are common between all products in the company. The last level in the product family structure is the Feature level. The Feature level specifies all the component features that define that component. Figure 4-13 represents the module, component and feature levels of the front channel head sub-assembly (S1).

Each component has a different set of features and parameters. For example, one component in the front channel head sub-assembly (S1) is the REPAD (Com S2), two repadsare used in this specific chiller front head but they are different. They differ from each other based on parameters and features. The two main parameters for the repad are the ring diameter (Ø) and thickness (THK). These features are defined in the feature level. All information of components and modules are summarized in Table 4-5 and Table 4-6 respectively.

Table 4-5 S1 Sub-assembly Components

SUB-ASSEMBLY COMPONENT			**DESCRIPTION**	**Features**	**MATERIAL**
CODE	**QTY.**	**NAME**			
Com.S1.	1	Stationary (Front)/Channel Shell	Rolled Plate	30" OD 1-1/2" THK 26-7/8" LG	SA-70-N
Com.S2.	1	Stationary Head-Bonnet	Head	30" OD 1-1/2" THK	SA-70-N
Com.S3.	1	Stationary Head Flange	Flange	8"	SA-350
Com.S41.	2	Repad	Plate	Ø10" × 5/8" THK	SA-70-N
				Ø20" × 3/8" THK	SA-70-N
Com.S31.	1	Pass Partition	Plate	43"×35"×1/2" THK	SA-70
Com.S36.	2	Lifting Lug	Plate	Type-2	SA-70-N
Com.S42.	1	Gasket	NA	1/8" THK	SS-316

Table 4-6 “M” Module Components

MODULE COMPONENT			DESCRIPTION	Features	MATERIAL
NAME	CODE	QTY.			
MEP5.12". Stationary Head Nozzle	Com.C1.	1	Pipe	12" ND 0.688" THK 4-1/8" LG	SA-106
	Com.C2.	1	Elbow	12" ND 0.688" THK 90° L.R.	SA-234
	Com.C3.	1	Flange	12" ND 300 # RFWN	SA-105
MF5.3".12". Stationary Head Nozzle	Com.C1.	2	Pipe	3" ND 0.3" THK 8-9/16" LG	SA-106
				12" ND 0.688" THK 13-7/16" LG	SA-106
	Com.C3.	2	Flange	3" ND 300 # RFSO	SA-105
				12" ND 300 # RFSO	SA-105

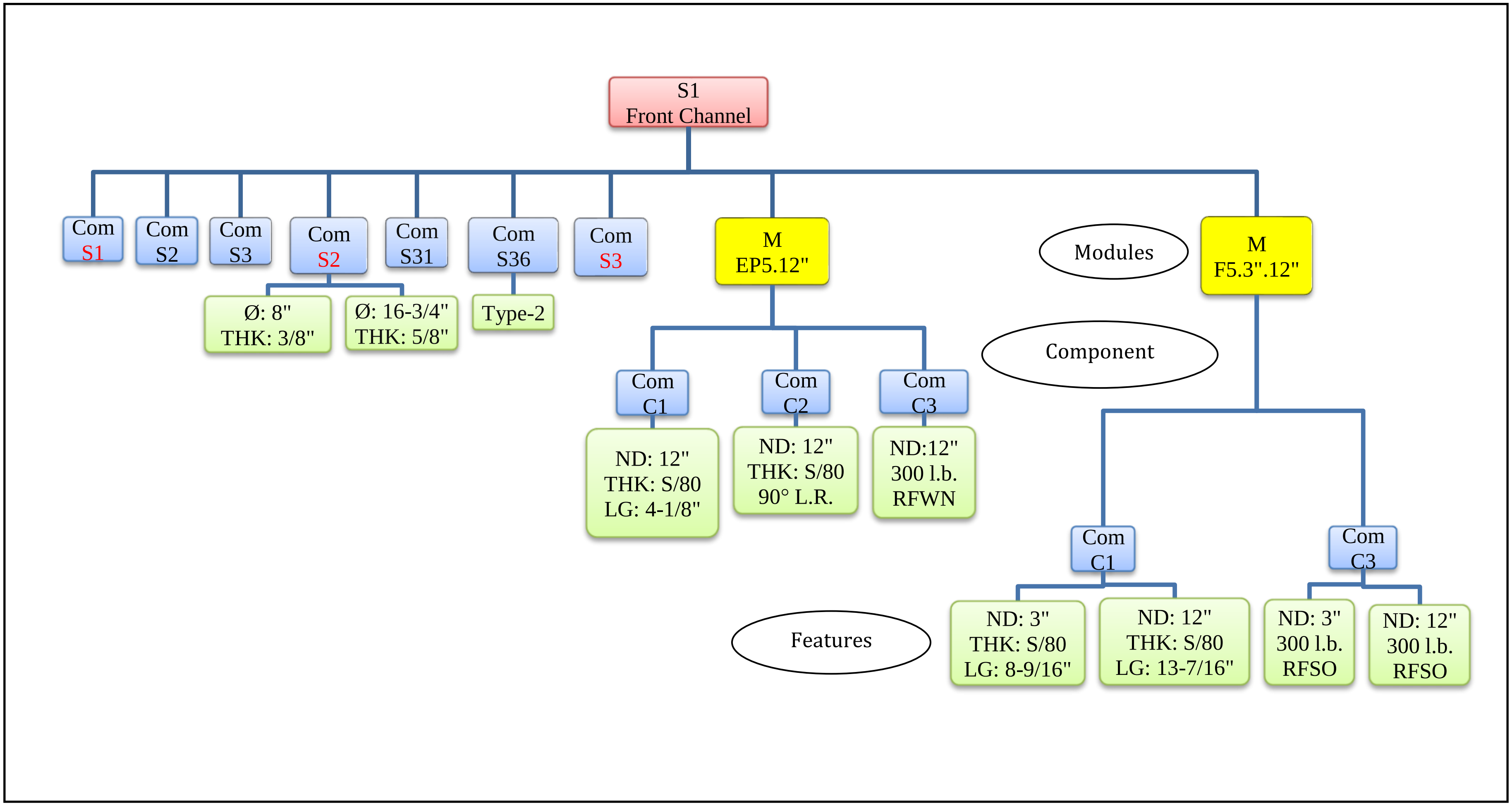


Figure 4-13 Front Channel Sub-assembly (S1)

4.2.2. Different Analogical Concepts

As indicated in Figure 3-3, analogous cost estimation is one of the costing techniques uses in this study. There are two different analogical methods: one is the quantitative analogical approach which is component feature-based, and the other one is the qualitative analogical approach which is process feature-based. The Feature level of the tube bundle (S3) illustrates the difference between these two analogical methods. Figure 4-13 illustrates the component and feature levels of the tube bundle.

Considering Figure 4-14 all features for different components are component feature-based so the components are different based on their shape and size. Therefore, these differences do not affect their underlying production processes. The supply chain provides these components based on the different sizes and raw material prices. However, one component is process feature-based. The TUBESHEET component has two main features. It can be a big or small tubesheet. These features cause differences in the raw material prices and size like component feature-based, but they also require different manufacturing production processes. That is why they are categorized as process feature-based. The new costing model and the IDEF3 process description capture method are used to define and collect information for the qualitative analogical costing method which is process feature-based, which cannot be obtained only by using the product family architecture.

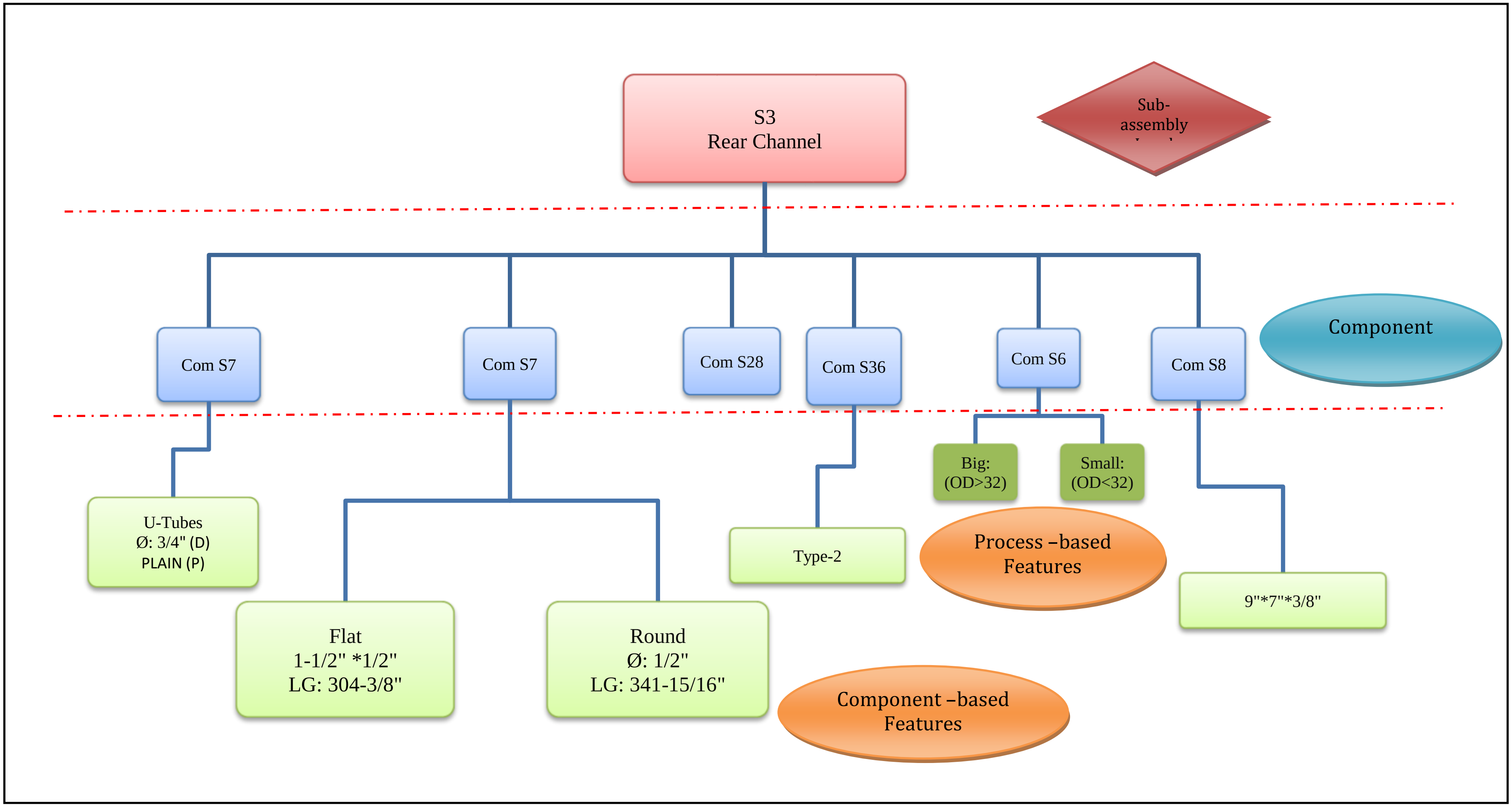
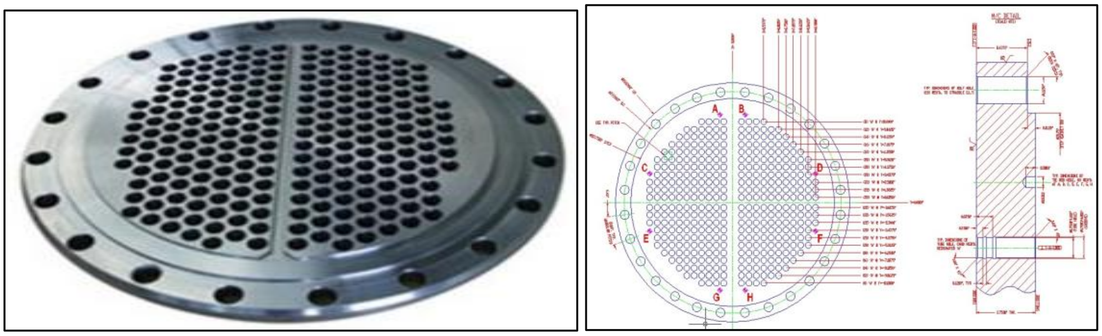


Figure 4-14 Rear End Head (S3) PFA with Process and Component Features

4.3. Implement The Proposed Cost Estimation Framework

In this section, the new cost estimation model is implemented at the initial stages of design for all parts produced in the machine shop. Figure 4-15 shows the finished product and its initial blueprint. One of the main goals of the case study was to estimate part cost based on early product design information.



(a) (b)

Figure 4-15 Machine Shop Part Sample. (a) Final Product (b) Blue Print

The machine shop at XXX International, Inc. has three CNC machines which are the QuickMill, the Fadal, and the Lathe. The QuickMill and Fadal perform the drilling, burnishing, and grooving, processes. The Lathe performs the turning process. First, a list of all parts that are produced in the machine shop has created. The five main parts produced in machine shop, are: TUBESHEET, BAFFLE, COVER FLANGE, FLANGE, and BOLTING PAD. During the second stage of the costing process useful and relevant cost information is collected using the Product Family Architecture and the IDEF3 Process Description Capture Method. The most critical cost information is the core production processes performed in the machine shop, including the relevant processes and product parameters.

The core-sheared processes between all parts produced in the machine shop are: Drilling, Turning (Plate Turning or Ring Turning), Programming, Initial Setup, Loading, and Unloading. The additional core processes, which are not sheared and only needed for one part type are: Chamfering, Grooving, and Burnishing. In the next step, the related parameters for those processes are defined to calculate the cycle time for each of the processes. The values of the different parameters are defined in the blueprint based on engineering and customer requirements. Those values can then be extracted and used as the input data, relating to the processes for the calculation of the related machining time and cost.

For instance, one of the core processes which is notably common between all parts is the drilling process. Figure 4-16 and Figure 4-17 illustrate where the cost and production information are respectively found through the use of the IDEF3 processes capture description method and the Product Family Architecture for the drilling process. The drilling cycle time is calculated based on the Equation 4-1. The feeding rate is a function of the material, and hole diameter, in addition to how the expert machinist defines it. Therefore, the parameters for the drilling process are: plate thickness, feeding rate (material and hole diameter), and the number of holes. As a numerical example, the cycle time for drilling 1952 holes with a 0.6330 diameter in carbon steel plate two inches thick is as follows:

$$Drilling\ Cycle\ Time = \left[\frac{Plate\ Thivkness\ (inchs.)}{Feeding\ Rate\ \left({}^{inchs.}/_{min.}\right) \times\ 60({}^{mins.}/_{hr.})} \times\ Number\ of\ the\ Holes\right]_{hours} \qquad (4-1)$$

$$Drilling\ Cycle\ Time = \left[\frac{2\ (inchs.)}{12\ ({}^{inchs.}/_{min.}) \times\ 60({}^{mins.}/_{hr.})} \times\ 1952\right] = 5.42\ hours$$

$$Drilling\ Cycle\ Time = \ 5.42\ hours\ \ = 5\ hours\ and\ 25\ minuts$$

Where;

$Plate\ Thichnesss = 2\ inchs.$

$Number\ of\ the\ Holes = 1952$

$Feeding\ rate\ (material\ , hole\ diameter) = Feeding\ rate\ (SA\ , 0.6330) = 12\ inchs\ per\ minute.$

$Material: Carbon\ Steel\ (SA)$

$Hole\ Diametere: 0.6330\ inchs.$

USED AT:	ANALYST: Zahra Banakar DATE: 15 Jun 2017	×	WORKING	REVIEWER:	DATE:
			DRAFT		
	PROJECT: Project Description Capture		RECOMMENDED		
	NOTES: 1 2 3 4 5 6 7 8 9 10 REV:		RELEASED		
UOB No. UOB6	UOB Name: Select Machining Centre Objects: TUBESHEET Constraints: Outer Diameter Description: If the outer diameter (OD) of the sheet is less than 30, Machine centre is FADAL Otherwise, Machine centre is QUICKMILL	UOB Label:	Select Machining Centre		
UOB No. UOB12	UOB Name: Drilling Tube Hole Objects: TUBESHEET Constraints: NA Description: Plate Thickness = 2 inch , Number of Tube Holes = 1952 , Feeding Rate (SA, 0.6330) = 12 inch/min	UOB Label:	Drilling Tube Hole		
CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Drilling Tube Hole UOB			FORM TYPE:	

Figure 4-16 UOB Elaborations for Drilling Processes

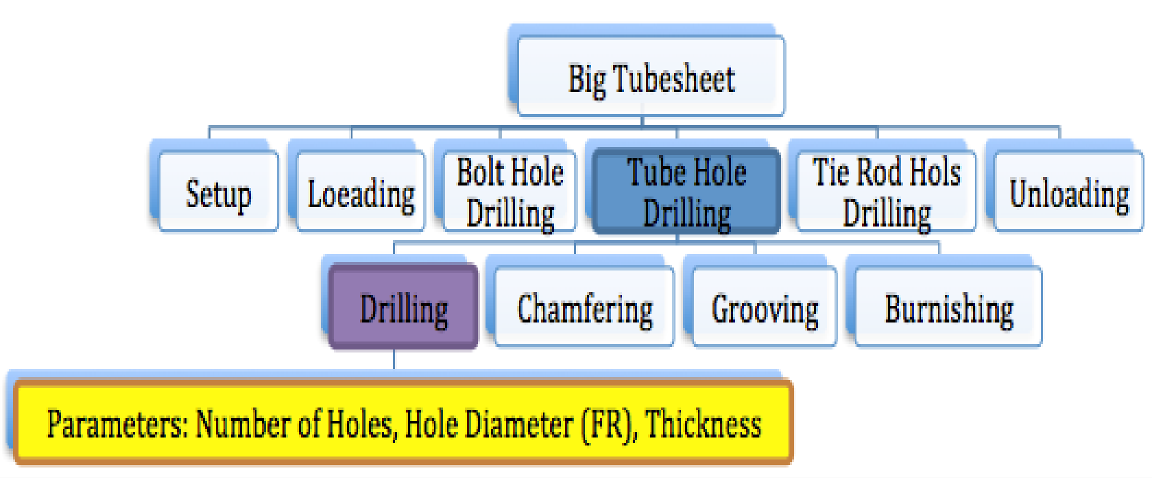


Figure 4-17 Detailed Level of the Product Family Architecture (PFA)

The machining cycle time for all the processes can be calculated based on the core processes, as well as the related parameters by implementing the same system. The core processes for all parts produced inside the machine shop are summarized in Table 4-7. Table 4-8 summarizes the cycle time formula and the related parameters for each core process.

Table 4-7 Core Processes for All Parts Produces in the Machine Shop

PARTS	CORE PROCESSES
TUBESHEET	Drilling
	Plate Turning
	Chamfering
	Grooving
	Burnishing
	Milling
BAFFLE	Drilling
FLANGE	Drilling
	Ring Turning
BOLTING PAD	Drilling
	Ring Turning
COVER FLANGE	Drilling
	Plate Turning

Table 4-8 Cycle Time Formulas and Related Parameters for Core Processes

CORE PROCESSES	**PROCESS CYCLE TIME**	**PROCESS PARAMETERS**
Drilling	$\left[\frac{Plate\ Thickness_{(inchs.)}}{Drilling\ Feeding\ Rate_{\left(inchs./_{min.}\right)}\times 60_{\left(mins./_{hr.}\right)}}\times Number\ of\ the\ X\ Holes\right]_{hrs.}$	Plate Thickness (P.THK.) Drilling Feeding Rate (D.FR.) Number of the X Holes (No.XHs.)[1]
Turning	$\left[\frac{(Total\ Material\ Romoved\ Volume)_{(inch.^3)}}{Material\times MaterialRemovingRate_{\left(inch.^3/_{min.}\right)}\times 60_{\left(mins./_{hr.}\right)}}\right]_{hrs.}$	Material (SA. or SS.) MRR (MRR_{SA} or MRR_{SS}) Volume Parameters
Chamfering	$\left[NumberoftheXHoles\times 0.0006_{\left(hrs./_{hole.}\right)}\right]_{hrs.}$	Number of the X Holes (No.XHs.)[1]
Grooving	$\left[NumberoftheXHoles\times SA\times 0.002_{\left(hrs./_{hole.}\right)}\right]_{hrs.}$ $\left[NumberoftheXHoles\times SS\times 0.004_{\left(hrs./_{hole.}\right)}\right]_{hrs.}$	Number of the X Holes (No.XHs.)[1] Material (SA or SS)
Burnishing	$\left[\left(\frac{Plate\ Thickness_{(inchs.)}}{Burnishing\ Feeding\ Rate_{\left(inchs./_{min.}\right)}\times 60_{\left(mins./_{hr.}\right)}}\times Number\ of\ the\ X\ Holes\right)\times Iterations\right]_{hrs.}$	Plate Thickness (P.THK.) Burnishing Feeding Rate (B.FR.) Number of the X Holes (No.XHs.)[1]Iterations (I.)
Milling	$\left[\frac{\left((TrapLength\times TrapWidth\times TrapDepth)\times NumberoftheTraps\right)_{(inch.^3)}}{Material\times MaterialRemovingRate_{\left(inch.^3/_{min.}\right)}\times 60_{\left(mins./_{hr.}\right)}}\right]_{hrs.}$	Trap Length (T.L.) Trap Width (T.W.) Trap Depth (T.D.) Number of the Traps (No.T.) Material (SA. or SS.) MRR (MRR_{SA} or MRR_{SS})

1. The Number of the Holes depends on the product and drilling process. For the TUBESHEET there are three different types of holes which are: Bolt Hole, Tube Hole and Tie Rod Hole. For Bolt Holes drilling, the number of holes is the number of Bolt Holes (No.Ts.BHs.). For the Tube Holes it will be number of Tube Holes (No.Ts.THs.). For the tie rod holes it will be number of Tie Rod Holes (No.Ts.TieHs.). For the baffle there are two types of the holes, baffle holes (No.Bf.Hs.) and baffle tie rod holes (No.Bf.TieHs.). For the FLANGE drilling process the number of the holes is (No.Fl.Hs.). For the BOLTING PAD it is (No.BP.Hs.) and for the COVER FLANGE it is (No.CF.Hs.).

A Microsoft Excel Spreadsheet was designed to formulate the new cost estimation method for all the parts produced in the machine shop using their respective core processes and parameters. Among all the parts that are produced in the machine shop, the TUBESHEETS are the most complicated parts, as they have more than one process and the highest production cycle time. Therefore, it was selected as a sample, and the machining cycle time for all core processes was calculated, and the cost estimation for manufacturing the TUBESHEETSwas obtained.

The core processes for the TUBESHEET can be extracted from Table 4-7which are: drilling, turning, chamfering, grooving, burnishing, and milling. All of the parameters for the manufacturing processes of the TUBESHEET are available in Table 4-8. The values of these parameters are provided on a blueprint created by the designers. These parameter values were extracted from the blueprint and then entered into the Excel spreadsheet. The green area in Table 4-9 shows the TUBESHEET parameters.

During the second step, all of the parameters taken from Table 4-9have been used to calculate the manufacturing cycle time for each of the core processes. One of the main processes of TUBESHEET production is drilling. In accordance withthe data in Table4-8the main parameters for drilling cycle time are: plate thickness, feeding rate, material and hole diameters, and the number of holes. However, the three drilling processes for TUBESHEET production are categorized as: Bolt Hole drilling, Tube Hole drilling, and Tie Rod Hole drilling. All of these drilling processes have the same parameters, but use different values. The parametric drilling processes and their corresponding cycle times are summarized for the TUBESHEET component in Table 4-10.

Table 4-9 TUBESHEET Description

Job # 16R3788B		TUBESHEET DESCRIPTION				
		Material	Plate Diameter	Plate Thickness	Steps	
		SA	25	2	Step No.	Step Diameter
		Number of BOLT Holes	Number of TUBE Holes	Number of Traps Plate	1	19.1875
Quantity	2	28	498	0	Weight	
		BOLT Hole Diameter	TUBE Hole Diameter	CLAD		
		0.875	0.633	1	277.835	
Total Drilling, Grooving, Burnishing, Milling Time Per Job		19.88			hours	
Total Turning Time Per Job		5.68			hours	
Total TUBESHEET Machining Time Per Job		25.56			hours	
TOTAL TUBESHEET MANUFACTURING COST ($50 Per hour)		$1,277.96			PRICE $	
TOTAL TUBESHEET MANUFACTURING COST ($100 Per hour)		$2,555.93				

Table 4-10 Drilling Processes and Cycle Time for TUBESHEET

Programming		1.00					hours
Initial Setup		1.50					hours
Loading		0.50					hours
BOLT HOLE DRILLING		Thickness +0.25	No. BOLT Holes	Material	Hole Diameter	Feeding Rate	Time Unit
		2.2500	28	SA	0.8750	8	
Insert the Tool		0.25					hours
BOLT Hole Drilling Time		0.13					hours
Total BOLT Hole Drilling Time		0.38					hours
CLAD BOLT Hole Drilling Time		CLAD THK	No. BOLT Holes	Material	Hole Diameter	Feeding Rate	Time Unit
		0.50	28	SS	0.875	3.5	
CLAD Setup Time		0.25					hours
Total CLAD BOLT Hole Drilling Time		0.32					hours
TUBE HOLE DRILLING		Thickness+ 0.25	No. TUBE Holes	Material	Hole Diameter	Feeding Rate	No. Inserts
		2.2500	498	SA	0.6330	15	1.303
Change the Drilling Tool		0.25					hours
Change the Inserts		0.33					hours
TUBE Hole Drilling Time		1.25					hours
Total TUBE Hole Drilling Time		1.82					hours
CLAD TUBE Hole Drilling Time		CLAD THK	No. TUBE Holes	Material	Hole Diameter	Feeding Rate	Time Unit
		0.5	498	SS	0.633	4.5	
CLAD Setup Time		0.25					hours
Total CLAD TUBE Hole Drilling Time		1.17					hours
Tie Rod Holes		Depth	No. Tie Holes	Material	Hole Diameter	Feeding Rate	Marking Feeding Rate
		0.3800	10	SA	0.5313	5	10
Turn the Sheet		0.25					hours
Change the Tool	Marking Tool	0.25					hours
	Drilling Tool	0.25					
Tie Rod Hole Marking Time		0.10					hours
Tie Rod Hole Drilling Time		0.17					hours
Total Tie Rod Drilling Time		1.02					hours
Total Drilling Time Per TUBESHEET		7.71					hours

The next core process for TUBESHEET production is turning. There are two types of turning: plate turning and ring turning. The cycle time of the turning process is based on the Material Removal Rate (MRR) and the volume of the material that it removes. The relationship between MRR, volume, and turning cycle time is stated in Equation 4-2.

$$Turning\ Cycle\ Time = \left[\frac{Volume\ (inch^3)}{MRR\ \left({}^{inch^3.}/_{min.}\right) \times\ 60\left({}^{mins.}/_{hr.}\right)}\right]_{hours} \qquad (4-2)$$

The only difference between plate turning and ring turning is the volume of the removal material geometry and related parameters. The turning process for the TUBESHEET is plate turning. The main parameters for the plate turning cycle time are: plate thickness, plate diameter, step diameter, number of steps and the CLAD option. The parametric processes for the plate turning cycle time are summarized in Table 4-11.

Table 4-11 Turning Processes and Cycle Time for TUBESHEETS

TURNING PROCESS ON LATHE								
Programming		1.00						hours
Initial Setup		0.75						hours
Loading		0.25						hours
Change the Tool		0.50						hours
MACHINING		External Radius	Internal Radius	Depth	Volume $(inch^3)$	Total Volume $(inch^3)$	Turning MRR	Time Unit
Finishing	Edge	12.625	12.500	2.250	22.200	97.174	80	
	Surface	12.500	0.000	0.025	12.272			
		12.500	0.000	0.025	24.544			
Step Machining		12.500	9.594	0.250	50.430			
Total Machining Time Per Plate		1.21						hours
Unloading		0.25						hours
Total Turning Time Per Plate		3.96						hours

The other core processes for the TUBESHEET are: chamfering, grooving, burnishing, and milling. Chamfering is a spot operation with fewer parameters, and the only parameters for this process are the number of Tube Holes, multiplied by 0.006 (hrs./per hole). The grooving process is a spot operation like chamfering. However, the constant value is changed based on the different materials. Therefore, the parameters for grooving are the number of Tube Holes and the TUBESHEET material. The constant values for carbon steel (SA) and stainless steel (SS) are 0.002 and 0.004 (hrs./per hole) respectively. In regards to the burnishing process, the main parameters are similar to the drilling parameters. The only variation is the difference in the feeding rate. The main parameters for the burnishing process are: plate thickness, the number of Tube Holes, the burnishing feeding rate, tubesheet material and tube hole diameters. Finally, the production cycle time for milling is based on the MRR and milling volume. The main parameters are: MRR, trap length, trap width, trap depth and the number of traps. The parametric processes for chamfering, grooving, burnishing, and milling cycle times are summarized in Table 4-12.

Table 4-12 Grooving, Milling, Burnishing Processes for the TUBESHEET

Cleaning	0.25					hours
TUBE HOLE CHAMFERING	Number of TUBE Holes					Spot Operations
	498					0.0006
Change the Tool	0.25					hours
Chamfering Time First Side	0.30					hours
Chamfering Time Second Side	0.75					hours
Total Chamfering Time	1.30					hours
TUBE HOLE GROOVING	Number of TUBE Holes		Material			Spot Operations
	498		SA			0.002
Change the Tool	0.25					hours
Grooving Time	1.00					hours
Total Grooving Time	1.25					hours
TUBE HOLE BURNISHING	Thickness+0.25	No. Tube Holes	Material	Hole Diameter	Feeding Rate	Number of Iteration
	2.2500	498	SA	0.6330	43	1
Change the Tool	0.25					hours
Burnishing Time	0.43					hours
Total Burnishing Time	0.68					hours
TRAP PLATE	Number of Traps	Length	Width	Depth	Volume	Milling MRR
	0	25.0000	0.5000	0.2500	0.0000	1.25
Change the Tool	0.0000				hours	
End Milling Time	0.0000				hours	
Total Surface Grooving Time	0.0000				hours	
Total Grooving, Burnishing, Milling Time Per TUBESHEET	3.48				hours	

4.3.1. Cost Estimation Results

Some statistical methods have been used, to check the adequacy of the model. First, the new model is run using three months of data from the shop. The resulting production time estimates generated by the parametric activity models were compared to time card records of the actual time spent by machine shop personnel. Then, all parameters values determined from the building drawing and used as the input data in the new cost estimation model. The process time's base on the new model also recorded the actual time for the processes which can be obtained from time cards. For the final data analysis, the job number of the part, the cycle time estimation generated by the new model and the actual time for each part is shown in Table 4-13 for FLANGE being a part sample and drilling process, and as a process sample for the other parts and core processes, this information is also provided in Appendix B.

According to Table 4-13 there is a variation between the estimated cycle times and the actual times. In the last column, the negative values indicated the saving times for the machine shop, and where the actual machining time is less than the predicted time, and the positive values show the extra machining hours spent on some of the jobs. The next step features the percentage of the total cost which could be captured by implementing the proposed model and is estimated using Equation 4-3.

$$\frac{Total\ Production\ Cost\ for\ the\ part\ (\$)}{\text{Total Actual Costs for the product (\$)}} * 100 \quad (4-3)$$

Table 4-14 summarizes the calculations and the detailed information for the FLANGE part being a sample, in addition to detailed information for the other parts has been provided in Appendix B.

Table 4-13 New Model Time Estimation and Actual Time for FLANG Part

JOB Number	**NEW MODEL TIME ESTIMATION (hrs.)**			**ACTUAL TIME (hrs.)**			**Differences Between ACTUAL and Estimation Time (hrs.)**
	Ring Turning Process	Drilling Processes	Total Processes Time	Ring Turning Process	Drilling Processes	Total Processes Time	
F16R3738ASH	2.96	2.41	5.37	5.5	2.25	7.75	2.38
F16R3738CSH	7.35	4.66	12.01	8.5	4.75	13.25	1.24
F17R4133CSH	6.85	2.68	9.53	6.25	3.5	9.75	0.22
F17R4294ASH	4.29	3.36	7.65	6.5	2.5	9	1.35
F17R2194ASH	6.29	2.38	8.67	4	2.5	6.5	-2.17
F17R4406DSH	3.29	2.44	5.73	2.5	2.25	4.75	-0.98
F17R4406DCH	3.17	2.42	5.59	2	1.75	3.75	-1.84
F17R3908ASH	3.28	3.06	6.34	3.75	4.5	8.25	1.91
F17R4256ASH	3.72	3.21	6.93	2.5	4.75	7.25	0.32
F17R4114CSH	2.85	2.45	5.3	2.5	3.5	6	0.7
F17R3886BSH	10.62	2.92	13.54	8.5	2.5	11	-2.54
F17R3886BCH	10.9	2.92	13.82	8.5	2.5	11	-2.82
F17R3926ASH	7.59	2.58	10.17	6.25	2.25	8.5	-1.67
F17R3926ACH	8.43	2.6	11.03	8.25	2.5	10.75	-0.28
F17R4203ASH	7.45	4.97	12.42	9	2.75	11.75	-0.67
F17R4443ASH	4.81	3.28	8.09	3.25	2	5.25	-2.84
F17R4114ASH	4.27	3.32	7.59	3.25	4.5	7.75	0.16
F17R4232ASH	9.17	6.97	16.14	10.5	5.75	16.25	0.11

Table 4-14 Average Percentage of the Total Costs for the FLANGE Part

JOB Number	Total Production Costs for the Part ($)	Total Actual Costs for the Product ($)	Percentages of the Total Costs
F16R3738ASH	426.25	8,786.25	4.85%
F16R3738CSH	728.75	8,865.00	8.22%
F17R4133CSH	536.25	8,222.50	6.52%
F17R4294ASH	495.00	6,380.00	7.76%
F17R2194ASH	357.50	14,602.50	2.45%
F17R4406DSH	261.25	13,310.00	1.96%
F17R4406DCH	206.25	13,310.00	1.55%
F17R3908ASH	453.75	5,636.25	8.05%
F17R4256ASH	398.75	7,768.75	5.13%
F17R4114CSH	330.00	45,375.00	0.73%
F17R3886BSH	605.00	22,907.50	2.64%
F17R3886BCH	605.00	22,907.50	2.64%
F17R3926ASH	467.50	13,640.00	3.43%
F17R3926ACH	591.25	13,640.00	4.33%
F17R4203ASH	646.25	9,735.00	6.64%
F17R4443ASH	288.75	19,332.50	1.49%
F17R4114ASH	426.25	7,067.50	6.03%
F17R4232ASH	893.75	9,693.75	9.22%
Average percentage of the Total Costs			**4.65%**

In consideration to Table 4-15and Figure 4-18 among all the parts produced in the machine shop,the TUBESHEET is evidently the most expensive part, as it has 14% of the total product costs. Also, according to this analysis, 30% of the total product cost can be captured by applying the proposed cost estimation method.

Table 4-15 Total Percentage of the Product Costs

Part Description	Average percentage of the Total Costs
TUBESHEET	14.00%
BAFFLE	6.30%
COVER FLANGE	3.66%
FLANGE	4.65%
BOLTING PAD	2.15%
Total Percentage (%)	**30.76%**

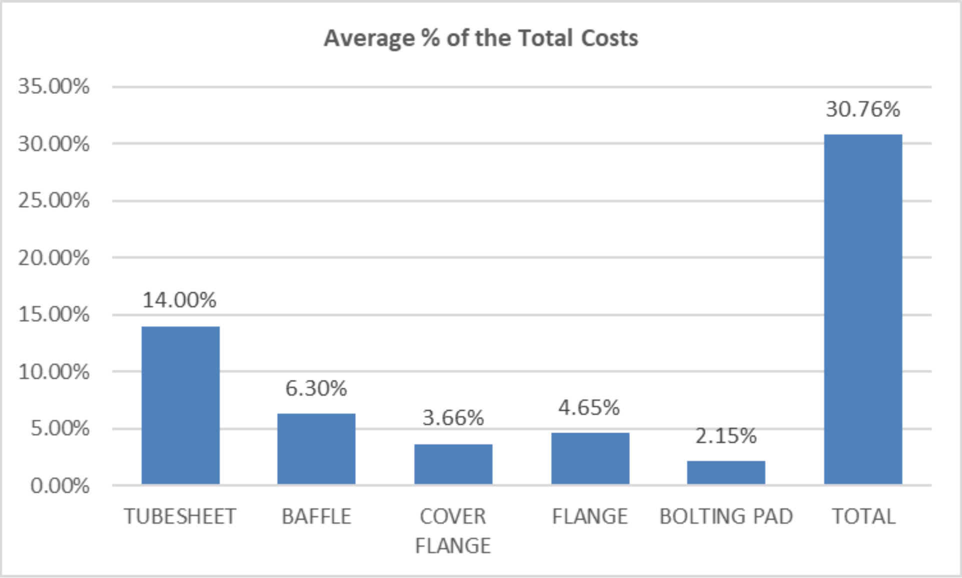


Figure 4-18 Total and Average Percentage of the Product Costs

4.3.2. RESIDUAL ANALYSIS

Primarily, the residual analysis verifies the model assumptions and the adequacy of the model. Moreover, some assumptions verified in this study are as follows:

1. The linear model is reasonable.
2. The constant varianceof the residuals.
3. The normality of the residuals.

For the first two assumptions, the useful plot is the residual value versus the predicted value. Figure 4-19 illustrates the residual versus the predicted value for the drilling process for the sample and the residual analysis for other process are presented in Appendix C. When considering the results seen in Figure 4-19 there is not any visible patterns between residuals and predicted values, but there is a random point plot. Therefore, the linear model is reasonable, and the residuals have constant variance. Finally, to check the third assumption, the normality test was run for the data. In this study, the Kolmogorov-Smirnov test of normality was conducted and the results are summarized in Table 4-16 moreover, the statistic value is less than the critical value (0.08628<1.35810). Thus, we fail to reject the hypothesis, and the residuals are considered to be normally distributed.

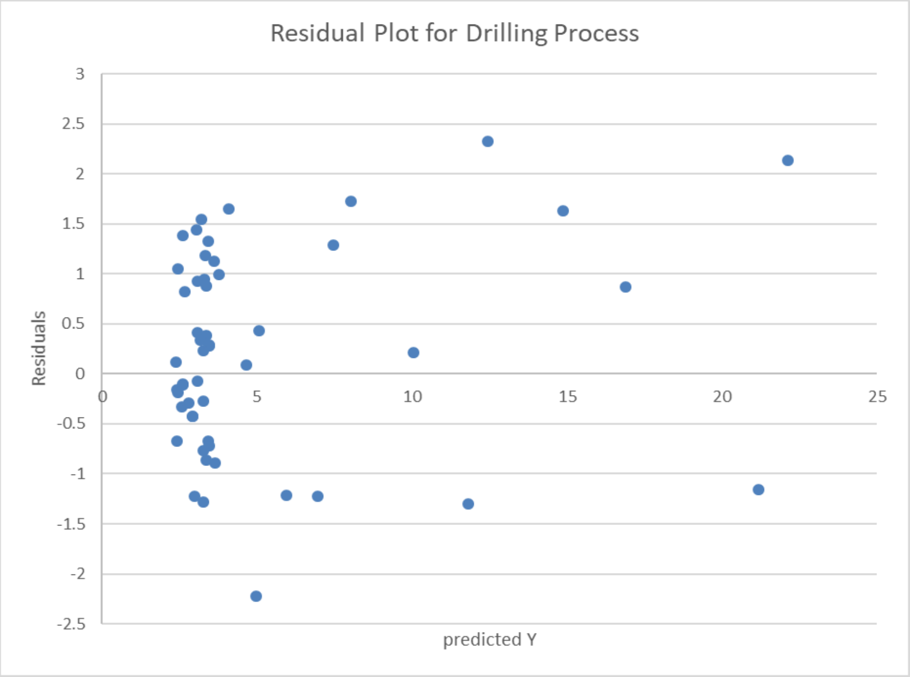


Figure 4-19 Residual Plot for the Drilling Process

Table 4-16 KOLMOGOROV-SMIRNOV Test Results

COUNT	52
MEAN	0.220576923
SD	1.02377
MAXIMUM DIFRENCES	0.08628
STATISTIC VALUE	0.08628
CRITICAL VALUE	1.35810
Normal Distribution	

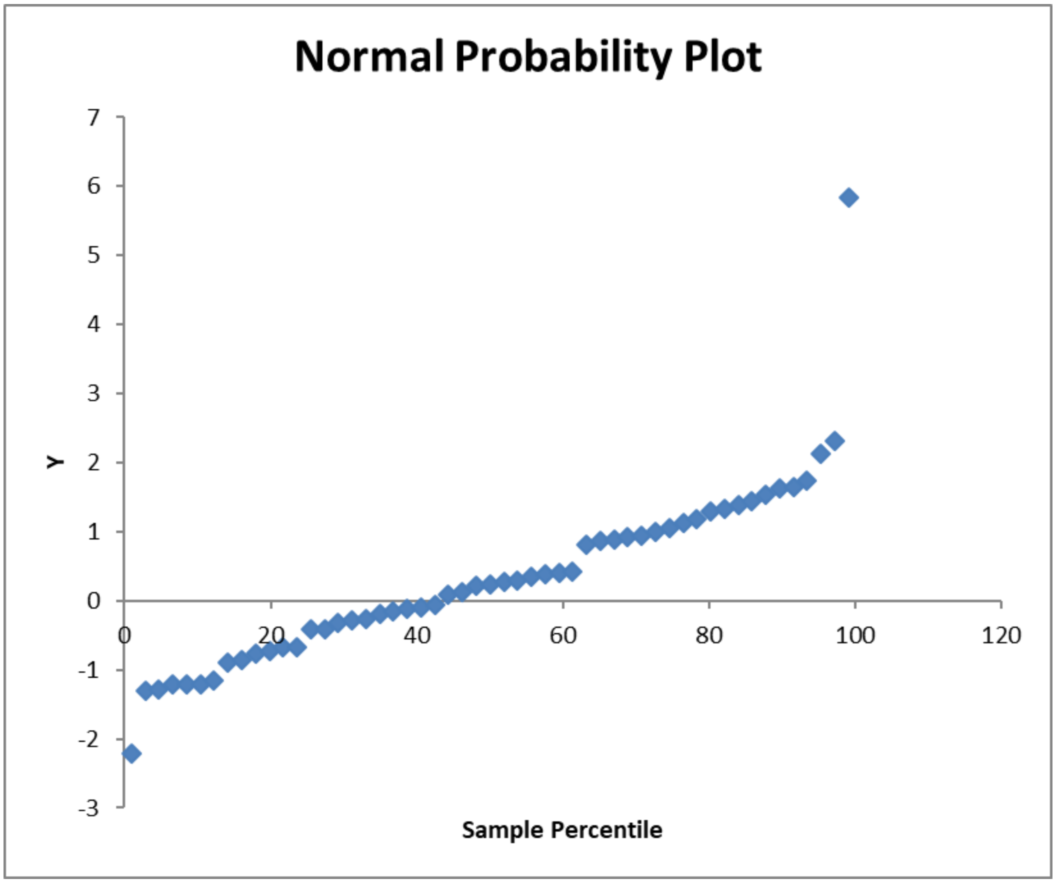


Figure 4-20 Normality Plot for Drilling Process Residuals

4.4. Combination Of Different Cost Estimation Methods

The In this section, the XXX International Inc. is considered for the case study, and activity-based costing is implemented by using the new costing model. The new cost model will be applied for all parts produced in the machine shop, and themachine shop costs for a product were calculated by applying current cost estimation method, traditional cost estimation method and new cost estimation model. Finally, the results from different costing systems would be compared.

4.4.1. Cost Models Applied for The Case Study

The current cost estimation method used by XXX International Inc. is the traditional costing method that uses a single burden rate. In this traditional costing system, the total product cost includes: the direct material cost, the direct labor, and the machine cost and overhead costs based on a single burden rate. The main overhead costs are: depreciation, inspection, utility costs, and engineering costs. The new cost model was implemented for all parts produced in the machine shop. However, among all the parts, the primary emphasis was on the TUBESHEET because of the high variety of its parameters and features.

Current Costing Model and Traditional Costing Model

The current costing model in the XXX International Inc. is like the traditional costing model and direct materials and labors are considered as direct costs. The overhead rate is a single overhead rate. In this model in order to define the single overhead rate the historical rate is used which is called a nominal overhead rate and it is based on management experience. Also, for machining cycle time the product design software is used, Table 4-17 indicates the cost estimation for the specific product based on current costing model.

Table 4-17 Current Cost Estimation Model Based on Nominal Overhead Rate

PR4546A	
Total direct Material	$1,374.000
Total Direct Labour	$1,260.000
Over Head	
Total Overhead	$1,820.00
Total Production Cost	$4,454.000

In a traditional costing model two direct costs are considered, in the costing system model which are materials and labors costs directly traced to the part. However, there are indirect costs, referred to as the overhead costs. In the traditional costing model, a single burden rate or overhead rate is used, the overhead rate was obtained from the direct labor costs method and calculated based on using Equation 4-4.

$$Overhead\ Rate = OH = \left(\frac{\text{Total Overhead Cost (\$)}}{\text{Total Labour Cost (\$)}}\right) * 100 \quad (4-4)$$

In this model the single overhead rate is defined based on indirect cost historical data. To calculate the overhead rate (burden rate) with the traditional costing model, the total overhead costs are calculated based on different cost sub-groups. Table 4-18 indicates the list of overhead costs for each of fifteen sub-groups and their related proportion to the total overhead costs for the entire facility. Table 4-19 shows the total overhead costs for the machine shop.

Table 4-18 Monthly Overhead Costs and Resources

No.	**Description**	**Costs**	**Proportion of Total OH Costs**
1	Machine Depreciation	\$11,682.29	16.04%
2	Building Depreciation	\$6,369.13	8.74%
3	Utilities	\$8,348.13	11.46%
4	Engineering Activities	\$10,000.00	13.73%
5	Administrator wages	\$3,365.00	4.62%
6	Supply chain	\$7,641.53	10.49%
7	Indirect laborers	\$1,915.64	2.63%
8	Security System	\$350.00	0.48%
9	Taxes	\$8,751.75	12.02%
10	Material Handling	\$7,666.67	10.53%
11	Maintenance	\$2,083.33	2.86%
12	Indirect Material	\$833.33	1.14%
13	Advertising	\$275.00	0.38%
14	Travel Costs	\$1,005.83	1.38%
15	Insurance	\$2,551.75	3.50%
Total		\$72,839.38	100%

Table 4-19 Monthly Overhead Costs and Resources for Machine Shop

No.	Description	Machine Shop OH Proportion	Costs	Proportion of Total OH Costs
1	Machine Depreciation	100%	\$11,682.29	28.51%
2	Building Depreciation	40%	\$2,547.65	6.22%
3	Utilities	60%	\$5,008.88	12.23%
4	Engineering Activities	70%	\$7,000.00	17.09%
5	Administrator wages	50%	\$1,682.50	4.11%
6	Supply chain	50%	\$3,820.76	9.33%
7	Indirect laborers	30%	\$574.69	1.40%
8	Security System	50%	\$175.00	0.43%
9	Taxes	30%	\$2,625.53	6.41%
10	Material Handling	30%	\$2,300.00	5.61%
11	Maintenance	60%	\$1,250.00	3.05%
12	Indirect Material	80%	\$666.67	1.63%
13	Advertising	80%	\$220.00	0.54%
14	Travel Costs	90%	\$905.25	2.21%
15	Insurance	20%	\$510.35	1.25%
Total			\$40,969.56	100%

Machine Depreciation

In this study, the Incremental Depreciation technique is used to calculate the machine depreciation per year. Where, the depreciation portion value (d) is calculated by dividing 1.5 of Straight-line Depreciation to machine life cycle (n).

$$Depreciation\ Portin\ Value = d = {}^{1.5}/_{n}$$

$$d = {}^{1.5}/_{20} = 0.075$$

In order to obtain the depreciation value at the end of each year, the present value is multiplied by depreciation portion value.

$$Machine\ Depreciation\ Value_{(first\ year)} = Present\ Value * (d)$$

$$Machine\ Depreciation\ Value_{(first\ year)} = \$1{,}869{,}166.00 * 0.075$$

$$Machine\ Depreciation\ Value_{(first\ year)} = \$140{,}187.50$$

$$Machine\ Depreciation\ Value_{(Monthly)} = \$11{,}682.29$$

Building Depreciation

To calculate building depreciation the first building value after considering a scrap rate should be obtained. The building value with scrap rate calculated by multiplying building value to the scrap rate. The scrap rate was 10% of the building value.

$$Building\ value\ considered\ scrap\ rate = Building\ value * Scrap\ rate$$

$$Building\ value = \$2{,}547{,}650.00$$

$$Scrap\ rate = 10\%\ of\ the\ bulding\ value$$

$$Scrap\ rate = \$2{,}547{,}650.00 * 0.1 = \$25{,}4765.00$$

$$Building\ value\ considered\ scrap\ rate = \$2{,}292{,}885.00$$

In the next step, the yearly building depreciation was calculated by building value with scrap rate by the lifecycle.

$$Facility\ Building\ Depreciation = \frac{Building\ value\ considered\ scrap\ rate}{Life\ cycle}$$

$$Building\ value\ considered\ scrap\ rate = \$2{,}292{,}885.00$$

$$Life\ cycle = 30$$

$$Facility\ Building\ Depreciation_{(Yearly)} = \frac{\$2{,}292{,}885.00}{30} = \$76{,}429.50$$

$$Facility\ Building\ Depreciation_{(Yearly)} = \$76{,}429.50$$

$$Machine\ Shop\ Building\ Depreciation = 40\%\ Facility\ Building\ Depreciation$$

$$Machine\ shop\ building\ proportion = \frac{Machine\ shop_{Square\ feet}}{Total\ Building_{Square\ feet}} * 100$$

$$Machine\ shope\ building\ proportion = \frac{20000}{50000} * 100 = 40\%$$

$$Machine\ Shop\ Building\ Depreciation_{(Yearly)} = \$30{,}571.80$$

$$Machine\ Shop\ Building\ Depreciation_{(Monthly)} = \$2{,}547.65$$

After overhead costs are calculated, the direct labor costs must be obtained. The total annual labor costs are calculated by multiplying total working hours with the average labor rate. Therefore, the total labor cost is equal to:

$$Machine\ Shop\ Labor\ Cost_{Per\ Labor} = 200_{hrs.}/_{month} \times 22.50_{\$}/_{hour} = \$4{,}500.00$$

$$Total\ Machine\ Shop\ Labor\ Costs = Machine\ Shop\ Labor\ Cost_{Per\ Labor} \times Number\ of\ Labors$$

$$Total\ Machine\ Shop\ Labor\ Costs = \$4{,}500.00 \times 3 = \$13{,}500.00$$

Then the overhead rate can be calculated based on Equation 4-4.

$$Overhead\ rate = \frac{\$40{,}969.56}{\$13{,}500.00} = 3.035 = 303.50\%$$

The same direct material and direct labor cost estimates shown in Table 4-17 are used in the traditional costing model with the allocated overhead calculated by using the single overhead rate defined by Equation 4-4 times the total direct labor costs. The total production cost estimate is simply the sum of my direct labor and material cost and my allocated overhead. The obtained results are shown in Table 4-20.

Table 4-20 Traditional Costing Model for Specific Product

PR4546A	
Total direct Material	$1,374.000
Total Direct Labour	$1,260.000
Over Head	
Total Overhead	$3,823.70
Total Production Cost	$6,457.70

New Cost Estimation Model

The first step of an accurate cost estimation based on the new model is by gathering the cost information in the useful form, which is conducted with product family architecture (PFA) and process description capture method (IEDF3) techniques and this information provide the part database. In the new costing model, the direct material can be traced directly to the cost of the product, like the traditional costing model. However, the overhead costs are calculated based on Activity- Based Costing (ABC), and it differs from the traditional costing methods. Also, another difference between the new costing model and traditional costing model or ABC methods is the direct labor costs estimations. In the new model parametric activity-based costing and feature based costing models are used for direct labor hours and costs estimation.

The first step is to prepare the list of the resources and their costs. In this study, the main resources that are used by the machine shop are considered and summarized in Table 4-19. The second step is to prepare the list of the activities and the resources they consume. The activities in the machine shop and related resources are shown in Table 4-21.

Table 4-21 Activities Pool and Resources

Activities	**Resources consumed**	**Activity Level**
Machining	Machine depreciation, Utilities, Building depreciation	Unit Batch
Engineering	Engineering activities	Product
Maintenance	Maintenance, Indirect laborer Travel costs, Indirect material	Product
Material handling	Material handling, Indirect laborer	Batch
Control	Administrator wages	Facility
Shipping	Supply chain, Building depreciation Indirect laborer	Product
Inventory	Material handling, Supply chain, Building depreciation	Product
Quality Control	Engineering activities, Indirect laborers Indirect material	Product
Other Administrating Activities	Security system, taxes, advertising, travel costs, insurance, administrator wages	Facility

After the resource pool and activity pool definition, the cost drivers for each activity should be determined for the next step. Usually, in activity-based costing methods, the proportions of each cost driver are assigned based on historical data. Some of the cost drivers are related to the direct labor hours, such as machining, but some are not. One advantage of the new costing model is to determine the proportion of the cost drivers based on the cost drivers' parameters instead of the historical data. In the new costing model, the parametric cost divers are replaced with historical cost drivers in order to improved cost estimation accuracy. Then, the cost driver rates were calculated by dividing the total activity costs with the cost driver proportions as illustrated in Equation 4-5.

$$Cost\ Driver\ Rate_{(Per\ Activity)} = \frac{Total\ Activity\ Costs}{Total\ Cost\ DriverPropotions\ Per\ Activity} \qquad (4-5)$$

Machining cost is calculated based on parametric activity-based costing in the following way:

$$\begin{aligned} Machining\ Cost(\$) &= (100\%\ of\ machine\ depreciaption\ cost) + (100\%\ of\ utilities\ cost) \\ &+ (50\%\ of\ machine\ shop\ building\ depreciation) \end{aligned}$$

$$Machining\ Cost(\$) = (\$140{,}187.50\ ) + (\$60{,}106.50) + (\$30{,}571.80 * 0.5)$$

$$Machining\ Cost(\$)_{Yearly} = \$215{,}579.90$$

$$Machining\ Cost(\$)_{Monthly} = \$17{,}964.991$$

$$Machine\ shop\ building\ proportion_{Machine\ Square\ feet} = \frac{Machine\ Space_{Square\ feet}}{Total\ Machine\ Shop\ Building_{Square\ feet}} * 100$$

$$Machine\ shop\ building\ proportion_{Machine\ Space} = \frac{10000}{20000} * 100 = 50\%$$

Material handling cost can be parameterized based on the number of jobs according to this calculation:

$$\boldsymbol{Production\ material\ handling} = (89\%\ of\ material\ handeling)$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck} = Number\ of\ jobs * Cost\ of\ energy$$

$$Number\ of\ jobs = 20$$

$$Cost\ of\ fuel\ for\ lift\ truck = Number\ of\ gas\ tank * Price\ per\ gas\ tank$$

$$Cost\ of\ fuel = 15 * \$15.50 = \$\ 232.50$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck\ per\ building} = \$4{,}650.00$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck\ all\ buildings} = \$9{,}300.00$$

$$Cost\ of\ fuel\ for\ truck = Total\ Miles_{miles.} * 5.7_{miles}/_{per\ gallon.} * 2.10_{\$}/_{per\ gallon.}$$

$$Material\ handeling\ Cost(\$)_{\ Truck} = 1270 * 5.7 * 2.10 = \$15{,}200.00$$

$$Total\ Material\ handeling\ Costs(\$)_{Yearly} = \$24{,}500.00$$

$$Total\ Material\ handeling\ Costs(\$)_{Monthly} = \$2{,}041.00$$

$$Production\ material\ handling = \frac{Production\ material\ handeling\ cost}{Total\ material\ handeling\ cost} * 100$$

$$Production\ material\ handling = \frac{\$24{,}500.00}{\$27{,}600.00} * 100 = 88.7\% \cong 89\%$$

$$\boldsymbol{Inventory\ material\ handling} = (11\%\ of\ material\ handeling)$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck} = Number\ of\ jobs * Cost\ of\ energy$$

$$Number\ of\ jobs = 20$$

$$Cost\ of\ fuel\ for\ lift\ truck = Number\ of\ gas\ tank * Price\ per\ gas\ tank$$

$$Cost\ of\ fuel = 5 * \$15.50 = \$\ 77.50$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck\ per\ building} = \$1{,}550.00$$

$$Material\ handeling\ Cost(\$)_{Lift\ Truck\ all\ buildings} = \$3{,}100.00$$

$$Material\ handeling\ Cost(\$)_{Monthly} = \$258.30$$

$$Inventory\ material\ handling = \frac{\$3{,}100.00}{\$27{,}600.00} * 100 = 11.2\% \cong 11\%$$

Control cost administrator workforce and wages is the predominant resource consumption with this activity, and the calculated cost is as follows:

$$Control\ Cost\ (\$) = (80\%\ of\ administrator\ cost)$$

$$Control\ Cost\ (\$)_{Yearly} = \$16{,}152.00$$

$$Control\ Cost\ (\$)_{Monthly} = \$1{,}346.00$$

Shipping cost depends on dimension, weight, and location of the product, however, according to the historical data it is considered as 70% of the supply chain costs and the shipping area costs considered as building depreciation proportion. The shipping costs calculated as follows:

$$\begin{aligned}
&Shipping\ Cost\ (\$)\\
&\qquad = (30\%\ of\ supply\ chain\ cost) + (20\%\ of\ machine\ shop\ building\ depresiation)\\
&\qquad + (10\%\ of\ Indirect\ laborer)
\end{aligned}$$

$$Shipping\ Cost\ (\$) = (\$13{,}754.75) + (\$6{,}114.36) + (\$689.63) = \$20{,}558.74$$

$$Shipping\ Cost\ (\$)_{Monthly} = \$1{,}713.00$$

$$Machine\ shop\ building\ proportion_{Shipping\ Area} = \frac{Shipping\ Area_{Square\ feet}}{Total\ Machine\ Shop\ Building_{Square\ feet}} * 100$$

$$Machine\ shop\ building\ proportion_{Shipping\ Area} = \frac{4000}{20000} * 100 = 20\%$$

Inventory activity consumption supply chain, building depreciation, and material handling resources, and the cost of inventory is calculated according to the following steps:

$$\begin{aligned}
&Inventory\ Cost\ (\$)\\
&\qquad = (70\%\ of\ supply\ chain\ cost) + (30\%\ of\ machine\ shop\ building\ depresiation\ cost)\\
&\qquad + (11\%\ of\ material\ handeling\ cost)
\end{aligned}$$

$$Inventory\ Costs\ (\$) = (\$32{,}094.42) + (\$9{,}171.54) + (\$3{,}036.00)$$

$$Inventory\ Cost\ (\$)_{Yearly} = \$44{,}301.96$$

$$Inventory\ Cost\ (\$)_{Monthly} = \$3{,}691.00$$

Quality Control cost drive from engineering activities, indirect labor, such as inspector costs and indirect material such as gages.

$$\begin{aligned}
Quality\ Cost\ (\$) &= (30\%\ of\ Engineering\ activities) + (40\%\ of\ indirect\ laborer)\\
&\quad + (10\%\ of\ indirect\ material)
\end{aligned}$$

$$Quality\ Cost\ (\$) = (\$25{,}200.00) + (\$2{,}758.52) + (\$800.00) = \$28{,}758.52$$

$$Quality\ Cost\ (\$)_{Yearly} = \$28{,}758.52$$

$$Quality\ Cost\ (\$)_{Monthly} = \$2{,}396.00$$

The engineering activities involve software like Solid work or CAD and draft design. Also, besidesthe software, other resources like skilled professional engineers and workforceinvolvedin engineering activities. Engineering activities vary with the different parts the Table 4-22 and Table 4-23are shown this category in more depth for both the engineering activities and quality control. These activities are the initial design, design (engineering analysis), revisions, drafting, and prints (see Figure 4-21 for engineering activity mapping). After defining the activities, the resources for those activities should then be listed.

Table 4-22 Engineering Activities Rate for Engineering Activity

Activities	**Activity Cost per hour ($/hr.)**	**Machine Shop Parts**									
		P1		**P2**		**P3**		**P4**		**P5**	
		Time (hrs.)	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**
Initial Design	$65.00	3.00	$195.00	1.50	$97.50	1.00	$65.00	2.00	$130.00	2.50	$162.50
Design	$70.00	6.00	$420.00	3.00	$210.00	2.00	$140.00	4.00	$280.00	5.00	$350.00
Revisions	$35.00	1.00	$35.00	0.50	$17.50	0.50	$17.50	1.00	$35.00	1.00	$35.00
Drafting	$45.00	8.00	$360.00	5.00	$225.00	3.00	$135.00	7.00	$315.00	7.00	$315.00
Prints	$3.00	0.16	$0.48	0.16	$0.48	0.16	$0.48	0.16	$0.48	0.16	$0.48
Engineering Cost per Part		$1,010.48		$550.48		$357.98		$760.48		$862.98	
Quantity		9		7		3		6		4	
Total Engineering Costs per part		$9,094.32		$3,853.36		$1,073.94		$4,562.88		$3,451.92	
Software Cost		$4,000.00									
Total Engineering Costs		$26,036.42									

Table 4-23 Engineering Activities Rate for Quality Control Activity

Activities	**Activity Cost per hour ($/hr.)**	**Machine Shop Parts**									
		P1		**P2**		**P3**		**P4**		**P5**	
		Time (hrs.)	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**	**Time (hrs.)**	**Act. Cost ($)**
Quality	$60.00	16.00	$960.00	5.00	$300.00	1.00	$60.00	7.00	$420.00	7.00	$420.00
Quantity		9		7		3		6		4	
Total Engineering Costs per Part		$8,640.00		$2,100.00		$180.00		$2,520.00		$1,680.00	
Total Engineering Costs per Part		$15,120.00									

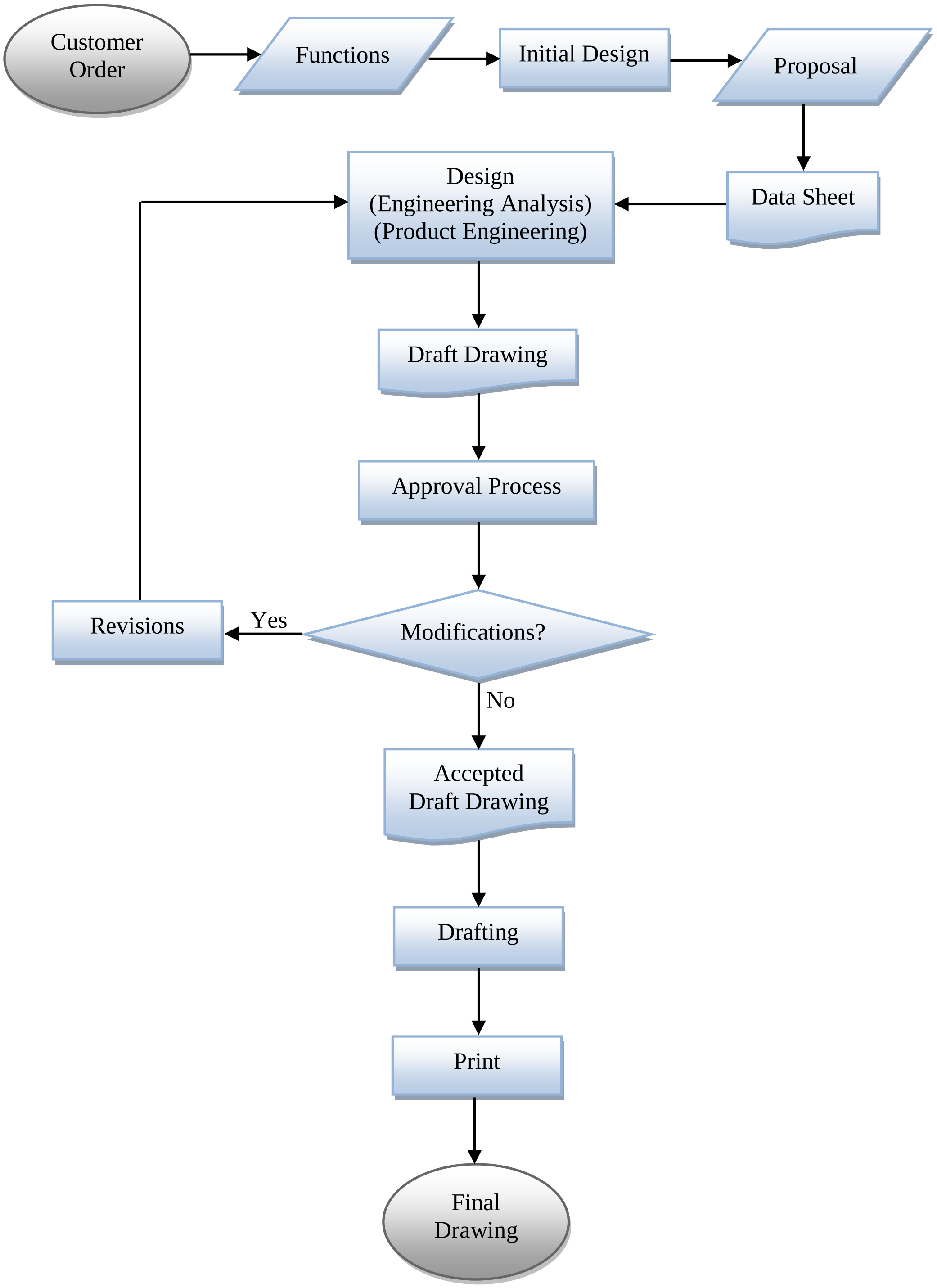


Figure 4-21 Engineering Activity Mapping

At this point, the overhead cost of each activity per product group can be calculated based on Equation 4-6.

$$Overhead\ Cost\ Per\ Activity = Cost\ Driver\ Rate\ \times Cost\ Driver\ Proportions\ of\ Activity \qquad (4-6)$$

One of the main differences between the traditional cost estimation method and Activity Based Costing is that the single overhead rate was replaced with multi-cost driver rates which led to more accurate cost estimation. Therefore, when implementing the new costing model, the simple cost driver rates were replaced with the parametric cost drivers, and the accuracy of the new model increased incredibly in comparison to the traditional costing model. Also, new parametric activity based costing model is presented considering the unutilized capacity of resources. Table 4-24 and Table 4-25 indicates the parametric activity based costing model without considering the unutilized resource capacity for actual activities time and estimated activities time base on parametric drivers respectively for the specific product.

Table 4-24 Parametric Activity Based Costing Using Actual Values

PR4546A	
Total direct Material	$1,374.000
Total Direct Labor	$697.500
Over Head	
Machining	$1,536.83
Engineering	$576.40
Maintaining	$295.30
Material handling	$120.10
Control	$79.18
Shipping	$100.78
Inventory	$246.89
Quality Control	$314.18
Others	$264.77
Total Overhead	$3,534.41
Total Production Cost	$5,605.915

Table 4-25 Parametric Activity Based Costing Using New Cost Estimation Values

PR4546A	
Total direct Material	$1,374.000
Total Direct Labor	$675.000
Over Head	
Machining	$1,464.62
Engineering	$566.35
Maintaining	$312.75
Material handling	$120.10
Control	$79.18
Shipping	$100.78
Inventory	$246.89
Quality Control	$351.87
Others	$264.77
Total Overhead	$3,507.30
Total Production Cost	$5,556.301

In the next step Table 4-26 and Table 4-27 show the parametric activity based costing model considering unutilized capacity costs for the actual activity time and estimated activity time respectively for the specific product (See Appendix D. for cost driver and cost driver rates based on different costing models). Finally, Table 4-28 shows the cost drivers and cost driver rates for all machine shop activities and parts considering unutilized capacity of resources based on the parametric activity based costing model.

The result of the overhead costs for each activity and the production cost based on the new costing model for all parts produced in the machine shop are shown in Table 4-29. In order to estimate the unit cost of each part produced in the machine shop, a total direct material and labor cost was calculated. The total direct material and labor cost was obtained by multiplying the direct material cost and the direct labor cost with the entirety of the parts produced. However, in the new costing model the direct labor cost for the machine shop was calculated by multiplying the total machining hours with average unit-labor cost (see Equation 4-7 for more information).

$$Direct\ Labor\ Cost = \left(Total\ Machining\ Time_{(hrs.)} \times Average\ Labor\ cost\ per\ hour_{(\$/hr.)}\right)_{(\$/parts)} \quad (4-7)$$

Table 4-26 New Cost Estimation Model Considering Unutilized Capacity Using Actual Values

PR4546A	
Total direct Material	$1,374.000
Total Direct Labor	$697.500
Over Head	
Machining	$1,577.62
Engineering	$453.78
Maintaining	$445.01
Material handling	$87.38
Control	$55.89
Shipping	$71.14
Inventory	$173.05
Quality Control	$338.23
Others	$186.89
Total Overhead	$3,389.00
Total Production Cost	$5,460.503

Table 4-27 New Cost Estimation Model Considering Unutilized Capacity Using Estimated Values

PR4546A	
Total direct Material	$1,374.000
Total Direct Labor	$675.000
Over Head	
Machining	$1,432.86
Engineering	$347.82
Maintaining	$499.17
Material handling	$87.38
Control	$55.89
Shipping	$71.14
Inventory	$173.05
Quality Control	$325.95
Others	$186.89
Total Overhead	$3,180.17
Total Production Cost	$5,229.165

Table 4-28 Cost Driver and Cost Driver Rates

Activities	Total Cost of activity	Cost Drivers	P1	P2	P3	P4	P5	Total Cost driver Proportion	Cost Driver Rates
Machining	$215,579.90	Machining hrs.	219.12	45.54	40.19	41.1	22.03	367.98	585.85
Engineering	$26,036.42	Engineering hrs.	163.44	71.12	19.98	84.96	62.64	402.14	64.74
Maintaining	$28,217.42	Maintenance hrs.	135	24	12	12	20	203	139.00
Material handling	$24,500.00	Production runs	9	2	2	2	2	17	1485.51
Control	$16,152.00	Production runs	9	2	2	2	2	17	950.12
Shipping	$20,558.74	Production runs	9	2	2	2	2	17	1209.34
Inventory	$44,301.96	Parts number	18	12	3	9	6	48	922.96
Quality Control	$15,120.00	Engineering hrs.	144	35	3	42	28	252	60.00
Others	$54,012.60	Production runs	9	2	2	2	2	17	3177.21

P1: TUBESHEET
P2: BAFFLE
P3: COVER FLANGE
P4: FLANGE
P5: BOLTING PAD

The total production cost is the sum of the total direct material, direct labor, and overheads. When the total production cost is obtained, it is then divided by total product number per part category. The unit costs based on the new costing model was computed. All the cost estimation calculations based on the new costing model are shown in Table 4-29.

Table 4-29 New Costing Model for All Parts Produced in Machine Shop

Activities	**Machine Shop Parts**					**Total**
	P1	P2	P3	P4	P5	
Total direct Material ($/product)	$8,925.386	$3,038.979	$925.154	$660.953	$522.978	$14,073.449
Total Direct labor ($/product)	$4,930.200	$1,024.650	$904.275	$924.750	$495.675	$8,279.550
Over Head ($/product) for each Activity						
Machining	$128,370.75	$26,679.46	$23,545.18	$24,078.30	$12,906.20	$215,579.90
Engineering	$10,581.87	$4,604.64	$1,293.60	$5,500.71	$4,055.61	$26,036.42
Maintaining	$18,765.28	$3,336.05	$1,668.02	$1,668.02	$2,780.04	$28,217.42
Material handling	$13,369.57	$2,971.02	$2,971.02	$2,971.02	$2,971.02	$25,253.63
Control	$8,551.06	$1,900.24	$1,900.24	$1,900.24	$1,900.24	$16,152.00
Shipping	$10,884.04	$2,418.68	$2,418.68	$2,418.68	$2,418.68	$20,558.74
Inventory	$16,613.23	$11,075.49	$2,768.87	$8,306.62	$5,537.74	$44,301.96
Quality Control	$8,640.00	$2,100.00	$180.00	$2,520.00	$1,680.00	$15,120.00
Others	$28,594.91	$6,354.42	$6,354.42	$6,354.42	$6,354.42	$54,012.60
Total Overhead ($)	$244,370.70	$61,439.99	$43,100.03	$55,718.00	$40,603.95	$445,232.67
Total Production Cost ($/product)	$258,226.287	$65,503.620	$44,929.456	$57,303.704	$41,622.599	$467,585.666

After engineering activities, the next step in the cost estimation process is to define the manufacturing processes/activities and relevant resources. The manufacturing activities in this study are classified as being two main activities. The first is the core activities, such as drilling and turning which are common methods used by all the parts. The second group contains the other activities which vary from part to part. All the parameters and features that trigger the activities are evaluated, to create the parametric cost drivers for the new cost estimation model. At this stage, the parametric based activity driver pool is generated based on the components design specifications and a binary digit used as an action trigger. If the action has the parameter, then the binary digit is “1,” and the action is triggered. If the action does not have the parameters or attributes the binary code, will be “0” and the activity will not be triggered. Finally, the activity time is estimated based on the parametric activities that are defined in the new cost estimation model for each process. All these steps are summarized for the TUBESHEET in Table 4-30.

4.4.2. Cost Analysis

One problem with the previous costing models is the lack of a generic model. In the proposed model, the cost of each activity is calculated based on the parametric activity cost driver. When the parameters of the activity change based on features on the part, the new costing model will estimate the activity costs based on parametric cost equations. Additionally, as the parameters change, the activity costs will be updated and change in accordance with the new parameters, which will allow the new cost model to be more generic.

Also, another concept of the new costing model is process and component sharing. Each process is a group of activities working together to perform a specific function. There are many core activities that are common in the product family structure. One of the main characteristics of the new costing model is the ability to calculate each activity cost. If there is a new product development in the family, then there will be common shared activities, which will be the new parametric costing model, and can estimate these activities cost more accurately.

A comparison between five different costing models applied to a specific product produced by XXX International Inc. is presented below. The results of this comparison are shown in Table 4-31 and Figure 4-22.

Model A represents the current cost estimation practice used at XXX International Inc. This cost estimate is obtained by adding the total direct material cost and a total labor cost generated by multiplying the estimated production time obtained from the product design engineers by a nominal costing factor which estimates both direct and indirect labor costs (Table 4-17). The value of this nominal costing factor is based on management experience. Model B represents the traditional cost estimation technique that includes direct material costs, direct labor costs, and an overhead value generated by a single overhead rate multiplied by the direct labor cost (Table 4-20).

Model C represents the first of two cost estimation methods that uses the parametric activity-based costing methods developed in this research to establish production time estimates and direct labor costs. A parametric strategy was also used to create a multi-factor cost driver rate approach (Table 4-28) for allocating overhead expenses based on five different classes of cost drivers. In Model C, these cost driver rates are based on the cost of all of the resources provided to the system. The total estimated production cost for the part using the proposed parametric activity based method is shown in Table 4-25.

Model E represents the second cost estimation method that uses the proposed parametric activity based costing method. The key difference between Model E and Model C relates to the issue of under-utilized capacity. The overhead allocation rates used in Model C were based on the total costs of resources provided by the system. In Model E the overhead allocation rates were calculated based on the predicted levels of each of the cost drivers actually used. This was done to ensure that the product cost estimates were not burdened with the cost of unutilized capacity. The product cost estimate based on Model E is provided in Table 4-27.

Model D represents what we feel is the actual cost of producing the part. This cost includes the direct material costs and the actual recorded labor hours multiplied by their respective hourly labor rates. Allocated overhead costs were based on cost-driver rates that were adjusted for unutilized resource capacity in the system. The actual cost values are provided in Table 4-26.

Table 4-30 Parametric Activity Drivers for TUBESHEET

Parametric Activity	**Activity Drivers (Parameters)**	**Parameter Type**	**Binary Code**	**Parametric Process Cycle Time**
Drilling	Plate Thickness	NA	1	$\left[\frac{P.THK._{(inchs.)}}{D.FR._{(inchs./min.)} \times 60_{(mins./hr.)}} \times No.Hs.\right]_{hrs.}$
	Feeding Rate	Drilling	1	
		Burnishing	0	
	Holes	Bolt	1/0	
		Tube	1/0	
Plate Turning	Material	SA	1/0	$\left[\left(\left[\pi \times P.THK. \times \left[\left(\frac{P.DI.+0.25}{2}\right)^2 - \left(\frac{P.DI.}{2}\right)^2\right]\right]_{inch.^3} + \left[\pi \times 0.25 \times \left(\frac{P.DI.}{2}\right)^2\right]_{inch.^3} + \left[\left(\pi \times 0.25 \times \left(\frac{P.DI.}{2}\right)^2\right) \times C\right]_{inch.^3}\right)_{(inch.^3)} \Big/ Material \times MRR_{(inch.^3/min.)} \times 60_{(mins./hr.)}\right]_{hrs.}$
		SS	1/0	
	MRR	MRR$_{SA}$	1/0	
		MRR$_{SS}$	1/0	
	Plate Thickness	NA	1	
	Plate Diameter	>=32	1	
		<32	0	
	CLAD	NA	1/0	
	Step Diameter	NA	1/0	
	Number of the Steps	NA	1/0	
Chamfering	Holes	Bolt	0	$\left[No.Hs. \times 0.0006_{(hrs./hole.)}\right]_{hrs.}$
		Tube	1	
Grooving	Material	SA	1/0	$\left[No.Hs. \times SA \times 0.002_{(hrs./hole.)}\right]_{hrs.}$
		SS	1/0	
	Holes	Bolt	0	$\left[No.Hs. \times SS \times 0.004_{(hrs./hole.)}\right]_{hrs.}$
		Tube	1	
Burnishing	Plate Thickness	NA	1	$\left[\left(\frac{P.THK._{(inchs.)}}{B.FR._{(inchs./min.)} \times 60_{(mins./hr.)}} \times No.Hs.\right) \times I\right]_{hrs.}$
	Feeding Rate	Drilling	0	
		Burnishing	1	
	Holes	Bolt	0	
		Tube	1	
	Iteration	NA	1	
Milling	TRAP	NA	1/0	$\left[\frac{\left((T.L. \times T.W. \times T.D.) \times No.T.\right)_{(inch.^3)}}{Material \times MRR_{(inch.^3/min.)} \times 60_{(mins./hr.)}}\right]_{hrs.}$
	Number of the Traps	NA	1/0	
	Material	SA	1/0	
		SS	1/0	
	MRR	MRR$_{SA}$	1/0	
		MRR$_{SS}$	1/0	

Table 4-31 Comparison of the Different Costing Models

Cost Estimation Model	Overhead Rate	Total Production Costs	Model Error
Model A Current Cost Estimation Model	$1,820.00	$4,454.000	-15.19%
Model B Traditional Cost Estimation Model	$3,823.70	$6,457.70	22.96%
Model C Parametric Activity Based Costing Model Using Estimated Values	$3,507.30	$5,556.30	5.80%
Model D Parametric Activity Based Costing Model Considering Unutilized Capacity Using Actual Values	$3,180.29	$5,251.79	NA
Model E Parametric Activity Based Costing Model Considering Unutilized Capacity Using Estimated Values	$3,024.85	$5,073.86	-3.39%

Table 4-31 provides a comparison of the overhead and total production costs generated by the five cost models. Negative values in the Model Error column indicate a cost estimate that is below the assumed actual product production cost. Positive values represent cost estimates that are above the assumed production cost. In Figure 4-22 we see that XXX International Inc.’s current product cost estimation method (Model A) provides a substantially lower cost estimate, nearly 15% below the assumed actual cost (Model D). The traditional cost estimation method (Model B) which uses a signal overhead allocation rate produced a product cost estimate that was 23% higher than the assumed actual cost.

The product cost estimate values generated using the two proposed parametric activity based costing methods are both closer to the assumed actual cost value than either XXX International Inc.’s current cost estimation method or the traditional cost estimation method. If we use the proposed parametric activity-based costing method that considers the cost of all of the resources provided to the system (Model C) we see that our estimate is a little over 6% of our assumed actual product cost. If we use the parametric activity-based costing method but calculate overhead rates based on our estimates of actual resource utilization (Model E) we see that our cost estimate is about 3.39% below what we assume is the actual product cost of the part (Model D).

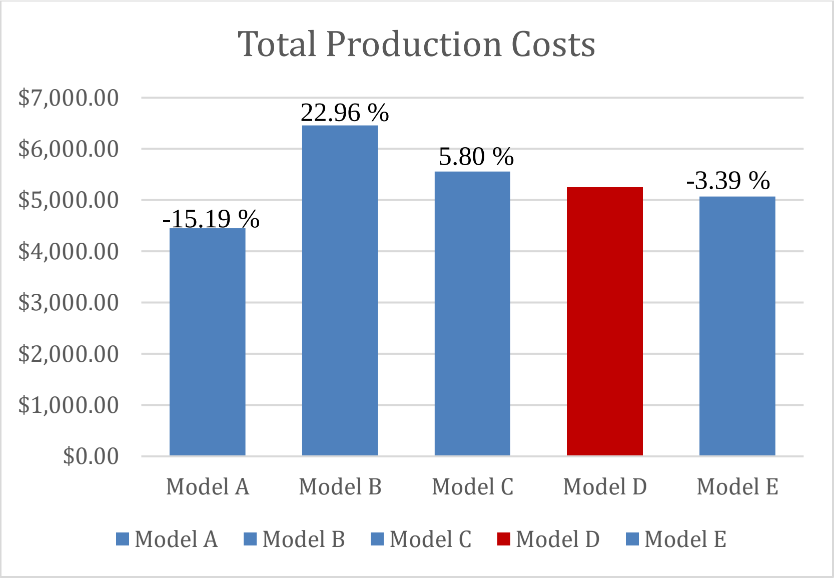


Figure 4-22 Production Cost Comparisons

From this analysis of the performance of the four product cost estimation methods when compared to an assumed actual product cost, we see that our proposed costing methods provide better cost estimates than the method currently used at XXX International Inc. or the traditional product cost estimation method. The purpose for developing the cost estimate determines which of the two proposed parametric activity-based costing models should be deployed. If you are using the method to generate a cost estimate for the purpose of a quote to a prospective customer then you should use Model C which considers the costs of all of the applicable system resources regardless of their actual level of utilization. The rational for this is that the costs for the deployed resources will have to be covered regardless if the resource is fully utilized or not.

There is a hazard with using Model C however. If the enterprise has poor resource utilization, then the resulting product cost estimates will be systematically high. This may result in your products appearing overpriced compared to those offered by a more efficient competitor. Costing Model E only considers the cost of utilized resources when calculating the cost driver rates used in activity-based overhead allocation. Cost estimates generated using Model E will systematically provide unrealistically low cost estimates. These low estimates result from the fact that it is impossible to run any real complex enterprise with a 100% utilization rate for all of its resources. Therefore, the cost estimates obtained from Model E should be considered as aspirational cost values that would be achieved at 100% efficiency. The deference in the cost estimates obtained by using Models C and E can be used by management to see how resource utilization impacts the product cost estimates used in their organization.

4.5. Techniques Support Activity-Based Management (ABM)

An Activity-Based Management system can be a useful information system, helping effective operations processes and has different managerial applications in operations management. The analysis of the Activity-Based Costing is an essential and useful tool for management in simplifying and speeding up the production line. Activity Based Management (ABM) can be implemented as a useful information system helping affective operations processes. ABM has different managerial applications in operations management. Many operations decision can be improved through cost management implementation. Some of the operational issues that can be improved by activity-based costing/management system are quality, productivity and efficiency improvement, decision-making analysis for different design options and other applications.

4.5.1. Activity And Process Analysis

The detailed analysis of the activities can be helpful in two ways; the first is the cost of each activity which can be analyzed as a percentage of total cost. The second is the non-value adding activities that can be eliminated by using a detailed analysis of the processes based on the activities. The first required step is to calculate each activity cost as the percentage of total cost. Moreover, this is only possible by using the activity-based costing approach, as it improves through the new parametric activity-based costing model. This step helps management to realize the core processes and activities, including the cost of the mentioned core activities.

When the Activity-Based Management (ABM) system is used for the analysis is not limited to the cost, as a similar analysis can be conducted based on the time each activity requires. Moreover, the result can be used for production, planning, and scheduling. The time of each of the core activities can be calculated in a ratio, to show the total production time. The most time-consuming activities that are detected by time analysis in Table 4-32 which demonstrates the result of the time analysis. After cost and time analysis is controlled through the ABM system, the most time-consuming activities, including the most costly ones are then defined and are considered in more depth. Therefore, the new cost estimation model serves as a useful management tool that provides a better production, planning, and time scheduling, with more accurate cost estimation. Finally, it will provide decision-making tools for the design, operations and quality purposes.

To summarize, in this section the actual implementation of the new costing model has been discussed. The parametric activity-based costing model is developed for all the parts produced in the machine shop. Finally, the Activity-Based Management (ABM) was implemented for cost and time analysis. The result led to more accurate cost estimation, more predictable production, planning and scheduling, and other applications in the operation, quality and design areas.

Table 4-32 Generic Time Analysis for Activities

Activity	**Resources**	**Machine Shop Parts**									
		P1		**P2**		**P3**		**P4**		**P5**	
		Time hrs.	**(%)**	**Time**	**(%)**	**Time**	**(%)**	**Time**	**(%)**	**Time**	**(%)**
Drilling,Burnishing, Grooving,Milling Big Part	QuickMill	207.71	34.31%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%
Drilling,Burnishing, Grooving,Milling Small Part		78.34	12.94%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%
Drilling Big Part		0.00	0.00%	51.13	28.41%	16.90	23.27%	16.52	13.99%	0.00	0.00%
Drilling Small Part		0.00	0.00%	57.46	31.93%	15.36	21.15%	6.79	5.75%	7.46	24.96%
Drilling,Burnishing, Grooving,Milling Small Part	Fadal	199.44	32.94%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%
Drilling Small Part		0.00	0.00%	71.36	39.66%	0.00	0.00%	24.94	21.12%	9.73	32.55%
Turning Big Part	External Service	28.70	4.74%	0.00	0.00%	21.49	29.59%	9.31	7.89%	0.00	0.00%
Turning Small Part	Lathe	91.20	15.06%	0.00	0.00%	18.87	25.98%	60.50	51.25%	12.70	42.49%
Total		605.39	100.00%	179.95	100.00%	72.62	100.00%	118.06	100.00%	29.89	100.00%

P1: TUBESHEET
P2: BAFFLE
P3: COVER FLANGE
P4: FLANGE
P5: BOLTING PAD

4.5.2. The Evaluation Of Product Design Alternatives

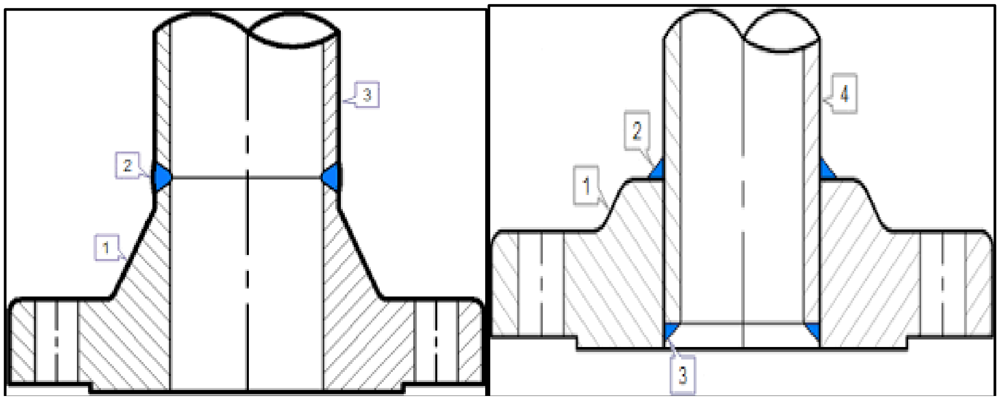
In this section, the new costing model is used to evaluate different design options. One of the most common modules in the XXX International Inc. product family structure is connections/nozzles. There are many combinations and varieties for those connections based on the application and customer requirements. They can have a simple design with no subassembly such as a pipe, coupling, flange connections or they may have a more complicated design with some subassembly processes such as a sump, connections with an elbow, or a combination of flange and pipe. Considering the product family architecture (PFA) for connection modules and subassemblies, the most common parts in a complicated design are flanges. However, the flanges can be different based on the features. One feature that makes a radical difference between flanges is their type. The two main types of the flanges are the differences between these two “Weld-Neck-Flanges” and “Slip-On-Flanges”, flange types are shown in Figure 4-23.

(a) (b)

Figure 4-23 Different Types of Flanges. (a) Weld-Neck Flange and (b) Slip-On Flanges

One parameter that affects the cycle time for connections subassembly is the type of the flanges because there are different production processes and activities for these two types of flanges. Sometimes, the designers should use the specific type, or the customer asks for that specific types. However, most times the designer have an option of whether use Weld-Neck (RFWN) or Slip-On (RFSO) Flanges. Therefore, in the situation that any type can be used the decision would be based on the costs. At first glance, it might be seen that the SO design is cheaper than the WN because the price of WN flanges in all sizes is higher than the SO ones. However, costs analysis just based on the raw material does not show the accurate estimation, and it could not result in appropriate decisions, other costs such as processes cost should be considered to improve the accuracy of cost analysis. One of the Activity Based Management (ABM) applications is the evaluation of different design options. Therefore, ABM can be implementedto improve the decision-making process between designs with RFWN or RFSO flanges.

A list of the raw material and processes needed for the two designs should be prepared. As mentioned before in this study IDEF3 (process description capture method) is one the tool to gather the useful cost information. according to the IDEF3 and sketch for RFWN, and RFSO flanges subassembly (Figure 4-24) bill of material (BOM) and bill of processes (BOP) for these two designs is summarized in Table 4-33.



1. WN flange 2. Butt Weld
3. Pipe or Fitting

1. SO flange 2. Outside Butt Weld
3. Inside Butt Weld 4. Pipe or Fitting

(a)

(b)

Figure 4-24 Different Types of Flanges Sketch. (a) Weld-Neck Flange and (b) Slip-On Flanges

Table 4-33 BOM and BOP of WN and SO Flanges

	RFWN Flange Design	RFSO Flange Design
Bill of Material (BOM)	RFWN Flange	RFSO Flange
	Pipe	Pipe
Bill of Processes (BOP)	FIT and Tack	FIT and Tack
	NA	Inside Welding
	Outside Welding	Outside welding
	Pipe Beveling	NA

Regarding Table 4-34 one difference in the raw material is between the flanges. Therefore, a list of the prices for RFWN and RFSO flanges for different size both for stainless steel (SS) and carbon steel (SA) can be obtained from the supply chain department. Another raw material common for both designs is the pipe. However, the length of the pipe is different for different designs. Considering the geometry of the RFSO flange, this design use more pipe than RFWN flange design. Figure 4-25 illustrates the extra pipe required for RFSO design, which is calculated from Equation 4-8.

$$Extra\ Pipe\ Lenght_{inchs\ or\ feet} = \left[C - \left({}^{3}\!/_{8}\right)\right]_{inchs} = \left[\frac{\left(C - \left({}^{3}\!/_{8}\right)\right)}{12}\right]_{feets} \qquad (4-8)$$

Where;

$C = Length\ Through\ Hub\ for\ WN\ Flange$

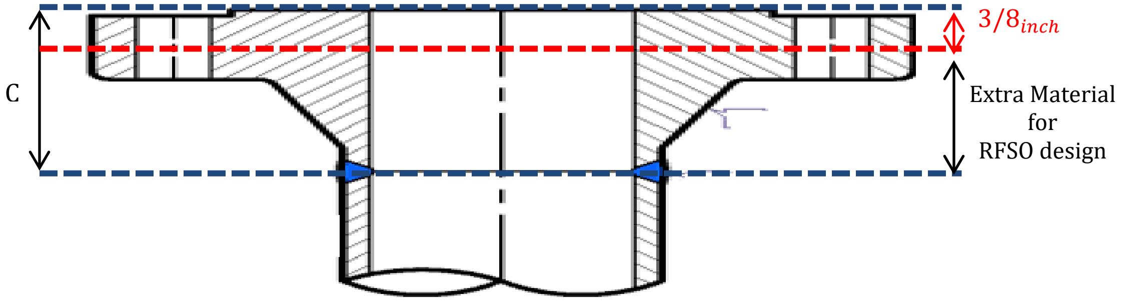


Figure 4-25 Extra Material in RFSO Design

To find the length through a hub for different sized flanges, please see the standard flange information in Appendix D. So far, the differences between raw material or component features that cause the differences in costs are determined in the next step is to evaluate the process cycle time for each design.

According to Table 4-34 and considering the bill of the processes, there are two common processes between the two designs options which are fit and tack and outside welding. However, the outside weld differs for each design due to the differences in the welding procedure for each type of flange. Therefore, the only processes that can be neglectedare the fit and tack, but all other processes should be parameterized for cost analysis. To have an accurate cost estimate for the welding process, it is necessary to estimate welding cycle time in detail. Many types of research and handbooks have mentioned the deposition rate as one of the appropriate factors for estimating the welding process cost. The deposition rate indicates the usable weld metal that is deposited in one hour. The deposition rate is calculated by Equation 4-9 and Equation 4-10.

$$Depositionrate = \left[\frac{Wirefeedspeed_{(in./_{min.})} \times 60_{(min/_{hr})}}{inchesofwireperlb_{(in./_{lb.})}}\right]_{(lbs./_{hr.})} \qquad (4-9)$$

$$Inchesofwireperlb = \left[\frac{1}{\left(\pi \times \left(D/_{2}\right)^{2}\right) \times d}\right]_{(in./_{lb.})} \qquad (4-10)$$

Where;

$D = wire\ diameter$

$d = density\ of\ filler\ metal$

For example, the deposition rate for a 0.035 ER 70s-2 wire which is done with GMAW process where running shielding gas is 5 $in./_{min.}$ is calculated as following:

$$Inchesofwireperlb = \left[\frac{1}{\left(\pi \times \left(0.035/_{2}\right)^{2}\right) \times 0.283}\right]_{(in./_{lb.})} = 3672.781_{(in./_{lb.})}$$

Where;
$D = 0.035$
$d = 0.283$

$$Depositionrate = \left[\frac{5_{(in./_{min.})} \times 60_{(min/_{hr})}}{3672.781_{(in./_{lb.})}}\right]_{(lbs./_{hr.})} = 0.0817_{(lbs./_{hr.})}$$

After calculating the deposition rate the welding time can be calculated by the Equation 4-11 and Equation 4-12.

$$WeldingTime = \left[\frac{Mass_{(lbs.)}}{Depositionrate_{(lbs./_{hr.})}}\right]_{(hrs.)} \qquad (4-11)$$

$$Mass = \left[Volume_{(in.^3)} \times Density_{\left(lbs./_{in.^3}\right)}\right]_{(lbs.)} \qquad (4-12)$$

Considering the Equation 4-11 and Equation 4-12two factors affected the welding time which are mass and deposition rate. These two factors are differing for RFWN and RFSO design options. The deposition rate parameters are determined based on the welding process specific for each flange type. Table 4-34 shows all welding procedure and related parameters for each type of flanges base on different material, design temperature, and sizes.

Another factor on welding time is the mass of welding wire used for welding area. In addition, mass is the function of volume and density. The density does not change for the different flanges and it changes based on flange material. However, the volume is change based on the flange type. Figure 4-26 illustrates the geometry of the welding area for RFWN flange. Considering the parameters in Figure 4-26 the welding volume is calculated by Equation 4-13.

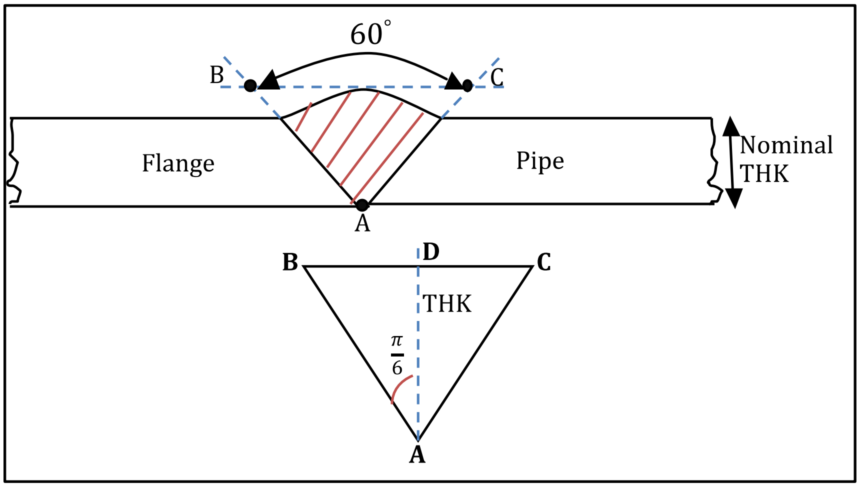


Figure 4-26 Geometry of Welding Area for RFWN Flange

$$\text{Area} = \left({}^{1}\!/_{2}\right) \times \text{AD} \times \text{BC}$$

$$\text{BC} = 2\text{BD}$$

$$\text{BD} = \text{THK} \times \text{TANGENT}\ ({}^{\pi}\!/_{6})$$

$$\text{BC} = (2) \times \text{THKS} \times \text{TANGENT}\ ({}^{\pi}\!/_{6})$$

$$\text{AD} = \text{THK}$$

$$\text{Area} = \left({}^{1}\!/_{2}\right) \times (\text{THK}) \times \left(2 \times \text{THK} \times \text{TANGENT}({}^{\pi}\!/_{6})\right)$$

$$\text{Area} = \left[(\text{THK}^{2}) \times \text{TANGENT}\ ({}^{\pi}\!/_{6})\right]_{\text{in.}^{2}}$$

$$\text{Volume} = \left[(\text{THK}^{2}) \times \text{TANGENT}\ ({}^{\pi}\!/_{6}) \times (\pi \text{D})\right]_{\text{in.}^{3}} \qquad (4-13)$$

Where;

$THK = NominalThickness + ({}^{3}\!/_{16})$

$D = DiameterofHubatPointofWeldingofRFWN$

Table 4-34 Deposition Parameters for WN and SO Flanges

Connection Size	Flange Type	DESIGN TEMPERATURE at -20 F									
		ROOT					FILL				
		Procedures	Processes	Class	Diameter	Wire feed speed rate (IPM) (in./min.)	Procedures	Processes	CLASS	Diameter	Wire feed speed rate (IPM) (in./min.)
More than 4 inches (>=4)	WN	WPS11	FCAW	E71T-12M	0.052	15	WPS11	FCAW	E71T-12M	0.052	15
	SO	NA	NA	NA	NA	NA	WPS11	FCAW	E71T-12M	0.052	15
Less than 4 inches (<4)	WN	SP-2	GMAW	ER 70s-6	0.035	5	WPS11	FCAW	E71T-12M	0.052	15
	SO	NA	NA	NA	NA	NA	WPS11	FCAW	E71T-12M	0.052	15
Connection Size	Flange Type	DESIGN TEMPERATURE LOWER -20 F									
		ROOT					FILL				
		Procedures	Processes	Class	Diameter	Wire feed speed rate (IPM) (in./min.)	Procedures	Processes	Class	Diameter	Wire feed speed rate (IPM) (in./min.)
More than 4 inches (>=4)	WN	PED4	FCAW	E71T-12MJ	0.052	7	PED4	FCAW	E71T-12MJ	0.052	7
	SO	NA	NA	NA	NA	NA	PED4	FCAW	E71T-12MJ	0.052	7
Less than 4 inches (<4)	WN	SP-2	GMAW	ER 70s-6	0.035	5	PED4	FCAW	E71T-12MJ	0.052	7
	SO	NA	NA	NA	NA	NA	PED4	FCAW	E71T-12MJ	0.052	7

Figure 4-27 illustrates the geometry of the welding area for RFSO flange. Considering the parameters in Figure 4-27. the welding volume is calculated by Equation 4-14.

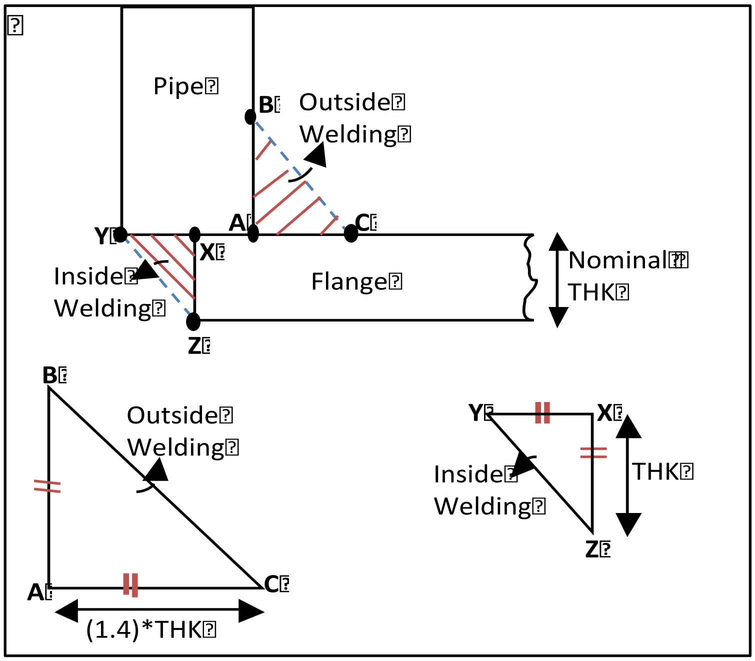


Figure 4-27 Geometry of Welding Area for RFSO Flange

$$OutsideArea = \left({}^{1}/{}_{2}\right) \times AB \times AC$$

$$AB = AC = (1.4) \times THK$$

$$OutsideArea = \left({}^{1}/{}_{2}\right) \times (1.4 \times THK)^2$$

$$InsideArea = \left({}^{1}/{}_{2}\right) \times XY \times XZ$$

$$XY = XZ = THK$$

$$InsideArea = \left({}^{1}/{}_{2}\right) \times (THK)^2$$

$$TotalArea = \left[\left({}^{1}/{}_{2}\right) \times (THK)^2 \times (2.96) = (1.48) \times (THK)^2\right]_{in.^2}$$

$$Volume = \left[(1.48) \times (THK)^2 \times (\pi D)\right]_{in.^3} \qquad (4-14)$$

$THK = NominalThickness$

$D = DiameterofHubatBaseofRFSO$

At this stage, the welding cycle time for RFSO and RFWN design options can be estimated base on different features such as: material, flange size, design temperature, and nominal thickness. However, there are at least eight possible thicknesses in this study. The results are presented for the most common standard thickness (STD). However, an Excel spreadsheet has been developed to estimate weld cycle times for any nominal thickness.

Table 4-35 Welding Cycle Time for Different Design Options

Connection CODE	WELDING TIME (hrs.)				Connection CODE	WELDING TIME (hrs.)			
	SA-STD		SS-STD			SA-STD		SS-STD	
	at -20F	Lower -20F	at -20F	Lower -20F		at -20F	Lower -20F	at -20F	Lower -20F
300SO-01	0.043	0.092	0.044	0.095	300WN-01	0.041	0.060	0.042	0.062
300SO-02	0.115	0.247	0.119	0.254	300WN-02	0.093	0.144	0.096	0.149
300SO-03	0.340	0.730	0.350	0.750	300WN-03	0.205	0.357	0.211	0.367
300SO-04	0.547	1.171	0.562	1.204	300WN-04	0.226	0.483	0.232	0.497
300SO-06	1.144	2.452	1.177	2.521	300WN-06	0.465	0.996	0.478	1.024
300SO-08	2.018	4.324	2.075	4.446	300WN-08	0.812	1.740	0.835	1.789
300SO-10	3.241	6.945	3.332	7.141	300WN-10	1.295	2.775	1.332	2.854
300SO-12	4.105	8.796	4.221	9.045	300WN-12	1.638	3.511	1.685	3.610
300SO-14	4.789	10.263	4.925	10.553	300WN-14	1.911	4.096	1.965	4.212
300SO-16	5.473	11.729	5.628	12.060	300WN-16	2.184	4.681	2.246	4.813
300SO-18	6.158	13.195	6.332	13.568	300WN-18	2.458	5.266	2.527	5.415
300SO-20	6.842	14.661	7.035	15.075	300WN-20	2.731	5.851	2.808	6.017
300SO-24	8.210	17.593	8.442	18.090	300WN-24	3.277	7.022	3.369	7.220

For the final cost analysis, the differences between RFWN and RFSO flange design options should be considered both for components and processes. To evaluate the components, features are considered,and for processes, the parameters are used. Based on the cost information the total prices for all RFWN and RFSO flanges are calculated. The extra process time and extra material prices are obtained and summarized in Table 4-36.

Table 4-36 Price Differences between RFWN and RFSO Flanges Design

SA/STD								
RFSO FLANGE		RFWN FLANGE		DIFFERENCES				
Nozzle Code	TOTAL Comparing PRICE $	Nozzle Code	TOTAL Comparing PRICE $	EXTRA Processes TIME		EXTRA Material PRICE $		TOTAL PRICE $ DIFFERENCES
				Welding (SO)	Beveling (WN)	Flange (WN)	Pipe (SO)	
300SO-01	$13.85	300WN-01	$21.63	$0.10	$4.50	$4.08	$0.71	-$7.77
300SO-02	$19.40	300WN-02	$25.32	$1.01	$4.50	$3.33	$0.91	-$5.91
300SO-03	$34.15	300WN-03	$32.72	$6.10	$4.50	$2.56	$2.38	$1.43
300SO-04	$50.66	300WN-04	$45.81	$14.45	$4.50	$7.69	$2.60	$4.86
300SO-06	$98.92	300WN-06	$73.97	$30.57	$4.50	$6.84	$5.72	$24.95
300SO-08	$170.00	300WN-08	$126.79	$54.27	$6.75	$13.78	$9.47	$43.21
300SO-10	$280.91	300WN-10	$216.56	$87.56	$6.75	$32.49	$16.03	$64.35
300SO-12	$353.03	300WN-12	$274.85	$111.00	$6.75	$48.07	$22.01	$78.19
300SO-14	$605.12	300WN-14	$455.64	$129.50	$6.75	$12.85	$26.73	$149.48
300SO-16	$691.30	300WN-16	$534.65	$148.00	$6.75	$16.44	$31.83	$156.64
300SO-18	$831.39	300WN-18	$717.34	$166.50	$6.75	$85.95	$40.25	$114.05
300SO-20	$923.20	300WN-20	$792.83	$185.00	$6.75	$93.58	$45.71	$130.38
300SO-24	$1,290.10	300WN-24	$1,054.42	$222.00	$6.75	$41.77	$62.19	$235.67
SS/STD								
RFSO FLANGE		RFWN FLANGE		DIFFERENCES				
Nozzle Code	TOTAL Comparing PRICE $	Nozzle Code	TOTAL Comparing PRICE $	EXTRA Processes TIME		EXTRA Material PRICE $		TOTAL PRICE $ DIFFERENCES
				Welding (SO)	Beveling (WN)	Flange (WN)	Pipe (SO)	
300SO-01	$14.36	300WN-01	$27.67	$0.10	$9.00	$5.18	$0.77	-$13.30
300SO-02	$20.42	300WN-02	$31.30	$1.04	$9.00	$4.70	$1.78	-$10.88
300SO-03	$41.88	300WN-03	$49.48	$6.28	$9.00	$9.00	$4.13	-$7.60
300SO-04	$62.79	300WN-04	$70.44	$14.85	$9.00	$20.00	$6.50	-$7.65
300SO-06	$118.49	300WN-06	$124.51	$31.44	$9.00	$41.00	$12.54	-$6.02
300SO-08	$207.12	300WN-08	$191.56	$55.80	$9.00	$55.00	$23.75	$15.55
300SO-10	$318.73	300WN-10	$277.18	$90.03	$11.25	$73.00	$35.77	$41.56
300SO-12	$443.64	300WN-12	$386.06	$114.14	$11.25	$94.00	$48.69	$57.58
300SO-14	$814.61	300WN-14	$732.70	$133.16	$11.25	$103.00	$63.00	$81.91
300SO-16	$1,011.41	300WN-16	$954.33	$152.18	$11.25	$160.00	$76.15	$57.08
300SO-18	$1,175.08	300WN-18	$1,082.97	$171.21	$11.25	$178.00	$110.16	$92.11
300SO-20	$1,524.08	300WN-20	$1,402.60	$190.23	$11.25	$195.00	$137.50	$121.48
300SO-24	$1,926.35	300WN-24	$1,797.87	$228.28	$11.25	$250.00	$161.46	$128.48

Regarding Table 4-36 and Figure 4-28 the following facts hold throughout the design space represented by the RFSO and RFWN design cost comparison:

- The welding costs for RFSO designs are always greater than for comparable RFWN designs. This is because the RFSO designs require both inside and outside welding.
- RFSO designs do not require the beveling process so RFWN designs encure this additional processing cost.
- The material costs for the purchased flange element is always more expensive for RFWN designs.
- The RFSO designs require longer pipe sections than the comparitive RFWN designs.

Another important factor is the material. If the design is based on carbon steel (SA) material it is more economical to use RFSO design for size 01 and 02 (300SO-01,02) and other sizes there would be more saving if the RFWN is used, which are 300WN-03 to 300WN-24.However, sometimes it would be necessary to use stainless steel material in the production. If the design is based on stainless steel (SS) material it is more economical to use RFSO design for size 01 to 06 (300SO-01 to 300SO-06) and for other sizes, there would be more saving if the RFWN is used which are 300WN-08 to 300WN-24.

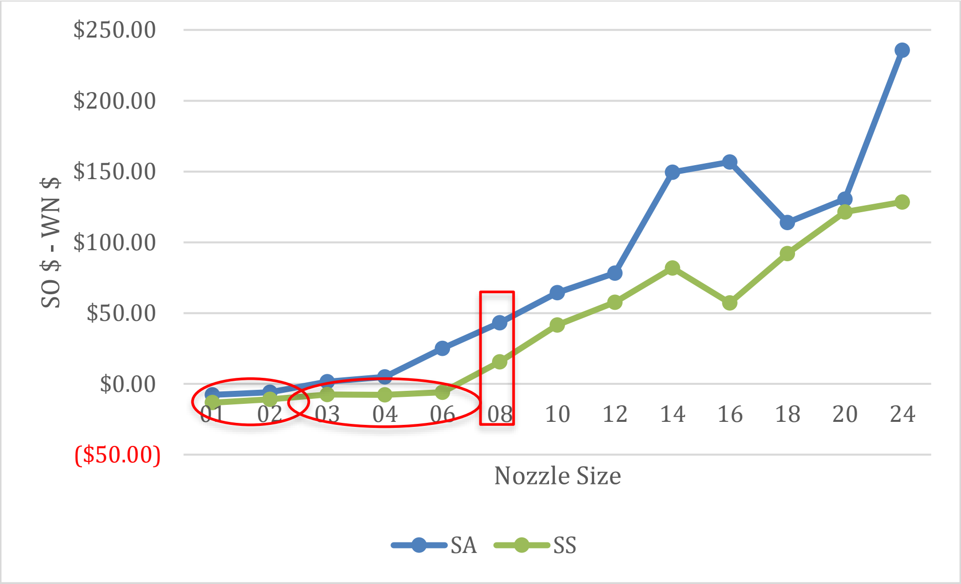


Figure 4-28 Cost Analysis between RFWN and RFSO Flanges Design

Another cost analysis for different type of flanges can be done based on the material. If the engineering designer chooses between stainless steel or carbon steel flange the new model can provide useful information. According to Graph 4-29 and Graph 4-30 final price for both RFWN and RFSO flanges is higher for stainless steel material. However, in both type of flanges after certain flange size (size 10), the price of stainless-steel flanges is considerably higher than carbon steel.

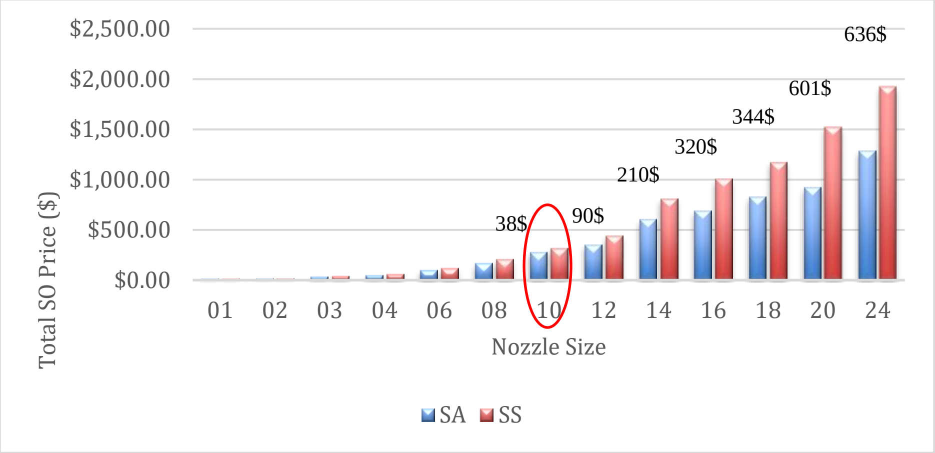


Figure 4-29 Material Based Cost Analysis for RFSO Flanges

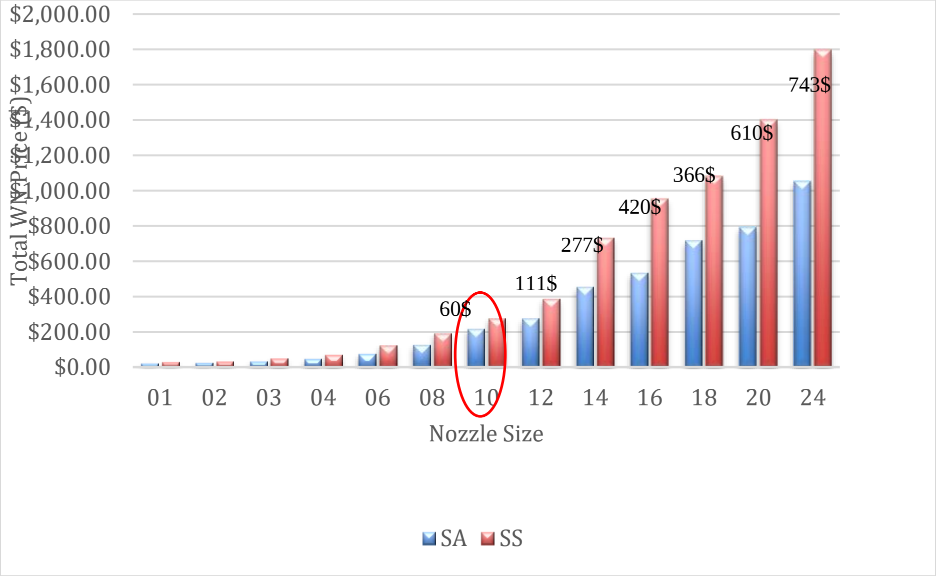
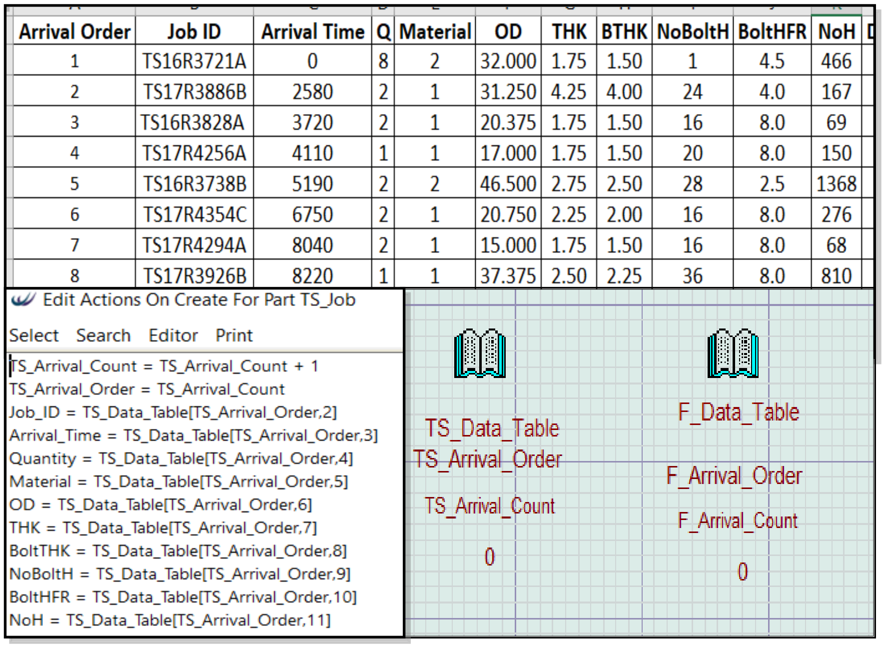


Figure 4-30 Material Based Cost Analysis for RFWN Flanges

4.6. Dynamic Simulation Modeling

Simulation-based cost estimation provides a powerful management tool for decision-making processes. In addition, simulation models are able to provide more details and also consider the variation of a dynamic manufacturing system. In order to simulate a product cost estimation model, the relevant cost information should implement and translate to the simulation environment. In this study, the WITNESS software is used as the simulation tool. It is used in order to simulate the parametric process and the activities that should be defined for the product. A part is defined as an "Entity" that passes through the system where different processes will be occurring to produce the final product. For example, the tubesheet entity would pass through the CNC machines for the machining processes such as turning, drilling, burnishing etc. First, core production activities and processes are defined by the use of the process description capture method (IDEF3). Then the production activities are defined in the simulation environment. The first step in the simulation model is to define the parameters for each part. An excel sheet design to contains all parameters for each part and then it enters the model by means of "Data Table". Also for each specific parameters an attributes defined in simulation environment and then for each part and in "Action on Create" the attributes for the specific part carries the value by reading those value from excel sheet (Figure 4-31).

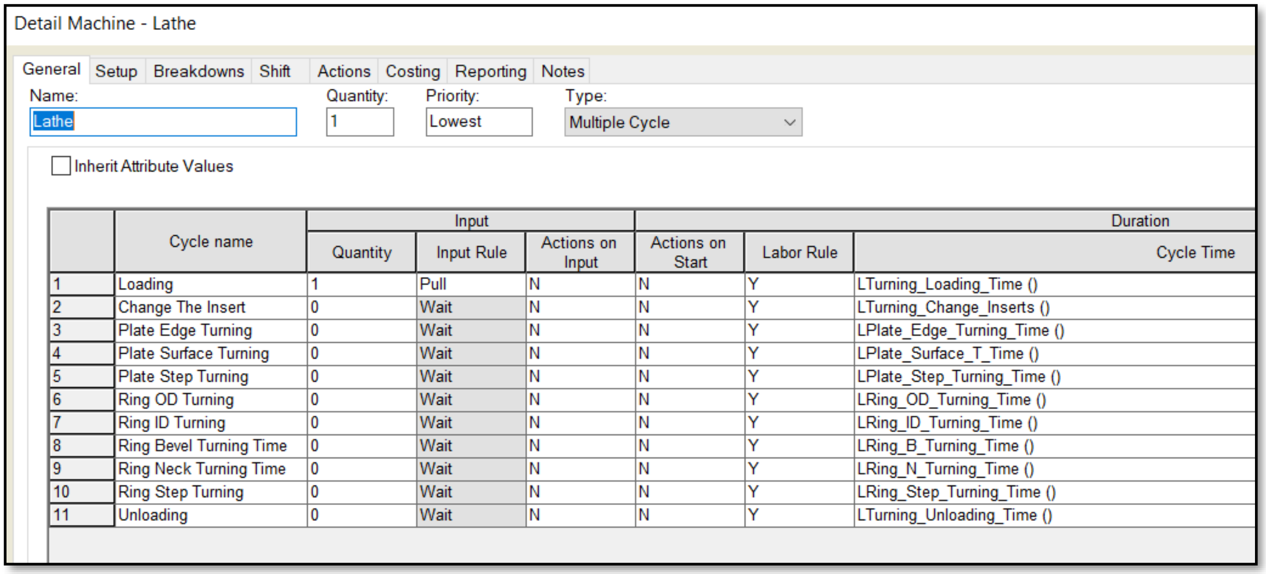


Arrival Order	Job ID	Arrival Time	Q	Material	OD	THK	BTHK	NoBoltH	BoltHFR	NoH
1	TS16R3721A	0	8	2	32.000	1.75	1.50	1	4.5	466
2	TS17R3886B	2580	2	1	31.250	4.25	4.00	24	4.0	167
3	TS16R3828A	3720	2	1	20.375	1.75	1.50	16	8.0	69
4	TS17R4256A	4110	1	1	17.000	1.75	1.50	20	8.0	150
5	TS16R3738B	5190	2	2	46.500	2.75	2.50	28	2.5	1368
6	TS17R4354C	6750	2	1	20.750	2.25	2.00	16	8.0	276
7	TS17R4294A	8040	2	1	15.000	1.75	1.50	16	8.0	68
8	TS17R3926B	8220	1	1	37.375	2.50	2.25	36	8.0	810

```
TS_Arrival_Count = TS_Arrival_Count + 1
TS_Arrival_Order = TS_Arrival_Count
Job_ID = TS_Data_Table[TS_Arrival_Order,2]
Arrival_Time = TS_Data_Table[TS_Arrival_Order,3]
Quantity = TS_Data_Table[TS_Arrival_Order,4]
Material = TS_Data_Table[TS_Arrival_Order,5]
OD = TS_Data_Table[TS_Arrival_Order,6]
THK = TS_Data_Table[TS_Arrival_Order,7]
BoltTHK = TS_Data_Table[TS_Arrival_Order,8]
NoBoltH = TS_Data_Table[TS_Arrival_Order,9]
BoltHFR = TS_Data_Table[TS_Arrival_Order,10]
NoH = TS_Data_Table[TS_Arrival_Order,11]
```

Figure 4-31 Parameters Definition in the Simulation Model

In order to construct the activity based model in the simulation one of the key contribution is to transfer the batch to the unit. Parts are entering the simulation model as the batch and then they goes in the machine cycles as a unit. In order to do that a “Production Machine Type” should be defined. The input quantity is “1” and the output quantity is the quantity of the units. In the next step the core process should be defined based on the parameters. For this purpose a CNC machine is defined – the most important properties of the machine that should be defined is the type of machine. In order to define different processes for a machine, the best option for the machine type is “Multiple Cycle”. Under a multiple cycle machine a different “Cycle name” can be added, and each cycle name can have numerous processes or activities. That is how the list of processes can be defined in the simulation environment (Figure 4-32).



Name: Lathe
Quantity: 1
Priority: Lowest
Type: Multiple Cycle

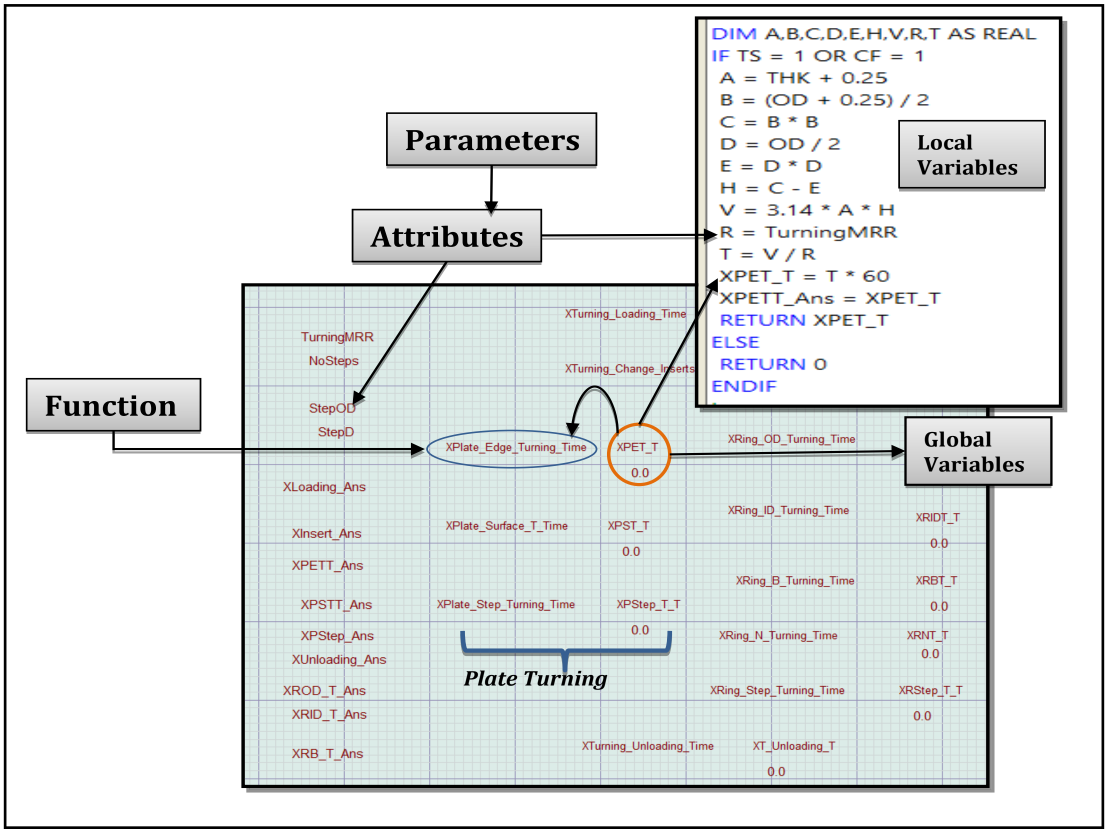
☐ Inherit Attribute Values

	Cycle name	Input			Duration		
		Quantity	Input Rule	Actions on Input	Actions on Start	Labor Rule	Cycle Time
1	Loading	1	Pull	N	N	Y	LTurning_Loading_Time ()
2	Change The Insert	0	Wait	N	N	Y	LTurning_Change_Inserts ()
3	Plate Edge Turning	0	Wait	N	N	Y	LPlate_Edge_Turning_Time ()
4	Plate Surface Turning	0	Wait	N	N	Y	LPlate_Surface_T_Time ()
5	Plate Step Turning	0	Wait	N	N	Y	LPlate_Step_Turning_Time ()
6	Ring OD Turning	0	Wait	N	N	Y	LRing_OD_Turning_Time ()
7	Ring ID Turning	0	Wait	N	N	Y	LRing_ID_Turning_Time ()
8	Ring Bevel Turning Time	0	Wait	N	N	Y	LRing_B_Turning_Time ()
9	Ring Neck Turning Time	0	Wait	N	N	Y	LRing_N_Turning_Time ()
10	Ring Step Turning	0	Wait	N	N	Y	LRing_Step_Turning_Time ()
11	Unloading	0	Wait	N	N	Y	LTurning_Unloading_Time ()

Figure 4-32 Turning Processes Definition in the Simulation Model

In the last step, a parametric process should be defined for a product. Parameters are defined by the use of variables and attributes; processes are also defined by use of a multiple cycle machine. In order to link parameters and processes, “Function” will subsequently be used. The functions can be defined based on variables, which are the parameters, and they can be used as a “Cycle Time” under multiple cycle machines that shows the process. That is how a parametric process can be defined as a part of the simulation environment. The parameters should be defined for the cycle times. A parameter has two properties, first one is what that parameter means, and the second is the value of that parameter. In order to translate the product parameter to the simulation environment “Variables” and

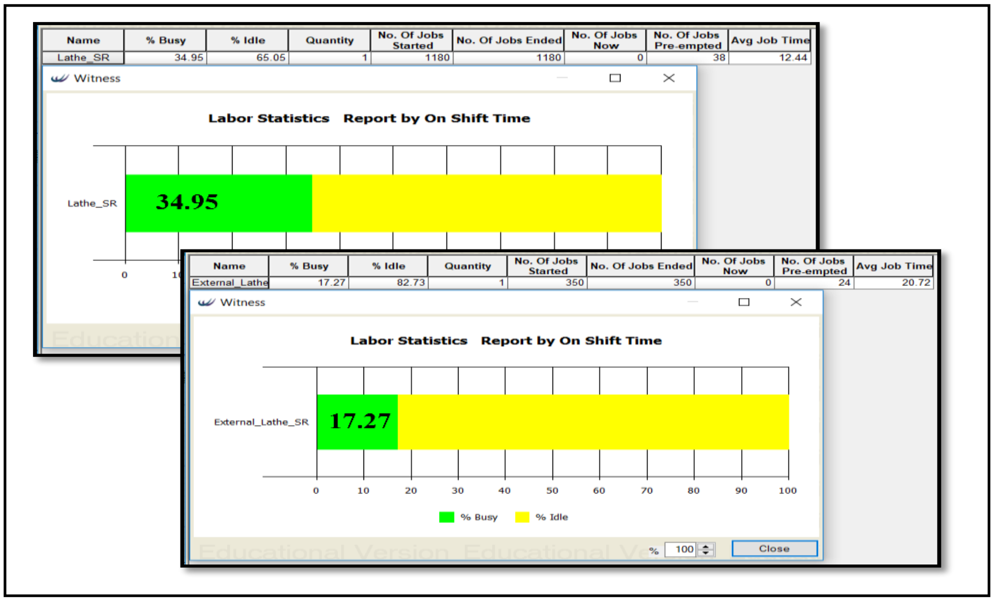
"Attributes" are used. The Variables are define the parameters (what are our parameters). The attributes are carrying the value of those parameters Figure 4-33 shows the variables and attributes and functions in the simulation model.



```
DIM A,B,C,D,E,H,V,R,T AS REAL
IF TS = 1 OR CF = 1
 A = THK + 0.25
 B = (OD + 0.25) / 2
 C = B * B
 D = OD / 2
 E = D * D
 H = C - E
 V = 3.14 * A * H
 R = TurningMRR
 T = V / R
 XPET_T = T * 60
 XPETT_Ans = XPET_T
 RETURN XPET_T
ELSE
 RETURN 0
ENDIF
```

Figure 4-33 Parametric Process Definition in the Simulation Model

Another application of the simulation model in this study is unutilized capacity recognition. The results from the statistical reports indicate the unutilized capacity of different elements in the system. Analyzing the report, the production volume and the number of new orders can then be identified. Also, the manufacturing scheduling and delivery time for a new order are predictable via simulation analysis. Figure 4-34 and 4-35 illustrates the unutilized capacity of the different machines.



Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Jobs Now	No. Of Jobs Pre-empted	Avg Job Time
Lathe_SR	34.95	65.05	1	1180	1180	0	38	12.44

Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Jobs Now	No. Of Jobs Pre-empted	Avg Job Time
External_Lathe	17.27	82.73	1	350	350	0	24	20.72

Figure 4-34 Capacity Analysis for Turning Process

Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Jobs Now	No. Of Jobs Pre-empted	Avg Job Time
Fadal_SR	37.69	62.31	1	2205	2205	0	0	7.18

Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Jobs Now	No. Of Jobs Pre-empted	Avg Job Time
QuickMill_SR	54.98	45.02	1	1561	1561	0	0	14.79

Figure 4-35 Capacity Analysis for Drilling Process

Considering Figure 4-34 if the vision is to increase the capability of the machine the new turning machine that can process parts with outer diameter more than 32 should be added to the system. The projected utilization of this larger lathe is estimated to be 17.27% which compared to the utilization of other machine shop resources this value was considered low. Therefore for turning process considering the machine capacity and capability there is no need to add any turning machine to the system. Regarding Figure 4-35 if just a new QuickMill adding to the model the capability of the system will increase. However, if the strategy is to increase the capacity of the drilling process either new QuickMill or Fadal can be added to the system. From capacity analysis it can be concluded that adding a new QuickMill with 54.98% of busy time increasing both capability and capacity of the machine shop.

CHAPTER 5

CONCLUSION

5.0. Introduction

This section presents conclusions and recommendations for future work and lines of inquiry related to this research. These conclusions relate to both the formulation of our proposed parametric activity-based cost estimation framework but also its suitability to for actual used in an enterprise that specializes in the production of a set of highly customized products that are based on an established product family architecture. We also draw conclusions concerning the use of the costing framework as a decision support tool within the enterprise. Recommendations for future work to expand this research are presented. Recommendations are made regarding how our current work can be further expanded and verified. Alternative methods for defining for defining the underlying parametric costing relationships are discussed. Proposed additional applications for the cost estimation framework are also presented.

5.1. Conclusions

The main objective of this study is to develop an integrated, generic, and dynamic production cost estimation framework that provides accurate cost information in a useful form. An appropriate generic and dynamic product-costing model with the ability to determine product cost estimates at the early stages of the design and development phase is of great value in order to compete within a global market. In addition, the product cost estimates generated by the costing framework provide a measure of new product development performance. Finally, the new cost estimation model is used as a decision-making tool in different areas such as product design, new product development, and product marketing.

Based on product costing literature we conclude that an integrated costing framework is required. The combination of activity-based costing, parametric costing and processes modeling has proven to be an effective tool for new product cost estimation. The role of the process models within the new costing framework is to provide the whole picture of what goes on in the company. Furthermore, the use of a product family architecture provides detailed and useful product design information in advance, which increases the accuracy of new product cost estimates.

In this study a new taxonomy of the product cost estimation techniques was developed where the analogous method is considered both a quantitative and qualitative classification. When products in the family differ from each other based on components and production processes, their costing models can be categorized as qualitative analogical. However, if the differences between the products in the family are based on product geometry and features (but they have the same production processes and components) then their costing model can be categorized as quantitative analogical methods. The product family architecture supports production cost estimation by providing cost information at detailed levels such as the product and feature levels.

From our case study of the machining operations at a small custom industrial vessel manufacturer, we conclude that the components of our proposed product costing framework are compatible with the needs of real manufacturers who produce complex customized products defined by an establish product family architecture. The PFA provides the structure that supports the use of analogical costing techniques. The Tubular Exchanger Manufactures Association PFA used by the case study organization provided a product design classification system based on product function. This functional product classification structure allows product designers to quickly identify a conceptual design for a broad family of industrial vessels. A manufacturing enterprise dedicated to the production of customized industrial vessels will develop design and production processes capable of quickly and cost effectively producing products within various subsets of the PFA. For example, in this case study we have elected to focus our efforts on analyzing the processes associated with the design and production of BKU industrial chillers. The TEMA PFA more specifically defines a BKU chiller as a system requiring a high pressure bonnet head with a kettle type reboiler shell and a U-type tube bundle at the platform level of the PFA.

Modern computer-aided design (CAD) tools facilitate the specification of parametric design templates capable of generating parameterized product designs at the sub-assembly, module & component, and feature levels of the PFA. Product functional design interfaces with manufacturing process specification and design at the module & component and feature levels of the PFA. The product costing framework also integrates with the PFA at the module & component and feature levels for this specific reason. Product costing methods based on component sharing will naturally fit into the module & component level of the PFA. Historic costs of specific modules or components determined for past products can be used to develop cost estimates for new products designed to utilize these same elements. If parametric relationships can be established across the features of a component family, the CAD design templates for the component family can quickly generate material cost estimates for any product design instance that is within the parameterized family. This parameterized product information is contained within the feature level of the PFA. A simple product feature relevant to this case study is the specification of a hole in a component. The need for that hole is defined by the function and performance characteristic of the end product. The information needed to geometrically define that hole also can be used to determine and quantify the manufacturing processes and production resources needed to produce that hole. Parametric relationships, or models, can be created which correlate the geometric features of a component to the processing time and resource costs of the production processes required to produce them. These parametric feature cost models support the creation of a parametric cost estimation method based on process sharing across various levels of the PFA.

Quantitative parametric cost estimation methods work very well at the product feature level. Processes performed at the feature creation level consist of discrete production steps. The cost parameterization of these low-level production steps can be complex but once defined are typically repeatable. As we move away from the low-level, feature creation processes to the higher-level product realization levels, we are forced to consider tasks or activities that are not as mechanistic or repeatable. These higher-level production tasks are influenced by the real-time state of the overall production environment rather than the geometric features of the component. Examples of these non-geometric factors that can influence production costs include resource availability, production batch sizes, and inventory level policies.

Through the application of the costing framework to the actual processes performed in the case study organization we verified that the IDEF3 process description capture method was capable of capturing process and activity cost data consistent with the companies product family architecture (PFA). The integration of the knowledge gained through the definition of the core processes using IDEF3 and the analysis of the components and their features within the product family architecture allow us to link our qualitative process descriptions with our quantitative feature-based process parameters. This integration occurs at the activity level allowing parametric process knowledge to inform our cost estimates within the traditional Activity Based Costing Method giving us a Parametric Activity Based Costing Model.

The new cost estimation model, Parametric Activity Based Costing Model considering unutilized capacity costs, is implemented at the initial stages of design for all parts produced in the machine shop. Some statistical models have been implemented accordingly, to check the adequacy of the model. Primarily, the residual analysis verifies the model assumptions and the adequacy of the model. The result of the different costing models was compared in more detail. The first costing model is the current costing model which is based on management experience and the second model is the traditional costing model with a single overhead rate .The third costing model is the parametric activity based costing method that was improved by considering the cost of unutilized capacity of the resources in the parametric activity based costing model.

The comparison of different cost estimation methods reduced the potential risk of the under estimation of production costs through overhead rate analysis. If the overhead rate is under estimated, the cost estimation will also under estimate the production costs and reduce the accuracy of the model. Also, the cost analysis of this study shows the over estimation of costs when using the traditional costing model based on a single overhead rate for the overhead cost allocation. The new costing model, with multiple overhead rate identification, that was parametrized based on the activity costs increases the accuracy of the model. A new parametric activity based costing model was developed and tested for a particular part. All activity costs and cost drivers were parameterized. The simple cost driver rates used in traditional activity based costing were replaced by the new parametric cost drivers.

Finally, one of the improvements in the new cost estimation model is the consideration of unutilized resource capacity. The comparisons between all models shows that the parametric activity-based costing method that considers the cost of all resources provided to the system (Model C) and the parametric activity-based costing method but calculate overhead rates based on our estimates of actual resource utilization (Model E) have the closest value to the actual product cost.

Also, this study indicates the probability that dynamic cost estimation can be achieved by utilizing simulation before actual manufacturing production. The simulation model can describe and analyze manufacturing activities before actual production is performance. Therefore, every production detail can be simulated and potential production problems can be identified and considered in the cost estimation before actual manufacturing performance. Also one of the strategic decisions that can be analyzed by simulation modeling is the decision to either increase the machine shop's capacity or capability. A parametric activity based model was developed in the WITNESS environment. The capacity analysis based on this model indicates that increasing the production capacity alternative is more productive rather than increasing the capability of the system.

Finally, Activity-Based Management (ABM) was implemented for cost and time analysis. The result led to the decision making analysis. ABM analysis was used to choose between different design options. Considering the product family architecture (PFA) for connections, modules, and subassemblies the most common part in a complicated designs are the flanges. However, the flanges can be different based on the features. One feature that makes a radical difference between flanges is their type. The two main types of the flanges are "Weld-Neck-Flanges" or "Slip-On-Flanges". ABM analysis enabled the creation of a design policy that identified the least cost type of flange to use.

5.2. Future Recommended Studies

Future research can be conducted in data mining area. In this study a parametric feature based model presented with many parameters. Machine Learning seems to be an effective and accurate method for production cost of mechanical parts especially at early stage of product development and process design. Therefore, a combination of statistical and data mining studies are recommended in order to check the correlation between parameters and provide a classification of the feature based parameters using a data mining model. Also, In order to pursue with this inquisition and survey in its being effective in all aspects of industry, the following recommendations are suggested:

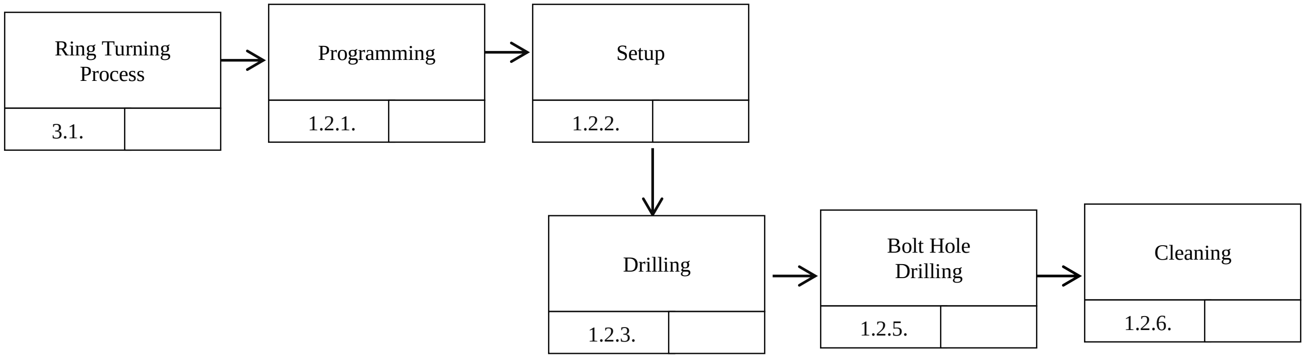
- Implementation of the new cost model in accounting, mechanical and operational software such as Aspen Tech as a mechanical software and Microsoft Project (MSP) as an operational and planning software.
- In this study the new costing model was implemented in the manufacturing industry. However, this model can be implemented in service industries such as health care for more accurate cost estimation.

For the last option, the impact of enterprise culture on the actual implementation of new cost modeling system is another area of future research. For many decades implantation of modern cost estimations are emphasis however, in the real world there is less motivation of using modern models advantages. Also, one of the missing factors of modern costing models is the lack of accounting definitions and concepts in production cost estimations. For instance, the inclusion of international exchange rates is one of the concepts that can be added to cost estimation analysis for global competitive market advantages.

Appendix A

Production Scenarios for FLANGE, BOLTING PAD, COVER FLANGE

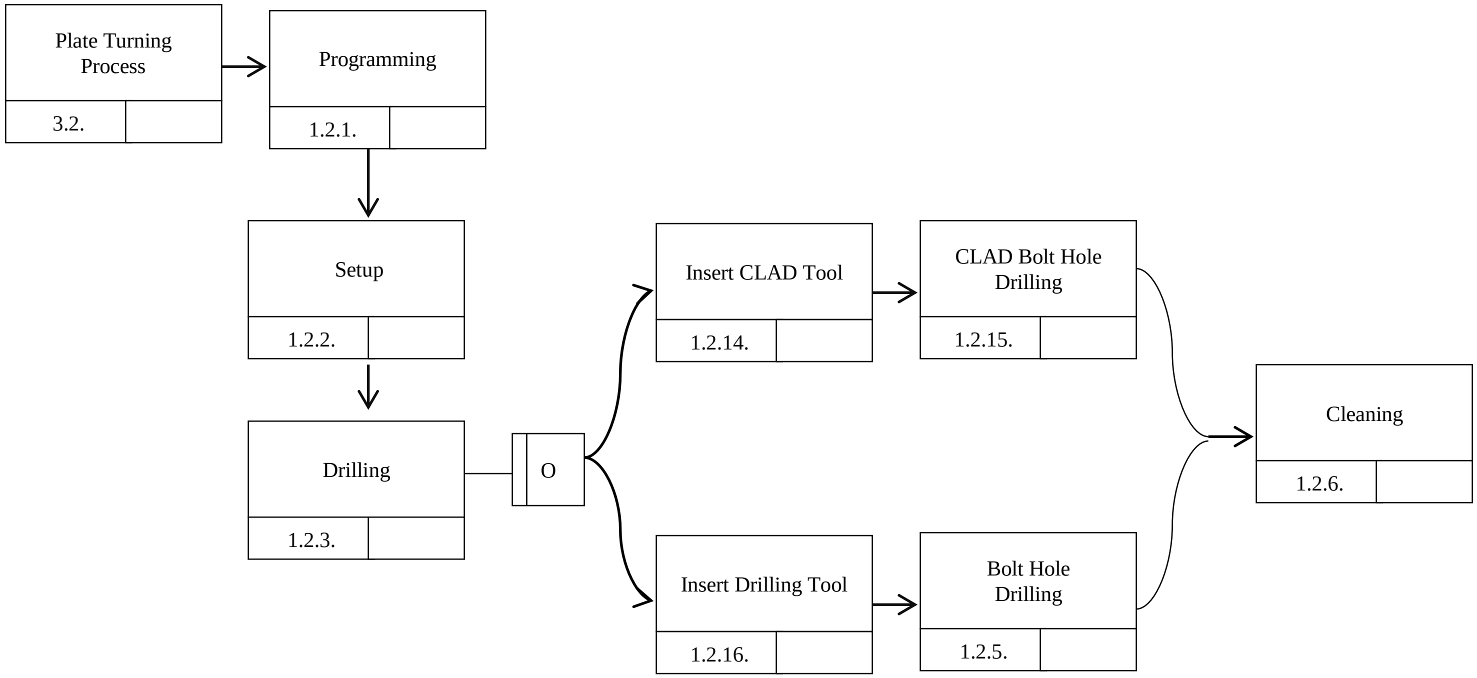
USED AT:	ANALYST: Zahra Banakar	DATE: 22 Sep 2018	×	WORKING	REVIEWER:	DATE:
				DRAFT		
	PROJECT: Project Description Capture			RECOMMENDED		
	NOTES: 1 2 3 4 5 6 7 8 9 10	REV:		RELEASED		



CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Quickmill Machine, FLANGE/BOLTING PAD Production Scenarios	FORM TYPE:

FLANGE/BOLING PAD Production Scenarios

USED AT:	ANALYST: Zahra Banakar DATE: 22 Sep 2018	×	WORKING	REVIEWER:	DATE:
			DRAFT		
	PROJECT: Project Description Capture		RECOMMENDED		
	NOTES: 1 2 3 4 5 6 7 8 9 10 REV:		RELEASED		



CONTEXT-SETTING REFERENCE	ITEM DESCRIBED: Quickmill Machine, COVER FLANGE Production Scenario	FORM TYPE:

COVER FLANGE Production Scenario

Appendix B

Cost Estimation Results

New Model Time Estimation and Actual Time for TUBESHEET

JOB Number	**NEW MODEL TIME ESTIMATION (hrs.)**			**ACTUAL TIME (hrs.)**			**Differences Between ACTUAL and Estimation Time (hrs.)**
	Turning Process	Drilling, Grooving, Burnishing, Milling Processes	Total Processes Time	Turning Process	Drilling, Grooving, Burnishing, Milling Processes	Total Processes Time	
TS16R3788B	9.11	37.15	46.26	9	35.5	44.5	-1.76
TS16R3828A	3.86	11.25	15.11	5.5	12	17.5	2.39
TS16R3788A	8.11	30.53	38.65	7.5	34.5	42	3.35
TS17R4354C	4.95	14.07	19.02	6	12.5	18.5	-0.52
TS17R3886B	9.92	21.05	30.97	5	26.5	31.5	0.53
TS16R3828B	3.89	10.28	14.17	4	6	10	-4.17
TS17R3908A	4.2	10.9	15.1	4.75	7	11.75	-3.35
TS17R3898B	2.91	6.61	9.52	4	7	11	1.48
TS16R3738A	4.81	13.22	18.03	5.5	13.25	18.75	0.72
TS17R4133C	4.67	11.95	16.62	5.75	13.5	19.25	2.63
TS17R4256A	2.99	7.26	10.25	2.5	6	8.5	-1.75
TS17R4406B	5.74	24.36	30.1	6.25	23.25	29.5	-0.6
TS17R4201A	4.01	10.79	14.8	6	9.5	15.5	0.7
TS17R4205A	3.03	6.69	9.72	3	8.25	11.25	1.53
TS17R4014A	3.17	6.51	9.68	4.5	6.75	11.25	1.57
TS17R4203A	6.18	21.74	27.92	6.75	22.75	29.5	1.58
TS17R4294A	4.39	12.35	16.74	4	11	15	-1.74
TS17R2235A	3.03	6.99	10.02	4.5	8.25	12.75	2.73
TS17R4443A	5.73	14.71	20.44	5.5	17.5	23	2.56
TS17R4333A	5.15	16.07	21.22	3	18	21	-0.22
TS17R4114A	4.8	13.98	18.78	5.25	16.25	21.5	2.72
TS17R4114B	3.35	6.86	10.21	4	7.5	11.5	1.29

Average Percentage of the Total Costs for the TUBESHEET Part

JOB Number	**Total Production Costs for the Part ($)**	**Total Actual Costs for the Product ($)**	**Percentages of Total Costs**
TS16R3788B	2447.50	12595.00	19.43%
TS16R3828A	962.50	5197.50	18.52%
TS16R3788A	2310.00	11522.50	20.05%
TS17R4354C	1017.50	10821.25	9.40%
TS17R3886B	1732.50	22907.50	7.56%
TS16R3828B	550.00	3206.25	17.15%
TS17R3908A	646.25	5636.25	11.47%
TS17R3898B	605.00	16926.25	3.57%
TS16R3738A	1031.25	8786.25	11.74%
TS17R4133C	1058.75	8222.50	12.88%
TS17R4256A	467.50	7768.75	6.02%
TS17R4406B	1622.50	24681.25	6.57%
TS17R4201A	852.50	2406.25	35.43%
TS17R4205A	618.75	14341.25	4.31%
TS17R4014A	618.75	4441.25	13.93%
TS17R4203A	1622.50	9735.00	16.67%
TS17R4294A	825.00	6380.00	12.93%
TS17R2235A	701.25	2510.00	27.94%
TS17R4443A	1265.00	19332.50	6.54%
TS17R4333A	1155.00	9982.50	11.57%
TS17R4114A	1182.50	7067.50	16.73%
TS17R4114B	632.50	5280.00	11.98%
Average percentage of the Total Costs			**13.75%**

New Model Time Estimation and Actual Time for BAFFLE

JOB Number	**NEW MODEL TIME ESTIMATION (hrs.)**	**ACTUAL TIME (hrs.)**	**Differences Between ACTUAL and Estimation Time (hrs.)**
	Total Processes Time	Total Processes Time	
Baff17R4109AM	10.04	10.25	0.21
Baff16R3828BM	3.3	4.25	0.95
Baff17R4256AM	5.96	4.75	-1.21
Baff17R4256AS	3.42	2.75	-0.67
Baff17R3908AM	3.37	4.25	0.88
Baff17R4133CM	8.02	9.75	1.73
Baff17R4133CS	3.76	4.75	0.99
Baff17R4014AM	3.27	3.5	0.23
Baff17R4232AM	3.37	3.75	0.38
Baff17R4201AM	3.46	3.75	0.29
Baff17R4294AM	3.42	4.75	1.33
Baff17R4406DM	3.62	4.75	1.13
Baff17R4406AM	12.43	14.75	2.32
Baff17R2235AM	3.64	2.75	-0.89
Baff17R4443AM	4.1	5.75	1.65
Baff17R4109BM	11.8	10.5	-1.3
Baff16R3721AS	7.46	8.75	1.29
Baff16R3788BM	22.12	24.25	2.13
Baff16R3788AM	21.16	20	-1.16
Baff16R3828AM	3.47	2.75	-0.72
Baff17R3926BM	14.87	16.5	1.63

Average Percentage of the Total Costs for the BAFFLE Part

JOB Number	Total Production Costs for the Part ($)	Total Actual Costs for the Product ($)	Percentages of Total Costs
Baff17R4109AM	563.75	3121.25	18.06%
Baff16R3828BM	233.75	3206.25	7.29%
Baff17R4256AM	261.25	7768.75	3.36%
Baff17R4256AS	151.25	7768.75	1.95%
Baff17R3908AM	233.75	5636.25	4.15%
Baff17R4133CM	536.25	8222.50	6.52%
Baff17R4133CS	261.25	8222.50	3.18%
Baff17R4014AM	192.50	4441.25	4.33%
Baff17R4232AM	206.25	9693.75	2.13%
Baff17R4201AM	206.25	2406.25	8.57%
Baff17R4294AM	261.25	6380.00	4.09%
Baff17R4406DM	261.25	13310.00	1.96%
Baff17R4406AM	811.25	18995.63	4.27%
Baff17R2235AM	151.25	2510.00	6.03%
Baff17R4443AM	316.25	19332.50	1.64%
Baff17R4109BM	577.50	2571.25	22.46%
Baff16R3721AS	481.25	18892.50	2.55%
Baff16R3788BM	1,333.75	12595.00	10.59%
Baff16R3788AM	1,100.00	11522.50	9.55%
Baff16R3828AM	151.25	5197.50	2.91%
Baff17R3926BM	907.50	13543.75	6.70%
Average percentage of the Total Costs			**6.30%**

New Model Time Estimation and Actual Time for COVER FLANGE

JOB Number	**NEW MODEL TIME ESTIMATION (hrs.)**			**ACTUAL TIME (hrs.)**			**Differences Between ACTUAL and Estimation Time (hrs.)**
	Turning Process	Drilling Processes	Total Processes Time	Turning Process	Drilling Processes	Total Processes Time	
CF17R2187B	3.16	2.88	6.04	3.5	2.75	6.25	0.21
CF17R2227 A	3.07	2.86	5.93	4	2.75	6.75	0.82
CF17R4406B	16.88	11.34	28.22	17.75	11.25	29	0.78

New Model Time Estimation and Actual Time for BOLTING PAD

JOB Number	**NEW MODEL TIME ESTIMATION (hrs.)**			**ACTUAL TIME (hrs.)**			**Differences Between ACTUAL and Estimation Time (hrs.)**
	Turning Process	Drilling Processes	Total Processes Time	Turning Process	Drilling Processes	Total Processes Time	
BP16R1823A	5.07	3.07	8.14	5.5	3	8.5	0.36
BP17R2227A	2.62	2.28	4.9	4	2.5	6.5	1.6
BP17R2227B	2.61	2.28	4.89	2.5	2	4.5	-0.39
BP17R2187B	3.47	2.44	5.91	3.75	3	6.75	0.84
BP17R2187C	3.09	2.34	5.43	3.5	2.5	6	0.57
BP17R2227C	3.27	2.34	5.61	2.5	2	4.5	-1.11
BP17R2086A	2.79	2.29	5.08	2.5	2	4.5	-0.58
BP16R1738B	3.27	2.34	5.61	3	1.75	4.75	-0.86

Average Percentage of the Total Costs for the COVER FLANGE Part

JOB Number	**Total Production Costs for the Part ($)**	**Total Actual Costs for the Product ($)**	**Percentages of Total Costs**
CF17R2187B	343.75	19362.5	1.78%
CF17R2227 A	371.25	13533.75	2.74%
CF17R4406B	1595	24681.25	6.46%
Average percentage of the Total Costs			**3.66%**

Average Percentage of the Total Costs for the BOLTING PAD Part

JOB Number	**Total Production Costs for the Part ($)**	**Total Actual Costs for the Product ($)**	**Percentages of Total Costs**
BP16R1823A	467.5	18340	2.55%
BP17R2227A	357.5	13533.75	2.64%
BP17R2227B	247.5	9652.5	2.56%
BP17R2187B	371.25	19362.5	1.92%
BP17R2187C	330	20137.5	1.64%
BP17R2227C	247.5	12622.5	1.96%
BP17R2086A	247.5	12588.75	1.97%
BP16R1738B	261.25	13378.75	1.95%
Average percentage of the Total Costs			2.15%

Appendix C

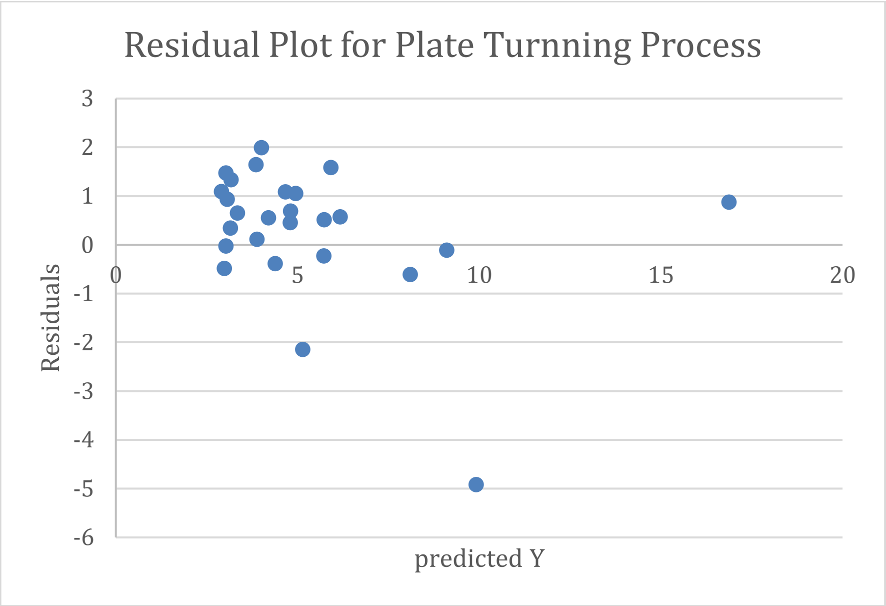
Residual Analysis

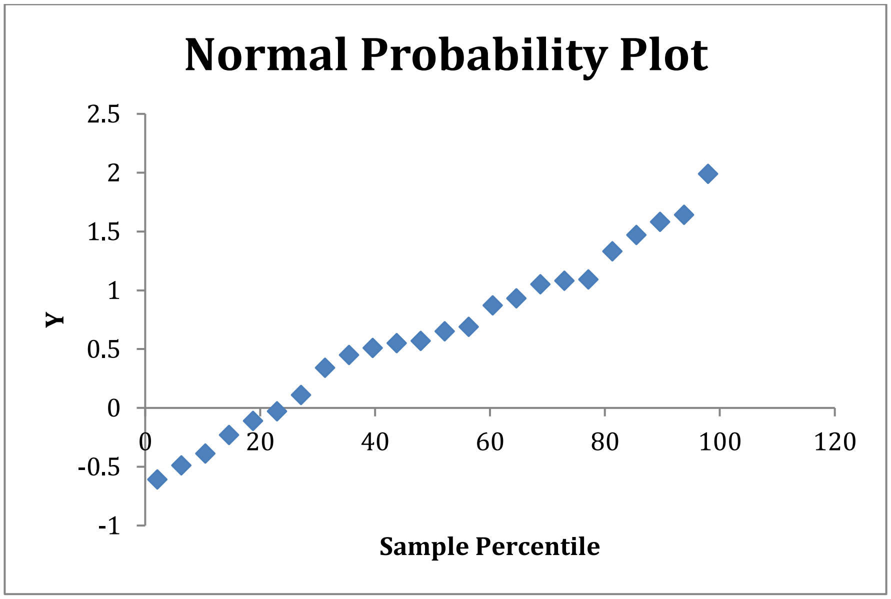
KOLMOGOROV-SMIRNOV TEST of NORMALITY for Drilling Process

VARIATION	CUMULATIVE	EXPECTED	(Rank-1)/n	NORM.S.INV	ACTUAL	DIFFERENCE
-2.22	1	0.019230769	0	-2.069901831	0.008565034	0.008565034
-1.3	2	0.038461538	0.019230769	-1.768825039	0.068736494	0.049505724
-1.28	3	0.057692308	0.038461538	-1.574444965	0.071360672	0.032899133
-1.22	4	0.076923077	0.057692308	-1.426076872	0.079695141	0.022002833
-1.22	5	0.096153846	0.076923077	-1.303782672	0.079695141	0.002772064
-1.21	6	0.115384615	0.096153846	-1.198379702	0.081153067	0.015000779
-1.16	7	0.134615385	0.115384615	-1.104835744	0.08874585	0.026638765
-0.89	8	0.153846154	0.134615385	-1.020076233	0.139007756	0.004392371
-0.86	9	0.173076923	0.153846154	-0.942075775	0.145601841	0.008244312
-0.77	10	0.192307692	0.173076923	-0.869423773	0.166628423	0.0064485
-0.72	11	0.211538462	0.192307692	-0.801094529	0.179116916	0.013190776
-0.67	12	0.230769231	0.211538462	-0.736315917	0.192178415	0.019360046
-0.67	13	0.25	0.230769231	-0.67448975	0.192178415	0.038590816
-0.42	14	0.269230769	0.25	-0.615141105	0.265755202	0.015755202
-0.42	15	0.288461538	0.269230769	-0.557884763	0.265755202	0.003475567
-0.33	16	0.307692308	0.288461538	-0.502402223	0.295360354	0.006898815
-0.29	17	0.326923077	0.307692308	-0.448425483	0.308988056	0.001295748
-0.27	18	0.346153846	0.326923077	-0.395725296	0.315903444	0.011019632
-0.19	19	0.365384615	0.346153846	-0.344102463	0.344194278	0.001959568
-0.16	20	0.384615385	0.365384615	-0.293381232	0.355043402	0.010341213
-0.11	21	0.403846154	0.384615385	-0.243404178	0.373385274	0.011230111
-0.1	22	0.423076923	0.403846154	-0.194028142	0.377089894	0.02675626
-0.07	23	0.442307692	0.423076923	-0.145120941	0.388270558	0.034806365
0.09	24	0.461538462	0.442307692	-0.096558615	0.449254615	0.006946923
0.12	25	0.480769231	0.461538462	-0.048223074	0.460870298	0.000668164
0.21	26	0.5	0.480769231	0	0.495878475	0.015109244
0.23	27	0.519230769	0.5	0.048223074	0.503671918	0.003671918
0.28	28	0.538461538	0.519230769	0.096558615	0.523142894	0.003912125
0.29	29	0.557692308	0.538461538	0.145120941	0.527031955	0.011429583
0.34	30	0.576923077	0.557692308	0.194028142	0.54643127	0.011261037
0.38	31	0.596153846	0.576923077	0.243404178	0.561873567	0.01504951
0.41	32	0.615384615	0.596153846	0.293381232	0.573395077	0.022758769
0.43	33	0.634615385	0.615384615	0.344102463	0.581042062	0.034342553
0.82	34	0.653846154	0.634615385	0.395725296	0.7208955	0.086280115
0.87	35	0.673076923	0.653846154	0.448425483	0.737071423	0.083225269
0.88	36	0.692307692	0.673076923	0.502402223	0.740248126	0.067171203
0.93	37	0.711538462	0.692307692	0.557884763	0.755829377	0.063521685
0.95	38	0.730769231	0.711538462	0.615141105	0.761917775	0.050379313
0.99	39	0.75	0.730769231	0.67448975	0.773841014	0.043071783

KOLMOGOROV-SMIRNOV TEST of NORMALITY for Drilling Process						
VARIATION	CUMULATIVE	EXPECTED	(Rank-1)/n	NORM.S.INV	ACTUAL	DIFFERENCE
1.05	40	0.769230769	0.75	0.736315917	0.79107674	0.04107674
1.13	41	0.788461538	0.769230769	0.801094529	0.812811719	0.04358095
1.18	42	0.807692308	0.788461538	0.869423773	0.825657812	0.037196274
1.29	43	0.826923077	0.807692308	0.942075775	0.851893726	0.044201418
1.33	44	0.846153846	0.826923077	1.020076233	0.860742446	0.03381937
1.38	45	0.865384615	0.846153846	1.104835744	0.871287859	0.025134013
1.44	46	0.884615385	0.865384615	1.198379702	0.883194158	0.017809542
1.54	47	0.903846154	0.884615385	1.303782672	0.901263515	0.01664813
1.63	48	0.923076923	0.903846154	1.426076872	0.915696676	0.011850522
1.65	49	0.942307692	0.923076923	1.574444965	0.918677424	0.004399499
1.73	50	0.961538462	0.942307692	1.768825039	0.929809354	0.012498338
2.13	51	0.980769231	0.961538462	2.069901831	0.968915197	0.007376736
2.32	52	1	0.980769231		0.979850559	0.000918672

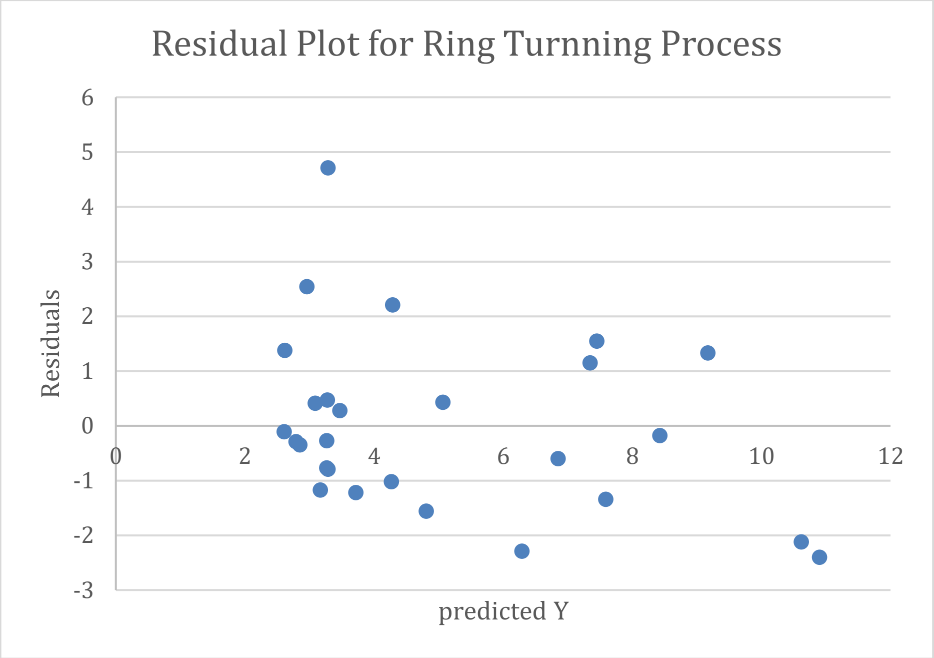
Residual Analysis for Plate Turning Process

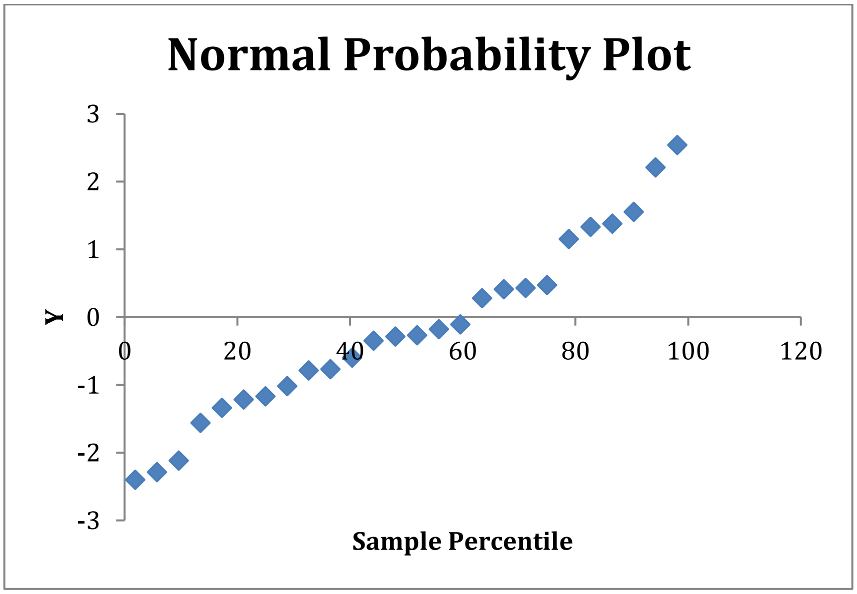




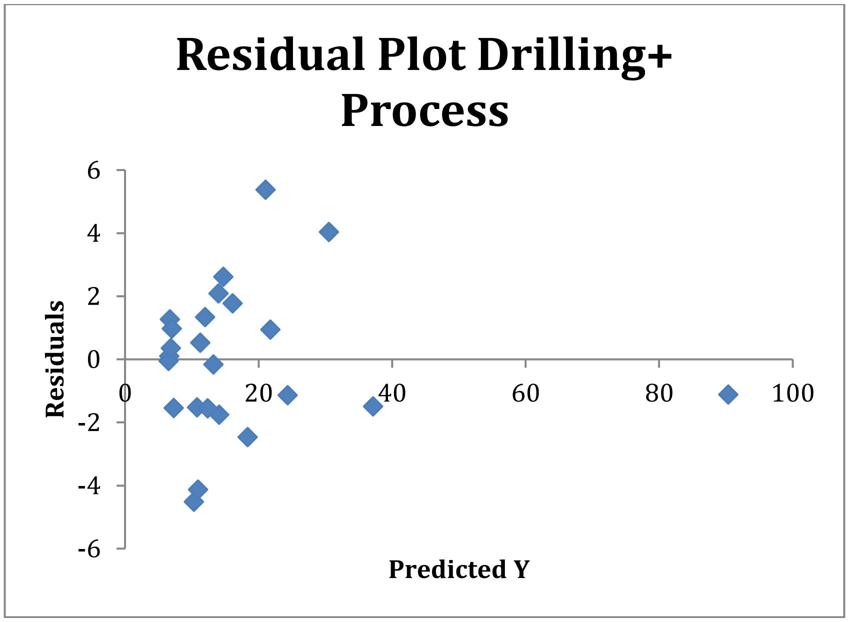
COUNT	26
MEAN	0.306538462
SD	1.37822
MAXIMUM	0.17610
STATISTIC VALUE	0.17610
CRITICAL VALUE	0.25957
Normal Distribution	

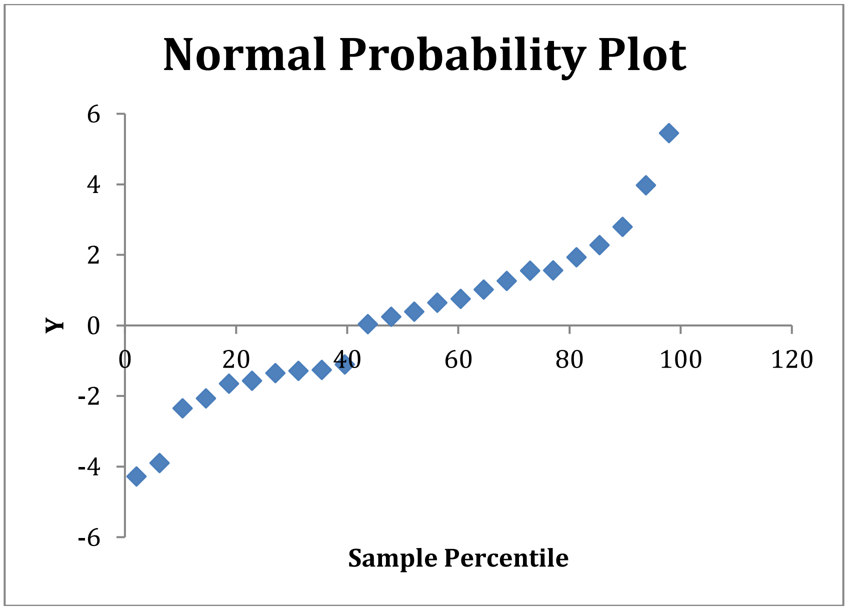
Residual Analysis for Ring Turning Process





COUNT	27
MEAN	-0.000740741
SD	1.60644
MAXIMUM	0.08845
STATISTIC VALUE	0.08845
CRITICAL VALUE	1.35810
Normal Distribution	





COUNT	24
MEAN	0.125416667
SD	2.33316
MAXIMUM	0.07677
STATISTIC VALUE	0.07677
CRITICAL VALUE	0.29405
Normal Distribution	

Appendix D

Cost Driver and Cost Driver Rates

Cost Driver and Cost Driver Rates for Parametric Activity Based Costing Using Actual Values

Activities	Total Cost of activity	Cost Drivers	P1	Total Cost driver Proportion	Cost Driver Rates
Machining	$17,964.99	Machining hrs.	31	362.38	49.58
Engineering	$4,900.00	Engineering hrs.	61.48	522.64	9.38
Maintaining	$2,351.45	Maintenance hrs.	27	215	10.94
Material handling	$2,041.67	Production runs	1	17	120.10
Control	$1,346.00	Production runs	1	17	79.18
Shipping	$1,713.23	Production runs	1	17	100.78
Inventory	$3,950.16	Parts number	3	48	82.30
Quality Control	$2,396.54	Engineering hrs.	43	328	7.31
Others	$4,501.05	Production runs	1	17	264.77

Cost Driver and Cost Driver Rates for Parametric Activity Based Costing Using Estimated Values

Activities	Total Cost of activity	Cost Drivers	P1	Total Cost driver Proportion	Cost Driver Rates
Machining	$17,964.99	Machining hrs.	30	367.98	48.82
Engineering	$4,900.00	Engineering hrs.	46.48	402.14	12.18
Maintaining	$2,351.45	Maintenance hrs.	27	203	11.58
Material handling	$2,041.67	Production runs	1	17	120.10
Control	$1,346.00	Production runs	1	17	79.18
Shipping	$1,713.23	Production runs	1	17	100.78
Inventory	$3,950.16	Parts number	3	48	82.30
Quality Control	$2,396.54	Engineering hrs.	37	252	9.51
Others	$4,501.05	Production runs	1	17	264.77

Cost Driver and Cost Driver Rates for Parametric Activity Based Costing Considering Unutilized Capacity Using Actual Values

Activities	Total Cost of activity	Cost Drivers	P1	Total Cost driver Proportion	Cost Driver Rates
Machining	$17,964.99	Machining hrs.	31	362.38	49.58
Engineering	$2,732.77	Engineering hrs.	61.48	522.64	5.23
Maintaining	$2,351.45	Maintenance hrs.	27	215	10.94
Material handling	$2,041.67	Production runs	1	17	120.10
Control	$1,346.00	Production runs	1	17	79.18
Shipping	$1,713.23	Production runs	1	17	100.78
Inventory	$3,950.16	Parts number	3	48	82.30
Quality Control	$1,640.00	Engineering hrs.	43	328	5.00
Others	$4,501.05	Production runs	1	17	264.77

Cost Driver and Cost Driver Rates for Parametric Activity Based Costing Considering Unutilized Capacity Using Estimated Values

Activities	Total Cost of activity	Cost Drivers	P1	Total Cost driver Proportion	Cost Driver Rates
Machining	$17,964.99	Machining hrs.	30	367.98	48.82
Engineering	$2,169.70	Engineering hrs.	46.48	402.14	5.40
Maintaining	$2,351.45	Maintenance hrs.	27	203	11.58
Material handling	$2,041.67	Production runs	1	17	120.10
Control	$1,346.00	Production runs	1	17	79.18
Shipping	$1,713.23	Production runs	1	17	100.78
Inventory	$3,950.16	Parts number	3	48	82.30
Quality Control	$1,260.00	Engineering hrs.	37	252	5.00
Others	$4,501.05	Production runs	1	17	264.77

Appendix E

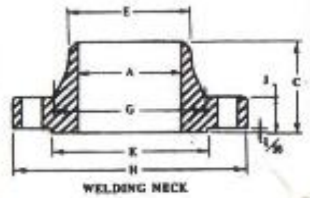
Weld-Neck Vs. Slip-On Flanges Standard Information

300 lb. FLANGES

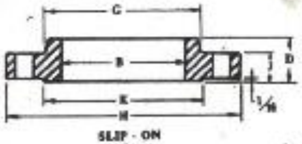
STANDARD ANSI B16.5

. All dimensions are in inches.
. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
. The 1/16 in. raised face is included in dimensions C, D and J.
. The lengths of stud bolts do not include the height of crown.
. Bolt holes are 1/8 in. larger than bolt diameters.
. Flanges bored to dimensions shown unless otherwise specified.
. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

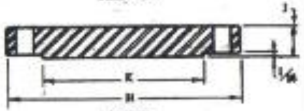
SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



WELDING NECK



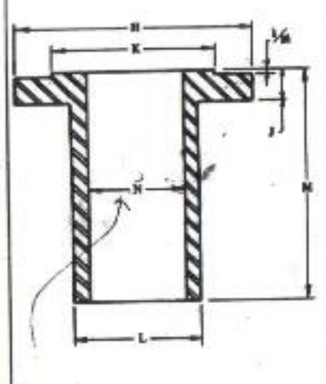
SLIP - ON



BLIND

minal ipe ize	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2	.62	.88	2 1/16	7/8	.84	1 1/2	3 3/4	9/16
3/4	.82	1.09	2 1/4	1	1.05	1 7/8	4 5/8	5/8
1	1.05	1.36	2 7/16	1 1/16	1.32	2 1/8	4 7/8	11/16
1 1/4	1.38	1.70	2 9/16	1 1/16	1.66	2 1/2	5 1/4	3/4
1 1/2	1.61	1.95	2 11/16	1 3/16	1.90	2 3/4	6 1/8	13/16
2	2.07	2.44	2 3/4	1 5/16	2.38	3 5/16	6 1/2	7/8
2 1/2	2.47	2.94	3	1 1/2	2.88	3 15/16	7 1/2	1
3	3.07	3.57	3 1/8	1 11/16	3.50	4 5/8	8 1/4	1 1/8
3 1/2	3.55	4.07	3 3/16	1 3/4	4.00	5 1/4	9	1 3/16
4	4.03	4.57	3 3/8	1 7/8	4.50	5 3/4	10	1 1/4
5	5.05	5.66	3 7/8	2	5.56	7	11	1 3/8
6	6.07	6.72	3 7/8	2 1/16	6.63	8 1/8	12 1/2	1 7/16
8	7.98	8.72	4 3/8	2 7/16	8.63	10 1/4	15	1 5/8
10	10.02	10.88	4 5/8	2 5/8	10.75	12 5/8	17 1/2	1 7/8
12	12.00	12.88	5 1/8	2 7/8	12.75	14 3/4	20 1/2	2
14	13.25	14.14	5 5/8	3	14.00	16 3/4	23	2 1/8
16	15.25	16.16	5 3/4	3 1/4	16.00	19	25 1/2	2 1/4
18	17.25	18.18	6 1/4	3 1/2	18.00	21	28	2 3/8
20	19.25	20.20	6 3/8	3 3/4	20.00	23 1/8	30 1/2	2 1/2
22	21.25	22.22	6 1/2	4	22.00	25 1/4	33	2 5/8
24	23.25	24.25	6 5/8	4 3/16	24.00	27 5/8	36	2 3/4
26	To be speci-fied	26.25	7 1/4	7 1/4	26 1/4	28 3/4	38 1/4	3 1/8
28		28.25	7 3/4	7 3/4	28 1/4	30 1/2	40 3/4	3 3/8
30		30.25	8 1/4	8 1/4	30 1/4	32 9/16	43	3 5/8

300 lb.
LONG WELDING NE



1. All dimensions are in inches.
2. Material most commonly used, steel SA 105. Available also in steel, alloy steel and non-ferrou
3. The 1/16 in. raised face is incl dimensions J and M.
4. The length of bolts do not incl height of crown.
5. Bolt holes are 1/8 in. larger th diameters.
6. Dimensions, M (length of weldin are based on data of major m turers. Long welding necks wit longer than listed are available on speci order.

SEE FACING PAGE FOR DIMENSION

Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	No
				1/16 Raised Face	Ring Joint				
K			BCD			L	M	N	
1 3/8	4	1/2	2 5/8	2 3/4	3			same as nominal pipe size	
1 11/16	4	5/8	3 1/4	3	3 1/2				
2	4	5/8	3 1/2	3 1/4	3 3/4	2 1/8	9		
2 1/2	4	5/8	3 7/8	3 1/4	3 3/4	2 1/2			
2 7/8	4	3/4	4 1/2	3 3/4	4 1/4	2 3/4			
3 5/8	8	5/8	5	3 1/2	4 1/4	3 5/16			
4 1/8	8	3/4	5 7/8	4	4 3/4	3 15/16			
5	8	3/4	6 5/8	4 1/4	5	4 5/8			
5 1/2	8	3/4	7 1/4	4 1/2	5 1/4	5 1/4			
6 3/16	8	3/4	7 7/8	4 1/2	5 1/4	5 3/4	12		
7 5/16	8	3/4	9 1/4	4 3/4	5 1/2	7			
8 1/2	12	3/4	10 5/8	5	5 3/4	8 1/8			
10 5/8	12	7/8	13	5 1/2	6 1/4	10 1/4			
12 3/4	16	1	15 1/4	6 1/4	7	12 5/8			
15	16	1 1/8	17 3/4	6 3/4	7 1/2	14 3/4			
16 1/4	20	1 1/8	20 1/4	7	7 3/4	16 3/4	10-14		
18 1/2	20	1 1/4	22 1/2	7 1/2	8 1/4	19			
21	24	1 1/4	24 3/4	7 3/4	8 1/2	21			
23	24	1 1/4	27	8 1/4	9	23 1/8			
25 1/4	24	1 1/2	29 1/4	8 3/4	9 3/4				
27 1/4	24	1 1/2	32	9 1/4	10 1/4	27 5/8			
29 1/2	28	1 5/8	34 1/2	10	11	29 1/2			
31 1/2	28	1 5/8	37	10 1/2	11 1/2	31 1/2			
33 3/4	28	1 3/4	39 1/4	11 1/4	12 1/4	33 3/4			

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Biographical Information

Zahra Banakar, interest in pursuing the Industrial, Manufacturing and Systems Engineering professionally began in 2007 with the beginning of master's coursework and research in Industrial and Manufacturing Engineering at the University of Malaya (UM), Department Engineering. During this time, she developed her knowledge, focusing mostly on the development and usage of the best strategic multi-criteria decision-making processes in order to select the most appropriate technology that achieves the organization's objectives, and maximizes the benefits of the technology. This research indicate development of an Analytical Hierarchy Process (AHP) decision-making model for the selection of Advanced Manufacturing Technology (AMT) has been influential to a diverse range of projects.

After completing her master degree at the University of Malaya in 2010, she turned her focus to the decision-making model based on organization merging probabilities while she started her master's degree and research in Engineering Management at the King's College University of London (KCL). Her research has particularly focused on the Bank mergers combining a discrete variant of the Smoluchowski coagulation equation with a reverse engineering method. This predictive model of bank mergers determines the next period financial behavior of bank mergers within a statistical-oriented setting. Since her career goal is to become a successful and reputed professional, she likes to fortify herself with professional expertise in the major areas of Industrial Engineering and she earned Ph.D. degree from University of Texas at Arlington (UTA) in 2018. As a doctoral degree candidate she continue her research on the design of cost-saving decision-making business models. Through this work, estimating production costs for new product development is conducted and total cost estimation accuracy improved through parametric activity based costing.