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# A parametric model for cost estimation in bidding activities


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*To my sisters.*

*An older sister is a friend and defender, a listener, conspirator, a counsellor and a sharer of delights. And sorrows too.*
*Pam Brown*

*I love you.*

*"Sono stati giorni magnifici" concluse felice "e sento che questo viaggio ha segnato una nuova epoca nella mia vita.*
*Però la parte migliore è stata tornare a casa"*
*L.M. Montgomery, Anna dai capelli rossi*

# Abstract

When is an New Product Development (NPD) successful? Three levers must be kept under control: customer satisfaction, Time To Market (TTM) minimization and cost minimization.

Cost is a crucial factor that contributes to the success of production and delivery of functional needs, especially within today's highly competitive market. To survive and thrive against competition, companies are increasingly required to improve their quality, flexibility, product variety and novelty, while consistently reducing the costs. One of the difficult tasks undertaken by designers is to evaluate the cost of a new design. When designers start to design a new product, cost is a critical factor in determining whether the product will be viable or not. Nowadays a company needs to estimate the cost of the product and the confidence of that estimate in order to start to design and manufacture a product in detail. Good cost estimation plays a significant part in the performance and effectiveness of a business enterprise as overestimation can result in loss of business and goodwill, whereas underestimation may lead to financial loss to the enterprise.

The last automotive trends stress the minimization of TTM. So the OEM resorts to outsourcing as a means of reducing operating costs, reducing time to market, increasing flexibility and acquiring new skills from outside (Momme J., 2001). However, although this option produces undisputed benefits, companies have faced all the limits and problems that this choice implies. In fact, outsourcing is a complex process, which involves many corporate functions and which, if treated superficially, can generate innumerable costs (Bettis, R., Bradley, S. and Hamel, G. 1992).

Before a supply relationship is established in a consolidated way with the customer, there are the evaluation and selection phases of the supplier. Supplier selection strategy is a critical issue in a supply chain management (SCM) system. Its outcomes impact relationships, profitability and reputation of businesses. Most of supplier selection processes are based on bidding and negotiation mechanism (Cakravastia & Nakamura, 2002; Cakravastia & Takahashi, 2004; Cakravastia, Toha, & Nakamura, 2002; Murthy, Soni, & Ghosh, 2004; Sadeh & Sun, 2003). The problem treated within the thesis occurs during the bidding phase, where the customer suffers from a high information asymmetry towards the supplier, especially if the supplier is new, and often relies on his personal experience for negotiation. The customer is missing an intelligent tool that supports him during this phase, forecasting the preference of opponents, improving negotiation decision quality and shorten required negotiation time.

There are not many examples in the literature that solve this problem. This thesis aims to build a mathematical tool that allows the prediction of the price proposed by suppliers during the bidding phase. The aim is on the one hand to reduce the information asymmetry and on the other to speed up the negotiation process.The price is one of the criteria used for the selection of suppliers, therefore its forecast would allow the customer to have a reference benchmark for their evaluation. It would also have more chance of avoiding their inefficiencies.

This process becomes even more critical if placed in the context of the automotive market. With the reduction of the TTM, the time that OEM companies have to present their offers during the car maker quotation phase, is diminished. Consequently, the time it takes for OEM suppliers to submit their offers also decreases. Often the OEMs, having to collect the offers of the suppliers, cannot get an accurate estimate of the cost of the product in time. This entails a slowdown in the process of assessing its feasibility but also fewer opportunities for its redesign. Overall, the quality of the offer is negatively affected and so the OEM risks not winning the car maker's quotation.

A mathematical tool is even more necessary if the company adopts an estimate by analogy to estimate the costs of the components purchased externally. More scientific articles over time have shown that an estimate by analogy leads to much larger errors than mathematical estimates. The estimate by analogy is based on one's personal experience, this makes the result unreliable. This must be avoided especially during the conceptual design phase.

In this dissertation was built a parametric model that tries to incorporate all the factors that could influence the final cost, both those due to the characteristics of the product and those due to variables independent of the component production process. So, the cost estimation phase that leads to the assessment of the feasibility of a project will no longer depend on the personal experience of a company employee or on the arrival of the suppliers' offers. The process will be improved in both quality and speed.

The final part shows the differences between the parametric and the analogical model, highlighting the benefits brought in the conceptual design phase. A statistical approach also allows the future development of other cost prediction models such as neural networks, which are not applicable to date due to the limited historical data.

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# Chapter 1

# Problems in the bidding phase

When is an New Product Development (NPD) successful? Three levers must be kept under control: customer satisfaction, Time To Market (TTM) minimization and cost minimization.

Cost is a crucial factor that contributes to the success of production and delivery of functional needs, especially within today's highly competitive market. To survive and thrive against competition, companies are increasingly required to improve their quality, flexibility, product variety and novelty, while consistently reducing the costs. In short, customers expect higher quality at an ever-decreasing cost. Companies that are unable to provide detailed and meaningful cost estimates at the early development phases have a significantly higher percentage of programs behind schedule and with higher development costs than those that can provide completed cost estimates (Wang and Potter 2007).

One of the difficult tasks undertaken by designers is to evaluate the cost of a new design. When designers start to design a new product, cost is a critical factor in determining whether the product will be viable or not. Nowadays a company needs to estimate the cost of the product and the confidence of that estimate in order to start to design and manufacture a product in detail. Reliable cost estimation of future products plays a significant part for designers in avoiding investing much time and losing considerable sums on non-economically viable products. Good cost estimation plays a significant part in the performance and effectiveness of a business enterprise as overestimation can result in loss of business and goodwill, whereas underestimation may lead to financial loss to the enterprise[17].

As regards the minimization of the TTM, however, companies have increasingly relied on outsourcing. In fact, globalization and technological innovations have allowed the creation of new markets and the entry of new competitors into existing ones, leading to an increase in competitive pressure on companies (Sanchez R., 1997), which, consequently, had to make in the face of these changes with greater organizational adaptability and flexibility, proposing new solutions both at an organizational and strategic level. Thus, the decision to resort to outsourcing as a means of reducing operating costs, reducing time to market, increasing flexibility and acquiring new skills from outside (Momme

J., 2001) was affirmed. However, although this option produces undisputed benefits, companies have faced all the limits and problems that this choice implies. In fact, outsourcing is a complex process, which involves many corporate functions and which, if treated superficially, can generate innumerable costs (Bettis, R., Bradley, S. and Hamel, G. 1992). Before a supply relationship is established in a consolidated way with the customer, there are the evaluation and selection phases of the supplier. Supplier selection strategy is a critical issue in a supply chain management (SCM) system. Its outcomes impact relationships, profitability and reputation of businesses. Most of supplier selection processes are based on bidding and negotiation mechanism (Cakravastia & Nakamura, 2002; Cakravastia & Takahashi, 2004; Cakravastia, Toha, & Nakamura, 2002; Murthy, Soni, & Ghosh, 2004; Sadeh & Sun, 2003).

The problem treated within the thesis occurs during the bidding phase, where the customer suffers from a high information asymmetry towards the supplier, especially if the supplier is new, and often relies on his personal experience for negotiation. The customer is missing an intelligent tool that supports him during this phase, forecasting the preference of opponents, improving negotiation decision quality and shorten required negotiation time. This tool can be found among the techniques proposed in cost engineering, which allow a predictive estimate of the cost of products purchased externally.

## 1.1 Cost Engineering in the bidding process

There are few examples in the literature dealing with this problem. Zeng and Sycara propose a sequential decision-making negotiation model, which provides an adaptive, multi-issue negotiation model capable of exhibiting a rich set of negotiation behaviors (Zeng & Sycara, 1998). Faratin et al. present a formal model of negotiation between autonomous agents, which defines a range of strategies and tactics that agents can employ to generate initial offers, evaluate proposal and offer counter proposals (Faratin, Sierra, & Jennings, 1998). Ren and Anumba state that multi-agent system (MAS) offer an innovative approach towards reducing the tremendous time and human resources invested in negotiation and present an agent learning approach integrated in MAS for construction claims negotiation (Ren & Anumba, 2002). To increase the social welfare of agents, Faratin et al. present a trade-off strategy where multiple negotiation decision variables are traded-off against one another (Faratin, Sierra, & Jennings, 2002). Following Faratin et al. (2002), Jonker and Robu model a mechanism in which agents are able to use any amount of incomplete preference information revealed by the negotiation partner to improve the efficiency of the reached agreements (Jonker & Robu, 2004).

There are mainly articles that deal with the strategies to be used during the negotiation phase. Other articles deal with cost engineering in the bidding phase but from the supplier's point of view. In fact, the supplier knows that an accurate bid price estimate is essential to continue the negotiation and have a good profit but a detailed cost estimation process is both costly and time consuming (PEH, 2008). However, in practice, the available bid-estimation time is often insufficient (Akintoye & Fitzgerald, 2000). Thus, conducting comprehensive and detailed cost estimations are not always possible. Thus, they are usually to use the cost estimation methods that do not take much time and can approximate a proper bid price, can help a contractor in making bid-price decisions when the available bid estimation time is insufficient.

The customer's point of view within the negotiation is not treated. There are no examples of how the customer can predict the future cost of the product supplied to him through cost estimation methods in order to reduce the information asymmetry, have a comparison benchmark and be able to negotiate the best possible price with the supplier.

Except for the article by C. C. Lee e C. Ou-Yang "A neural networks approach for forecasting the supplier's bid prices in supplier selection negotiation process". They have developed an artificial neural network-based predictive model with application for forecasting the supplier's bid prices in supplier selection negotiation process (SSNP). By means of the model, demander can foresee the relationship between its alternative bids and corresponding supplier's next bid prices in advance. The purpose of this paper is applying the model's forecast ability to provide negotiation supports or recommendations for demander in deciding the better current bid price to decrease meaningless negotiation times, reduce procurement cost, improve negotiation efficiency or shorten supplier selection lead-time in SSNP.[12] The artificial neural network-based predictive model, will be described below[12]:

1. *Choice of the input factors.*
   To do this prediction, it needs to describe which factors are relevant to the supplier's bid prices. In supplier selection negotiation process, the bidding strategies of suppliers are unknown to demander. The information that demander can gather are just from environment and the offers of both parties from past deal records. For environment information, such as inventory level ($inv_s$), scheduled production plan ($sd_s$) and surplus capacity of scheduled production plan ($q_s^{sd}$) of suppliers, it is assumed that the information are known to demander through the information sharing in supply chain system. In general, the negotiation process is interactive. That is, the bid prices of both sides are influenced each other. Therefore, in the utilization of past offer records, the current ($p_d(t-1)$) and last bid prices of demander ($p_d(t-2)$) and the current bid price of supplier ($p_s(t-1)$) are necessary to forecast the next bid price of supplier $s$ ($p_s(t)$). In addition, the other factors that affect the supplier's bid price are order quantity ($q_d$) and due date (dd) due to they result in the capacity load of suppliers. Summarize the above descriptions, it can be concluded that $p_s(t)$ is depended on environment (or non-offer) information: $inv_s$, $q_s^{sd}$, $sd_s$ and offer information: $q_d$, dd, t, $p_d(t-1)$, $p_d(t-2)$ and $p_s(t-1)$. With the conclusion, there are nine factors being used for the inputs to the artificial neural network proposed in this paper and the output is $\hat{\mathrm{p}}_s(t)$, the predicted bid price of supplier $s$. The artificial neural network-based (ANN) predictive concept model is depicted

in Fig.1.1 and which is developed under following assumptions:

- Demander uses this model to predict bid prices of a given supplier.
- The given supplier offers first then both parties take turns.
- Non-offer information, $inv_s$, $q_s^{sd}$, $sd_s$ of suppliers can be known by demander due to the information are shared in supply chain system.
- The supplier selection negotiation process is interactive.

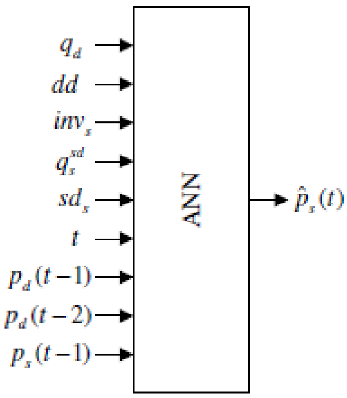


Figure 1.1: Artificial neural network-based predictive concept model.[12]

2. *Available input information to the ANN predictive model.*
The available input information to the ANN predictive model including non-offer information and offer information. All the non-offer information: $inv_s$, $q_s^{sd}$, $sd_s$ and two of offer information: $q_d$, dd are determined at the initial negotiation round and not changing during the supplier selection negotiation proceeding. However, t, $p_d(t-1)$, $p_d(t-2)$ and $p_s(t-1)$ are variant in the negotiation process round by round. The supplier selection negotiation process is initiated by means of demander offering $q_d$ and dd of a given order item to SSAM (Supplier Selection Auction Market). After that, starting with the supplier's offer then both-side parties takes turns to offer their own bid prices until negotiation outcome is got. The situation of applying the ANN model is before demander offering its bid price at each round. In the first prediction ($\hat{p}_s(1)$), the available input information for inputs to the ANN model are just $q_d$, dd, $inv_s$, $q_s^{sd}$, $sd_s$ and t since none of bid is offered before this time. When $t = 2$, in addition to previous available input information, $p_s(1)$and $p_d(1)$ are another information that can be used for inputs to the ANN model to predict $p_s(2)$. After $t = 2$, the nine input information can be completely gathered to predict the following $p_s(t)$, t = 3,4, . . . ,$t^{max}$. It is clear that $p_d(t-1)$ is a decision variable of demander in forecasting the next supplier's $p_s(t)$ at each round except the first. In other words, demander can adjust $p_d(t-1)$ in a rational range, such as not greater than its reservation price to estimate the supplier's next bid price $p_s(t)$. This function provides demander a guideline to forecast the required negotiation rounds and agreed prices according to varying decision alternatives

$p_d(t-1)s$ in the negotiation. Demander can choose the best decision alternative consistent with its objective.

3. *Architecture of the ANN predictive model.*
   As presented in Fig.1.2, the ANN predictive model is constructed as 9-12-1 multilayer perceptrons (MLPs) architecture. The number of neurons in input layer is equal to the number of classifications of available input information. In hidden layer, the number of neurons, 12 is obtained by means of trial-and-error experiments. Corresponding to $\hat{p}_s(t)$, the neuron in output layer is just one. In the networks, all neurons in one layer are only fully connected to all neurons in the next higher layer except the output layer. The activation functions of neurons in input layer are linear, whereas the neurons in hidden and output layer have sigmoidal signal functions since the bid prices of both-side parties are greater than zero.

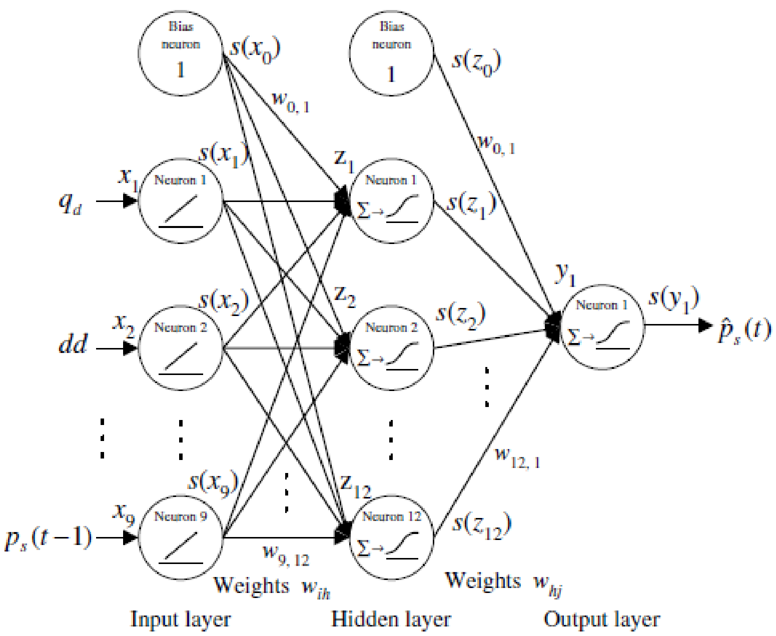


Figure 1.2: The ANN predictive model architecture.[12]

The results of training and test performance shown that the ANN predictive model being a good forecasting method in complex and variant negotiation environment even if the underlying relationship between inputs and outputs is nonlinear. Then, the trained ANN predictive model is applied to two negotiation scenarios and provides decision support to demander in negotiation process[12].

- **Scenario 1**
  In this scenario, the negotiation environment is set to be a normal condition: $q_d = 200$, $dd = 7$, $invs_s = 50$, $q_s^{sd} = 8$, $sd_s = 10$ and the negotiation objective of demander is achieving agreement with lower deal price at a

round less than $t_{max} = 10$. The purpose of scenario 1 is to address the forecast function of the ANN predictive model, which can assist demander to select proper bid from alternatives. In Table 3.3, three alternative bids denote the minimum, middle and maximum of a bid price range and they are generated by demander's preference. Note that the number of alternative bids is not fixed, it depends on demander's need. Generally, if demander has no intention to finish the deal at a specific round t, the alternative bids should be less than $p_s(t)$. Before demander bidding at each round, the trained ANN predictive model can be used to foresee the likely relationship between the current bid price of demander $p_d(t)$ and next bid price of supplier $\hat{p}_s(t+1)$.

That is, the model can provide different estimated results of alternative bids for negotiation support to demander. As Table 3.3 shown, when $t = 1$, forecast starts from the first round $\hat{p}_s(1) = 30.0435$ before supplier offering. After supplier offered $p_s(1) = 29.3764$, it is the turn for demander makes its first bid. Before offering bid, demander takes three alternative bids: 18, 22, 26 and uses the ANN predictive model to forecast their results (i.e., $\hat{p}_s(t+1)$). After obtaining the estimated results: 26.8684, 26.9962 and 27.5499, demander selects the proper one: 18 that consistent with its objective and offers to supplier. Repeating the process, the negotiation is finished at the sixth round and the agreed price is 22.5. Note that if demander expects to finish this deal early, it can select the higher bid price from alternatives. For instance, at round 3, if it selects bid price 25 instead of 21 then the deal would be finished at round 4. From Table 3.3, it is clear that the ANN predictive model can start forecasting from the first round even some offer information are not available. This ability is superior to the model of Carbonneau et al. (2008) that starts to predict opponent's offer from the third round. The ability is useful when demander expects to finish deal at early round.

- **Scenario 2**
  The scenario sets the negotiation environment in an urgent condition: $q_d = 290$, $dd = 6$, $invs_s = 30$, $q_s^{sd} = 3$, $sd_s = 11$. In this condition, the reservation price of supplier is high and may be greater than demander's. The ANN predictive model can be applied in this situation to predict the possibility of reaching agreement in advance. For this purpose, $\hat{p}_s(t)$ replaces $p_s(t)$ for the input factor to ANN predictive model in each forecasting since $p_s(t)s$ not offer yet. In this scenario, since $\hat{p}_s(1) = 59.5861$ is high, demander releasing the most sincerity and offering bid price equals to his reservation price 30. Forecast going on, demander also offers bid prices 30 at each round because of the higher $\hat{p}_s(t)$. Finally, the forecast result reveals that the successful deal is impossible. To valid this result, an actual negotiation process with the same condition of this scenario is proceeding. All the predicted and actual supplier's bid prices in whole negotiation process are presented in Tables 3.4 and 3.5, respectively. Referring to Tables 3.4 and 3.5, the ANN predictive model indeed does the right forecast. This function can assist demander to save the meaningless

| t | $\hat{p}_s(t)$ | $p_s(t)$ | $p_d(t)$ | |
|---|---|---|---|---|
| | | | Alternative bids | $p_s(t+1)$ |
| 1 | 30,0435 | 29,3764 | 18 | 26,8684 |
| | | | 22 | 26,9962 |
| | | | 26 | 27,5499 |
| Select bid price: 18 | | | | |
| 2 | 26,8684 | 26,734 | 20 | 25,1483 |
| | | | 23 | 24,2395 |
| | | | 26 | 23,5134 |
| Select bid price: 20 | | | | |
| 3 | 25,1483 | 25,2067 | 21 | 24,066 |
| | | | 23 | 23,4322 |
| | | | 25 | 22,881 |
| Select bid price: 21 | | | | |
| 4 | 24,066 | 24,2021 | 22 | 23,042 |
| | | | 23 | 22,7235 |
| | | | 24 | 22,4259 |
| 5 | 22,7235 | 23,0911 | 22 | 22,7044 |
| | | | 22,5 | 22,5298 |
| | | | 23 | 22,3609 |
| Select bid price: 22,5 | | | | |
| 6 | 22,5298 | 22,4688 | | |

Table 1.1: The bid prices of both-side parties in a given negotiation process.[12]

negotiation time and then adopt the necessary actions, such as lengthening due date or increasing reservation price for promoting a successful deal.

| t | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\hat{p}_s(t)$ | 59,5861 | 50,1214 | 47,9665 | 45,8354 | 43,8067 | 41,978 | 40,4224 | 39,1662 | 38,1932 | 37,4629 |
| $p_d$ | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | |

Table 1.2: The predicted supplier bid prices of whole negotiation process.[12]

| t | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $p_s(t)$ | 55,2041 | 48,0844 | 46,1449 | 44,4055 | 42,7847 | 41,2466 | 39,7713 | 38,3464 | 36,9632 | 35,6155 |
| $p_d(t)$ | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | |

Table 1.3: The actual supplier bid prices of whole negotiaton process.[12]

In addition to the ability of forecasting supplier's next bid prices, the model can also estimate the possibility of successful deal under a given negotiation environment. These results had proved that artificial neural networks approach is an adaptive negotiation support tool for applying in the sophisticated and challenged supplier selection negotiation process to achieve the demander's objective[12].

## 1.2 Traditional and new procurement management

Supplier selection approach is changing since the market requirements have evolved. The market research for new suppliers is an on-going activity of high priority for all companies in order to optimize costs, and upgrade the variety and typology of their products range to match the market needs. Particularly nowadays, where product life cycle is generally very short (3 to 4 years) and new designs often require new materials or new technologies[2].

Procurement department's traditional purchasing strategy considers price as the most important attribute. It also prefers a multi-supplier strategy assigning not more than 15% to 25% of the purchase orders to the same supplier, which provides the company more negotiating power, and protects the company against sudden price increases, or modifications in the delivery time. Only in exceptional cases, when there are no other alternative (monopoly market) or when time and resources to find and negotiate alternative suppliers are not available, it is approved to assign the 100% of the articles to the same supplier. Therefore, to follow this strategy, the main effort is to find suppliers that comply with all requirements, and then select the provider based on the price (the only selection criteria). If there are mistakes in this decision, it can be solved by changing provider (which is considered feasible in an open competitive market), as the price of change the supply is relatively low[16].

However, new Procurement Management approaches are moving towards the usefulness of building up a stable relationship with specific suppliers closing strategic agreements bringing benefits of closer collaboration or finding sinergies. For example, the company can consider a relation of partnership or even a strategic alliance with a supplier who provides a part or a component and with which it wishes to have a durable cooperation. On the other hand, this company can have a hierarchical relation and a significant number of suppliers for the standard parts in order to establish a competition between them and therefore reduce the purchasing costs[2].

This new approach has clear advantages, as shown in Table **??**, although the supplier selection process can be very different.

The difference of the new approaches is to apply a policy of using a single supplier (or a few), for a relatively long term, with agreement of continuous improvement and to maintain this relationship as long as there are no problems in the relationship with the supplier. These policies not only reduce the costs of finding new suppliers but bring other advantages such as obtain a more uniform quality or achieve economies of scale, gather lessons learnt through the continuity of supply, and provide estability to the supplier which allow it to make specific investments to improve his level of service and be more competitive[16].

Reduce the number of suppliers increases the company dependence on them. Confidence on the supplier becomes a major issue. The supplier selection process becomes more complex. It is a multi-criteria decision-making

| Multiple Suppliers | Single supplier |
|---|---|
| Ensure continuity of supply in case of problems | Easier to coordinate the relationship and manage the flow of materials and information |
| Avoid the risk of excessive dependence of the provider if we become their only customer | Less time and effort to promote closer relations with the supplier and to evaluate their performance |
| Lower cost of change the supplier | Quality, deadlines and service more uniform |
| Be able to use smaller supplier whose capacity could not take all the demand | To improve supplier responsibility. To use better the supplier capacity |
| | Lower costs of transport and distribution, and the possibility of reducing the total stock in the process |
| | Higher purchase volume allows the use economies of scale and price reduction |
| | Possibility of concentrating equipments, tools or expensive specific installations in a single source |

Table 1.4: Advantages some supplier versus single supplier[16].

process, where there are quantitative and qualitative criteria. Therefore, it is not enough to develop a standard selection criteria and apply it indiscriminately in any situation, it is necessary to identify the criteria to be used as obtain reliable information of the suppliers . All this leads to increase the cost associated with switching supplier[16].

## 1.3 Thesis Aim and Objectives

The thesis develops around a PCE (Product Cost Estimation) application case of a company that produces OEM (Original Equipment Manufacturer) products. For strategic reasons, the company makes full use of outsourcing, so it is not vertically integrated. The main core activity is the R&D from which the projects for the different products come. The components of the product are designed internally but produced externally and then assembled within the company. So a second key activity is the logistics of the production lines.

This choice of outsourcing influences the costs and times of the product development process, becoming a driver for the evaluation of different design alternatives (Asiedu et al., 1998) or for exploring different product architectures and/or even in enhancing platform decisions. This is even more important if one takes into account that the early design phases are the ones in which the chance to influence costs is the highest (Dowlatshahi, 1992), since the product concept is still being defined. 70 to 80% of the product cost is said to be committed by the end of the conceptual design stage. Therefore, it is important to estimate and optimize costs as early as possible since any changes during production are usually very costly. Because of the importance of the conceptual design, cost estimation, at this stage, should be precise and available as soon as possible and provide valuable information to product designers.

It is during the case study company's product development process that the illustrated bidding problem arises. The company buying components externally, has difficulties when evaluating the costs of the various design alternatives. Having to wait for the supplier offers to arrive, the cost estimation times for the new product are getting longer, making the company uncompetitive and unreactive. The aim of the thesis is to reduce the cost estimation times of new products by providing the company with a predictive method of estimating the costs of the components purchased externally. The benefits are multiple, the company disconnects from its suppliers, manages to be more competitive during the negotiation phase by reducing the information asymmetry, it reduces project design times. In addition, the cost obtained can be used as a benchmark for the evaluation of new suppliers and, at the same time, report any inefficiencies of suppliers with whom you have had long-term relationships.

To date, to obtain a predictive estimate, the case study company has adopted a method by analogy, that is, based on past offers from suppliers, it evaluates the cost of the new component by geometric similarity. The second objective of the thesis therefore, is also to offer the company a mathematical method that speeds up the process leading to more precise and reliable estimates. Despite this importance, having accurate cost estimates at the concept stage is very difficult. The available data are limited and this makes the estimating process extremely difficult. This will be evident during the development of cost estimation the model.

## 1.4 Thesis Structure

In summary, the Chapter 1 introduced the topic that will be at the center of the thesis: cost estimation during the bidding process. Once you understand and analyze the problem, the Chapter 2 starting from the literary revision offered by Niazi (2006), illustrates the most popular cost estimation methods currently available. Furthermore, particular attention was paid to the literary research of application cases as close as possible to the case study of the thesis. Nowadays, there are no totally identical cases to this proposed in the thesis, but a selection has been made based on criteria such as manufacturing industry and the material used for the estimated products.

The Chapter 3 starts with the central role of supplier in the NPD process. This helps to understand the different types of relationship that a customer has with is suppliers. It also proposes a literary review of the currently existing methods of evaluating and selecting suppliers. However, the chapter setting is totally different from the second one. The theory of the method is not illustrated, but the application cases belonging to the manufacturing industry that refer to each method are directly reported. This Chapter will put in evidence the lack of articles about the cost estimation during the bidding process.

The case study is introduced in the Chapter 4. Where the Automotive sector is first presented, so it's possible to understand what are the new market trends that influence companies' strategies. It is also useful for understanding how the company is located within the production chain. All this will provide a clearer and broader view on the origin of the problem presented by the company and on the motivation of the method chosen for its resolution. At the end there is a significant example about another case study found in literature. It helps to understand what the company want to do and future developments of cost model.

The cost estimation method chosen is analyzed in the Chapter 5. After a small theoretical introduction of the method, attention is focused on the decoupler which is the product chosen for the study. The reasons for choosing this product, the data collection and the structure of the dataset, which is the key to solving the case, will be illustrated.

The operational part is addressed in the Chapter 6 where the selected method is applied for all the product families chosen. After that, the results is exposed and an analysis on their reliability id made. The conclusion of the analysis includes comparisons between the different results that will be useful in order to understand where the analyzed case study turns.

The last Chapter offers a summary of what has been done in the previous chapters by comparing the proposed objectives with the results obtained, placing an emphasis also on the limits of this thesis. It also includes a discussion on future research opportunities in this field, in particular on the areas not yet addressed which, however, interest the majority of companies involved in innovative sectors.

# Chapter 2

# Cost Estimation Models

Product Cost Estimation has a long history and it has been investigated considering different aspects, getting specific attention in the last twenty years (Rush & Roy, 2000; Layer, et al., 2002; Newnes, et al., 2008). Actually, this theme is still a commonly debated topic in the literature (Xu, et al., 2012) and this is mainly due to its central role in affecting the performance of companies. Nowadays, a large quantity of methods and approaches is available, covering a broad range of applications in various sectors, for several products, components, processes, and purposes, as well as they are applied in different phases of product development process. Sometimes this variety can generate confusion about which method to choose for the case study.

The Adnan Niazi e Jian S. Dai (2006) [14] taxonomy is the center of the Chapter 2. It is the most utilized and accepted models' classification and for this reason it has been exposed in the first part of the chapter. The topic is deepened in the second part, that illustrates all the methodologies that have been widely used in the past. A final paragraph collects different practical examples of the methods application in the manufacturing industry. The Chapter 2 objective is to help to understand which method is correct to apply to the case study in exam also based on available data.

## 2.1 Cost Estimation Models Objectives

The key to thrive for a manufacturing enterprise in the twenty-first century is based on product quality, competitive cost, fast delivery, and flexibility. On the other hand, factors such as globalization, and mass customization, put an extra pressure on a business enterprise to survive and remain profitable at the same time. Although an innovative approach and a new product development process may attempt to deal with issues such as flexibility and product quality, they may still be time consuming and less cost effective. In addition, the prospective end user of a would-be product often demands a price quote as soon as possible, sometimes even unconcerned and oblivious of factors such as the extent of the customization, the nature of the data required, and the design complexity. To make matters worse, often a manufacturer ignores the significant factors, such as design module availability, manufacturability, and the level of accuracy required for processing time estimation. The overall situation, therefore, could either lead to an underestimation resulting in a profit loss and a blow to operational targets or a more profound strategic damage caused by overestimation leading toward the loss of customer goodwill and market share [14].

These are the fundamental points in a company, for this reason they are considered from the early phase of product development process, in which the R&D department is the most involved. Being constituted mainly by people with technical or scientific competencies, during the new product development (NPD) process this unit traditionally puts much more emphasis on the technologically innovative contents and on the absolute performance of the product, than on the impact of the adopted solutions on the economics and on related figures (like the manufacturing costs or the contribution margin generated by the new product).

In this sense, the process view of the firm can be of great help in making designers and product engineers more aware of the critical role played in determining the overall economic performance of the firm, as proved by the "life cycle costing" theory (Blanchard, 1979; Fabrycky, 1991; Shields and Young, 1991). Indeed, the life cycle theory states that, although the great majority of costs of a finished good are generated in the manufacturing/distribution stage (given also the repetitive nature of these activities for almost all kind of products), most of these costs are implicitly determined in the early phases of development. In Fig. 2.1, this is shown by the different profile of the "actual costs" and of the "committed costs" curves: the latter is built "translating" the costs occurred in the various stages of the life cycle back to the instant in which the different decisional processes that implicitly fixed those costs took place.

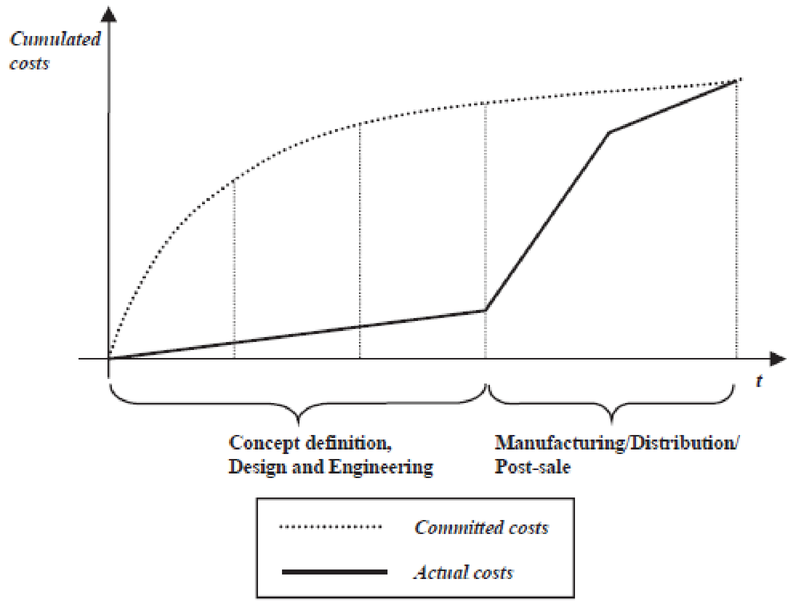


Figure 2.1: Committed costs and actual costs along the life cycle of a product. [14]

Since most of the product costs sustained during later in the production life cycle are determined during the conceptual design phase, the cost estimation in the early phase of the design cycle is crucial. Many researchers have emphasized the importance of cost estimation at the early design stages when 70–80% of a total product cost is determined [5].

More the project is advanced the less the possibility of reducing the final cost because of the high costs of modifications (see Fig. 2.2). Economic evaluation as early as possible, in the design phase, is therefore essential to find the best price–function compromise for the projects or product. However, economic evaluation during the design phase is not easy. It is very different from assessment when the product/process design is complete and detailed which allows the cost of all optimisation choices to be taken into account. In the design phase, the project or product is never completely defined. It is necessary in this phase to implement rapid and more or less precise cost estimation methods (depending on available data) allowing the designer to select one solution in preference to another on economic grounds[7]

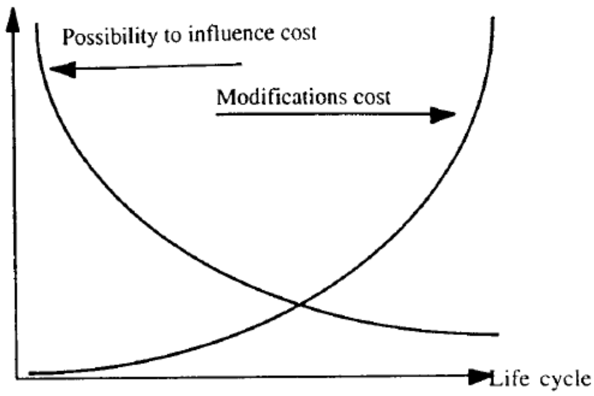


Figure 2.2: Efficiency of modifications. [7]

These considerations have led to the development of design rules and techniques, whose objective is to help engineers and designers in their decisional processes and make them aware of the implications of the alternative design solutions on the future costs of the product (Ulrich and Eppinger, 1995). In the life cycle theory the overall objective resides on the minimisation of the cumulated life cycle cost. Hence, the first step consists in estimating the "occurred costs" curve (and, then, the manufacturing costs, which represent the most important element). In particular about the case study in exam, if an assembler firm can make reliable predictions about the production costs of its suppliers (for purchased components), its bargaining power will be higher due to the reduction of information asymmetry (Porter, 1980).

### 2.1.1 Product Cost Estimation (PCE)

The Adnan Niazi e Jian S. Dai (2006) classification is based on grouping the techniques with similar features into various categories. The methodologies for cost estimation discussed in different categories are distinct and reflect the nature of that category. The PCE techniques are categorized into qualitative and quantitative as reported in Fig. 2.3. and are analyzed in the next paragraphs.

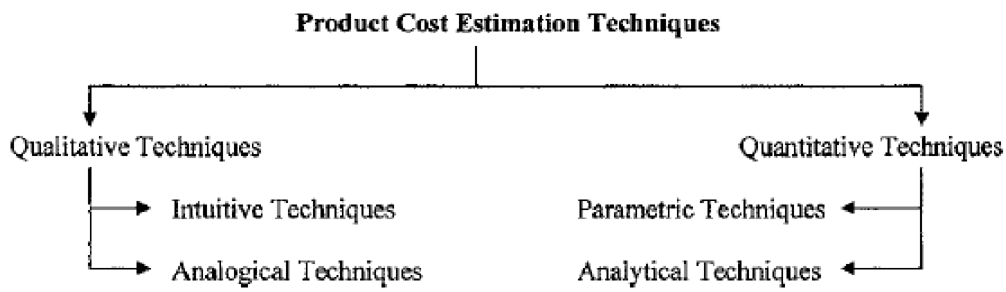


Figure 2.3: Initial classification of the PCE techniques. [14]

In addition, they are tabulated together with the key advantages, limitations, and corresponding published literature in Table 2.1.

| **Product Cost Estimation Techniques** | | | | **Key Advantages** | **Limitations** | **References** |
|---|---|---|---|---|---|---|
| **Qualitative Cost Estimation Techniques** | Intuitive Cost Estimation Techniques | Case-Based Systems | | Innovative design approach | Dependence on past cases | Rehman, S., and Guenov, M. D., 1998 Li-hua, X., and Yun-feng, W., 2004 Ficko, M., Drstvensek, I., Brezocnik, M., Balic, J., and Vaupotic, B., 2005 Balarman, V., and Vattam, S. S., 1998 |
| | | Decision Support Systems | Rule-Based Systems | Can provide optimized results | Time-consuming | Shehab, E. M., and Abdalla, H.S., 2002 Rehman, S., and Guenov, M. D., 1998 Gayretti, A., and Abdalla, H. S., 1999 |
| | | | Fuzzy logic Systems | Handles uncertainty, reliable estimates | Estimating complex features costs is tedious | Shehab, E. M., and Abdalla, H.S., 2001 Shehab, E. M., and Abdalla, H.S., 2002 |
| | | | Expert Systems | Quicker, more consistent and more accurate results | Complex programming required | Musgrove, J. G., 1992 Venkatachalam, A. R., Mellichamp, C. M., and Miller, D. M., 1993 Waring, C. W., 1991 |
| | Analogical Cost Estimation Techniques | Regression Analysis Model | | Simpler method | Limited to resolve linearity issues | Hundal, M., S., 1993 Poli, C., Escudero, J., and Fermandez, 1988 Lewis, J., 2000 Pahl, G., and Beitz, W., 1996 |
| | | Back Propagation neural network model | | Deal with uncertain and non-linear problems | Completely data-deprndant, Higher establishment cost | Zhang, Y. F., Fuh, J. Y. H., and Chan, W. T., 1996 McKim, R. A., 1993 Cavalieri, S., Maccarone, P., and Pinto, R., 2004 Shtub, A., and Zimerman, Y., 1993 Zhang, Y. F., and Fuh, J. Y. H., 1998 Chen, M.-Y., and Chen, D.-F., 2002 |

| | | | | | |
|---|---|---|---|---|---|
| **Quantitative Cost Estimation Techniques** | Parametric Cost Estimation Techniques | | Utilize cost drivers effectively | Ineffective when cost drivers can not be identified | Cavalieri, S., Maccarone, P., and Pinto, R., 2004 Hajare, A. D., 1998 Roberts, C. A., and Hermosillo, E. P., 2000 Boothroyd, G., and Reynolds, C., 1989 Dewhurst, P., and Boothroyd, G., 1988 |
| | Analytical Cost Estimation Techniques | Operation-based cost models | Alternative process plans can be evaluated to get optimized results | Time-consuming, require detailed design and process planning data | Jung, J.-Y., 2002 Feng, C.-X., Kusiak, A., and Huang, C.-C., 1996 Gupta, S. K., Nau, D. S., Regli, W. C., and Zhang, G., 1994 Wei, Y., and Egbelu, P., 2000 Kiritsis, D., Neuendorf, K. P., and Xirouchakis, P., 1999 |
| | | Break-down cost models | Easier method | Detailed cost information required about the resources consumed | Son, Y. K., 1991 Clark, F. D., 1997 Bernet, N., Wakeman, M. D., Bourban, P. E., and Månson, J. A. E., 2002 Ostwald, P. F., 1992 |
| | | Cost tolerance models | Cost effective design tolerances can be identified | Require detailed design information | Singh, N., 2002 Yeo, S. H., Ngoi, B. K. A., Poh, L. S., and Hang, C., 1997 Sfantsikopoulos, M. M., Diplaris, S. C., and Papazoglou, P. N., 1995 |
| | | Features-based cost models | Features with higher costs can be identified | Difficult to identify costs for small and complex features | Zhang, Y. F., Fuh, J. Y. H., and Chan, W. T., 1996 McKim, R. A., 1993 Cavalieri, S., Maccarone, P., and Pinto, R., 2004 Shtub, A., and Zimerman, Y., 1993 Zhang, Y. F., and Fuh, J. Y. H., 1998 Chen, M.-Y., and Chen, D.-F., 2002 |
| | | Activity -based cost models | Easy and effective method using unit activity costs | Require lead-times in the early design stages | Ben-Arieh, D., and Qian, L., 2003 Cooper, R., and Kaplan, R. S., 1988 Hundal, M. S., 1997 Beaujon, G. J., and Singhal, V. R., 1990 |

Table 2.1: The PCE techniques: key advantages, limitations, and list of discussed references. [14]

Choosing one cost estimation method or the other depends on the goals, on the decisions to be made, and on the surrounding uncertainty. Exact product costs can be computed only at the end of the product development process, when production is effectively started. However, firms must make estimates on product cost as early as possible, when preliminary choices are being made, and even before any design activity has actually taken place. Therefore, the choice of the method will be influenced by the stage of the design process and by the amount and quality of data that has been collected, as shown in Fig. 2.4.

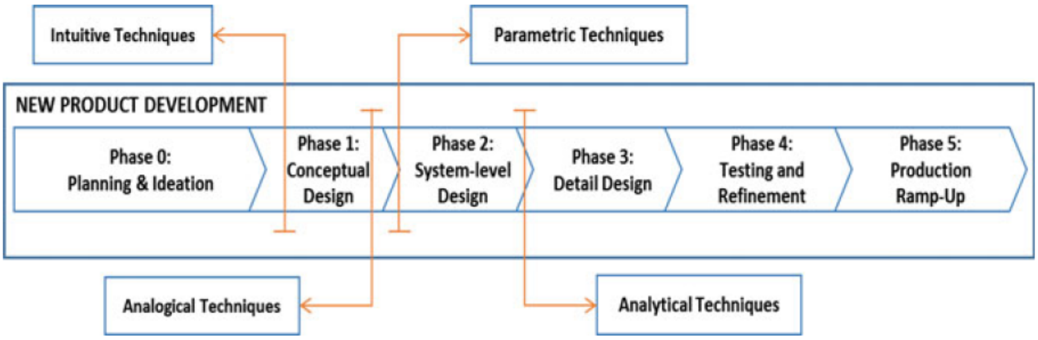


Figure 2.4: Use of cost estimation techniques in the product development process. [4]

Qualitative cost estimation techniques are usually appropriate during the early stages of design, as they are based on the comparison of the new product with previous ones, using historical data, past design experience, or manufacturing knowledge. Instead, quantitative techniques provide more accurate estimations, and their usage is often restricted to the final stages of the development process, when detailed information on product features, manufacturing, and service processes are available[4].

## 2.2 Qualitative Techniques

Qualitative cost estimation techniques are primarily based on a comparison analysis of a new product with the products that have been manufactured previously in order to identify the similarities in the new one. The identified similarities help to incorporate the past data into the new product so that the need to obtain the cost estimate from scratch is greatly reduced. In that sense, the past design and manufacturing data or previous experience of an estimator can provide useful help to generate reliable cost estimates for a new product that is similar to a past design case. Sometimes, this can be achieved by making use of the past design and manufacturing knowledge encapsulated in a system based on rules, decision trees, etc. Historical design and manufacturing data for products with known costs may also be used systematically to obtain cost estimates for new products. In general, qualitative techniques help obtain rough estimates during the design conceptualization. These techniques can further be categorised into intuitive and analogical techniques, which are discussed, immediately after, in detail [14].

### 2.2.1 Intuitive Techniques

The intuitive cost estimation techniques are based on using the past experience. A domain expert's knowledge is systematically used to generate cost estimates for parts and assemblies. The knowledge may be stored in the form of rules, decision trees, judgments, etc., at a specific location, e.g., a database to help the end user improve the decision-making process and prepare cost estimates for new products based on certain input information[14].Usually, since the used information is grounded on experience and memory only, without strong support of mathematical theories, this class of techniques is difficult to justify, and trade-offs among alternatives are difficult to evaluate (Ong, 1993). This study identified three subcategories under intuitive techniques.

- **Case-Based Methodology (CRB)**
  This approach also known as case-based reasoning (CBR) attempts to make use of the information contained in previous design cases by adapting a past design from a database that closely matches the attributes of a new design. This often requires making necessary changes to parts and assemblies of previous design cases and incorporating missing details to it. The process starts by outlining a new product's design specifications followed by retrieving a closest design match from a design database. This technique allows the cost estimation for a new product by combining the past results with those for the newly designed components and assemblies, thereby greatly reducing the need to design from scratch. The approach is, therefore, helpful in making good estimates at the conceptual design stage, since the use of the past cost data to generate new estimates greatly minimizes the estimation time. However, the methodology is applicable only when similar past designs are available to incorporate the relevant cost data during cost estimation for new products[14].

  An example, similar to the case study, is proposed by Ficko et al. (2005) conceived a CBR system for predicting total cost of the tool manufacture. The system is based on extracting geometrical features from computer-aided design (CAD) models stored in a database and calculating the similarities with the problem description of a new product's features. Although the developed system is only limited to tools for manufacture of sheet metal products by stamping, it provides good-quality predictions based on enough similar cases[9].

- **Decision Support System (DSS)**
  These systems are helpful in evaluating design alternatives. The main purpose of these systems is to assist estimators in making better judgments and decisions at different levels of the estimation process by making use of the stored knowledge of experts in the field. This is illustrated

in Fig. 2.5. To incorporate experts' experience, the artificial intelligence (AI) philosophy is used to represent and utilize a domain expert's knowledge in a way that is oriented toward problem solving and serves as a decision-aid tool. In the particular context of the PCE, it may constitute a segment of the system containing information about machining processes, manufacturability analysis and constraints, product characteristics with design functions, and relationships with each other set out in logical statements. It may also incorporate rules about the actions to be taken or more conventional mathematical formulas. It can point outside to external programs and databases that can be associated with it including some that can cope with uncertain or conflicting judgments.

One of the most common ways to represent DSS is based on storing design, manufacturing, or other constraints as a set of rules. Since many practical situations deal with uncertainty and nonavailability of heuristic data, fuzzy logic techniques are used to some extent to overcome such problems. Another nonconventional approach makes use of expert systems (ES) or expert support systems in the domain of DSS [14].

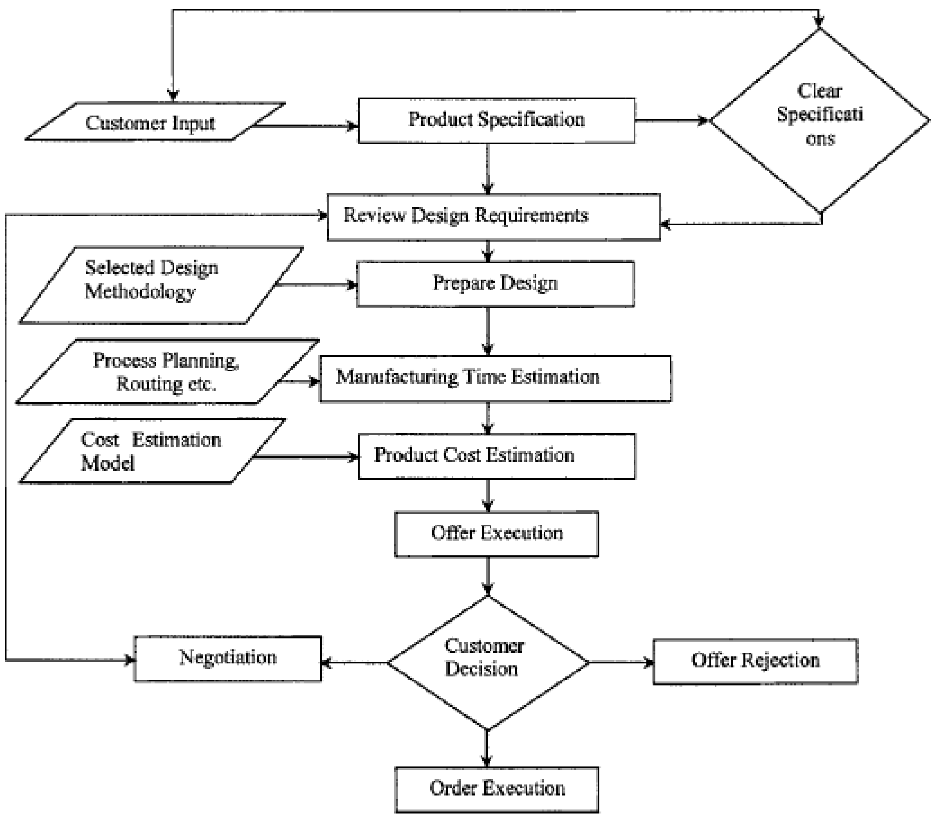


Figure 2.5: Decision-support-system approach to cost estimation. [14]

– *Rule-Based Systems*
These systems are based on process time and cost calculation of feasible processes from a set of available ones for the manufacture of a part based on design and/or manufacturing constraints. Such a

system reflects these constraints in a respective rule class with the information encapsulated in it by an expert in the area. A rule-based algorithm is an example of one such approach that helps to establish design and manufacturing constraints. This approach is shown diagrammatically in Fig. 2.6. Based on a set of user constraints, manufacturing processes are selected that are then used to calculate the product cost. The set of constraints may need to be changed to obtain a different set of manufacturing processes to obtain an acceptable product cost estimate. This methodology is helpful for cost optimization based on process evaluation criteria. However, obtaining the optimized results can be very time consuming, especially when there are a large number of processes to be evaluated[14].

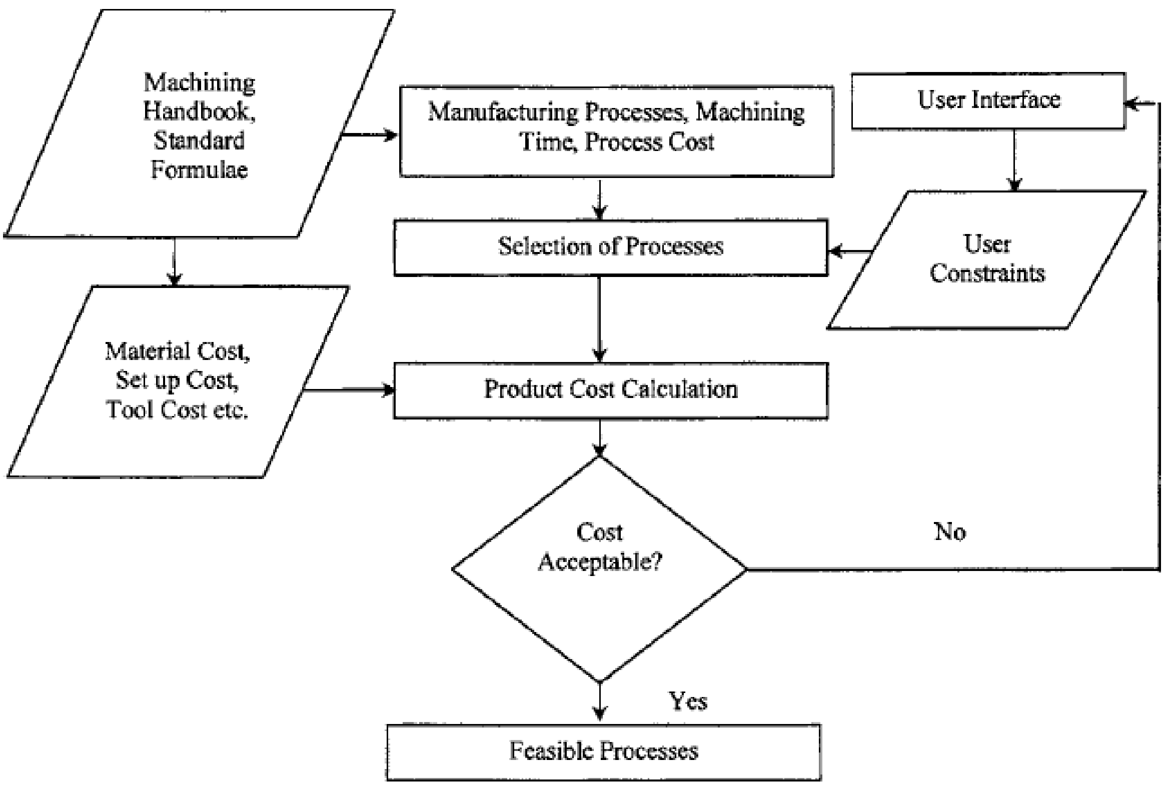


Figure 2.6: Cost estimation process model based on user constraints. [14]

Gayretli and Abdalla developed a rule-based algorithm for the selection and optimization of feasible processes to estimate process time and cost based on parts features. A detailed description of part features with possible processes and constraints was given. Process times were calculated using a standard formula as:

$$ProcessTime = \frac{FormFeatureVolume}{MaterialRemovalRate}$$

The process time is then used to calculate *lot time*, which is based on a form feature quantity. The total process cost is subsequently calculated as follows:

$$TotalProcessCost = LotTime * PHC$$

where PHC is the *productive hour cost* given by a cost estimation database. The total cost is then calculated as follows:

$$TotalCost = MaterialCost + \sum[(LotTime * PHC) + ToolCost + SetupCost]$$

The proposed system allowed the selection of a combination of feasible processes from the possible ones, and hence, the calculation of process time and cost based on the user input constraints (e.g., maximum allowable cost and process time for a particular feature). A criterion of feasibility was judged against the level of satisfaction for input constraints. The process allowed flexibility based on user constraints[10].

– *Fuzzy Logic Approach*
This approach to cost estimation is particularly helpful in handling uncertainty. Fuzzy rules, such as those for design and production, are applied to such problems to get more reliable estimates. However, estimating the costs of objects with complex features using this approach is quite tedious and requires further research in the area. A fuzzy technique example,proposed by Shehab and Abdalla, consisting of a decision table providing a means for system rules and indicating the relationships between the input and output variables of the fuzzy logic system, is used to handle the uncertain knowledge on cost estimation. The construction of a set of rules from the decision table enables the estimation of the machining time $T_i$ for a given feature, which is multiplied by the unit time cost $R_i$ to get the machining cost $C_m$ for that feature, i.e.:

$$C_m = R_i * T_i$$

The developed fuzzy-logic-based system was capable of estimating the total product cost apart from enabling the material selection and estimating the assembly cost, other studies considering other essential costs, such as nonproductive and setup costs [18].

– *Expert Systems*
This approach is based on storing the knowledge in a database and manipulating it on demand to infer quicker, more consistent, and more accurate results based on an attempt to mimic the human expert thought process with the help of an automated logical reasoning approach, normally achieved by rule-based programing. Within the specific context of cost estimation, the expert-system approach refers to a model and associated procedure exhibiting a degree of expertise comparable to that of a human expert in generating or to help in generating reliable cost estimates. Expert systems applied

to the PCE have mainly focused on formalizing the theoretical techniques largely from textbooks, etc., rather than encapsulating the practical knowledge [14].

Venkatachalam et. al (1993) utilize the expert-system model to implement the DFM approach for casting, forging, milling, and drilling processes. Design for manufacturability (DFM) is an approach to design that fosters the simultaneous involvement of product design and process design. The primary objective of DFM is to produce a design at a competitive cost by improving its manufacturability without affecting its functional and performance objectives. It generates benefits for the company productivity and costs. In particular, from the comparison between estimated and actual costs turned out that the estimates of manufacturing cost provided by the process selection and cost estimation module of the expert system deviate from the actual manufacturing cost values by a small margin[19].

### 2.2.2 Analogical Techniques

The analogical method allows an evaluation of the cost of a product compared with the cost of other already existing products. This method is mainly used through group technology. This technique consists of defining a codification of parts, which is frequently a morpho-dimensional codification, and comparing the functions of a new product (defined in the functional specifications sheet) with the functions already realised in existing products.The analogy is usually based on the intrinsic characteristics of a product, and more, in general, it comes from functional and geometrical aspects (Layer, et al., 2002). The analogical method has many advantages: its low cost; its ability to propose a solution rapidly; and its functioning is also transparent for user. However, this method generally requires an important database[8]. Moreover, in the application of this approach, there are the difficulties in the operationalisation of the concept of "degree of similarity" (how to measure it?) and the difficulty of incorporating in this parameter the effect of technological progress and of context factors. This kind of techniques is mainly adopted in the first phase of the development process of a product, because it allows obtaining a rough but reliable estimation of the future costs involved[5]. The most utilized analogical techniques are regression analysis models and back propagation methods.

- **Regression Analysis Models**
  Since the 1970s regression techniques have been used for cost estimation due to their well-defined mathematical background. Ever since, this technique has been applied to support cost engineers in different fields (Zang et al., 1996), (Shtub and Versano, 1999), (Chen and Chang, 2002), (Kim et al., 2004). These models make use of the historical cost data to establish a linear relationship between the product costs for the past design cases and the values of certain selected variables so that the relationship can be used to forecast the cost of a new product. The re-

gression analysis approach based on the similarity principle was adopted by Lewis that used existing designs to provide cost estimates for similar new designs[14].

- **Back-Propagation Neural-Network (BPNN) Models**
These models use a neural network (NN) that can be trained to store knowledge to infer the answers to questions that even may not have been seen by them before. This means that such models are particularly useful in uncertain conditions and are adaptable to deal with nonlinearity issues as well. The back-propagation neural network (BPNN) is the most common of all network types and also suits better the nature of the PCE[14]. Although the applications of NNs are numerous, they all share an important common aspect: the processes to be predicted are correlated with a large number of explanatory variables and there may exist high-level non-linear relationships between those variables. One of the main goals of NNs is to detect those high-level non-linear relationships to enable a better modelling of the process. NNs are in fact computer systems that simulate the learning effect of the human brain and are typically composed of a number of neurons, grouped in one or more hidden layers connected by means of synapse connections. The output of each neuron will be a weighted function of the different incoming signals. The weight of an interconnection between different neurons will depend on the contribution performance of that neuron to the final output. Fig. 2.7 shows the combination of different neurons (perceptrons) into an artificial neural network (multi-layer perceptron).

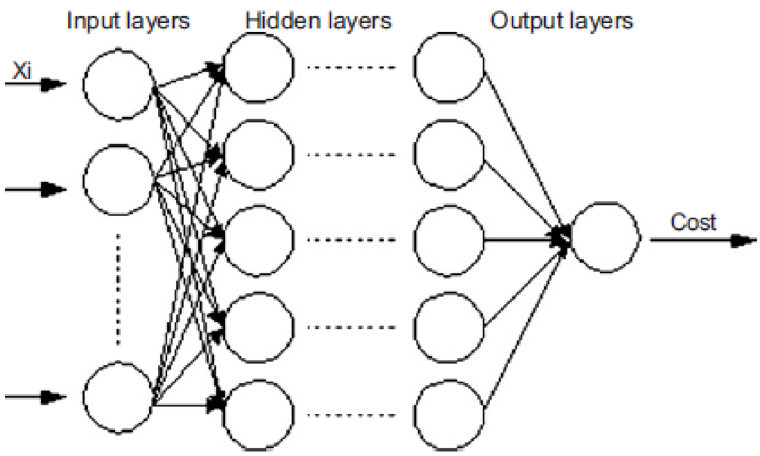


Figure 2.7: Multiple layer perceptron (MLP). [20]

For cost estimation, the different input signals (the possible contributing variables) are weighed and combined into a final cost model. By feeding parts with a known cost to the network, the network is trained to estimate the cost. This training implies that the different interconnection weights will be adapted every time a new part is fed to the network. Adaptation of the weights will be done based on a punishment/reward principle: if the interconnection did well during estimation of the previous part, this variable will be rewarded by increasing the weight of its interconnection to the output. If the interconnection performed badly, the interconnection weights will be decreased in the next iteration step. By minimizing the squared error between the estimate and the desired output (in our case the cost), the network is trained and as more parts are fed, the learning effect increases. However, one cannot keep on training the network into infinity. When new parts, not included in the training set, are fed to the network, inaccurate estimates can be generated. It can indeed happen that the network has focused too much on the specific data of the training set (i.e. overfitting), but fails to generalize when unknown parts are fed to the network (i.e. generalization ability of NNs). To ensure that NNs also generate accurate estimates for parts not included in the training set, a separate testing and validation set are used. The network will be trained until the error of the testing and validation set increases. At that point, training will be stopped to avoid overfitting. Neural networks are typically characterised by the number of hidden layers, the number of hidden neurons and the training algorithm. Those design parameters determine to a large extent the performance of the NN and will differ depending on the field of application. Both regression techniques and NNs are used frequently in cost estimation fields. Cavalieri et al. (2004) used both techniques for estimating production costs in the automotive industry. They found that NNs are a valid alternative for regression techniques when estimating production costs, especially when the form of the relationship between the dependent variable and independent variables are unknown. NNs prove to be very robust and can be adapted easily to certain design changes[20].

## 2.3 Quantitative Techniques

Quantitative techniques, on the other hand, are based on a detailed analysis of a product design, its features, and corresponding manufacturing processes instead of simply relying on the past data or knowledge of an estimator. Costs are, therefore, either calculated using an analytical function of certain variables representing different product parameters or as the sum of elementary units representing different resources consumed during a whole production cycle of a given product. Although these techniques are known to provide more accurate results, their use is normally restricted to the final phases in the design cycle due to the requirement of a detailed product design. Quantitative techniques can be further categorized into parametric and analytical techniques, which are discussed, in detail, immediately after[14].

### 2.3.1 Parametric Techniques

The Parametric Methods use the relationship between the product parameters and the lifecycle costs, built as an analytical function of a set of variables (as volume, weight, geometrical characteristic etc.). Parametric estimating has been recognised as a powerful tool in cases in which data collected are accurate enough, and assumptions are clearly identified and documented (Ong, 1993). However, the estimation is meaningless if only based upon statistical assumptions, in fact, common sense and engineering knowledge should always take into account at first to generate the hypothesis, successively tested by statistical analysis (Rush & Roy, 2000). The main advantage of Parametric methods is in the low amount of information required for the analysis, although sufficient data should be collected to build the analytical function and validate the obtained relationship. The parametric method is very useful because of its rapidity of execution. It can be criticised for working like a "black box": that is to say that from the specifications the only results we obtain are different costs. We do not know the origin of these costs which can discourage users. These parametric methods thus allow us to proceed from technical values characterizing the product and possessed by the engineer, to economic data. At least three types of parametric method have been identified[7]:

- **The method of scales**
  The method of scales applies generally to prevailing technologies to produce simple products of variable sizes. The implementation of this type of method necessitates the determination of the most significant technical parameter of the activity to be evaluated. This parameter allows us to define the ratio to quantify ($/ml, $/kg). The evaluation is determined then by analogy with finished products which places this method on the boundary between the analogic and the parametric. One of the major disadvantages of this method is the assumption of a linear relationship between the value of the considered parameter and the cost.

- **Statistical models**
  Statistical models are constructed around a set of statistical relationships which are supposed to be universal. To obtain this relationship, the set of activities for the realisation of a product is divided into different domains and each one is made the object of a mathematical formula. A model comprises three data types: technical specifications, relationships connecting data to some intermediate or final variables, constants. Of course, in practice, no completely universal model exists. One can find an example of a statistical model in G. Boothroyd et al. (1989) where, for a family of parts, the non-productive time or the manufacturing time is determined with the help of complex formulae.

- **Cost Estimation Formulae (CEF)**
  A cost estimation formula (CEF) is a mathematical relationship relating the cost of a product as a dependent variable to one or more independent cost drivers. One of the most used techniques for developing CEFs is the regression model of the least-squares best fit (LSBF). The most usual mathematical forms are the linear form, $Y = aX + b$ and the power form, $Y = bX^a$. The CEF is generally limited to a type of product, a type of manufacturing technology, or a step in the life cycle of the

product. However, the principal advantages of the CEFs are that they are fast and easy to use. They are also low-priced because they do not need the use of particular software or computer tools. During the design phase, the CEF allow us to establish the influence of parameters on the product cost, then, the designer will be able to optimise its design from an economical point of view. Moreover, the choice of parameters of the CEF can be made either with the help of experts or by a statistical identification. However, during the design phase, all the information is not available. Some specifications needed for the CEF cannot yet be defined. Consequently, the designer will have to estimate the missing parameters. Finally, to the extent that CEFs shows general trends, they cannot solve particular or atypical cases. There are two main parameter categories: physical values (conforming to the functional description) and dimensioning value (conforming to the solution description). One generally limits the CEF to between two and five parameters.

The construction of a CEF takes place in four steps:

1. *Choice of part parameters related to cost.* This choice of parameters is generally made by experts.
2. *Choice of the formula structure.* All kinds of structures can be used. Nevertheless, in practice, 95% of cases can be resolved by a multiplicative form which is easily linearisable:

$$C = b_0 * P_1^{b_1} * P_2^{b_2} \dots$$

3. *Computation of coefficients $b_i$ by a multiple linear regression.* The determination of $b_i$ can be easily obtained by a generalization of the method of least squares for several variables. This method necessitates some computation.
4. *Examination of obtained results.* The examination of results can be made for three points: margin of uncertainty of each coefficient $b_i$; margin of uncertainty on values of cost predicted by the CEF for a new project; simplification of the CEF.

During the publication of a CEF, it is necessary to specify, at the same time, the technological family to which it applies, the units of measure of all parameters, the number of used points, the confidence interval and its precision.

These techniques could be effective in those situations where the parameters, sometimes known as cost drivers, could be easily identified. Parametric models are generally used to quantify the unit cost of a given product. Cavalieri et al.[5] developed a parametric model for the estimation of unit manufacturing costs of a new type of brake disk using the weight of the raw disk, unit cost of raw material, and the number of cores as parameters in their model, which is expressed as follows:

$$C = FC + \left( C_{CO} N_{CO} + \frac{C_{rm} TF}{1 - SC} \right) W$$

where $C$ is the unit cost of the disk brake, $FC$ the fixed cost factor coefficient, $C_{CO}$ the core cost per kilogram of cast iron coefficient, $N_{CO}$ the number of cores, $C_{rm}$ the unit cost of raw material, $SC$ the scrap rate coefficient, $TF$ cast-iron–steel conversion factor coefficient, and $W$ the weight.

A simple linear regression model using one of the cost drivers would not be effective because of variances between the data. However, the developed model overcame this problem by using more parameters. Validation analysis of the model by comparing the estimated costs to the actual ones of the brake disks demonstrated the superiority of the proposed parametric model over the linear regression model[14].

### 2.3.2 Analytical Techniques

The Analytical Techniques consider a product as a decomposition of a series of elementary units or tasks, operations and activities (Niazi, et al., 2006). Based on this subdivision the costs are estimated as a sum of all the components, going deep to details such as, for instance, the time per operation, the labour cost, material cost and overhead costs, etc. (Rush & Roy, 2000). Due to that level of detail and precision required by this class of techniques, an understanding of the product and its main processes is necessary, consequently delegating their use to the more advanced phases of the product development process (Layer, et al., 2002). Analytical methods are the most accurate and consistent approaches for cost estimation. Moreover, they can be used in cases of changes in the product technology processes, by regenerating the model. The resulting estimate is useful mainly for detailed consideration on costs reduction, in particular when the product is already in the production phase. However, the primary weaknesses are represented by the effort in producing the estimates and the accuracy of estimation that relies significantly on the information available (Ong, 1993). Moreover, the amount of the data necessary for the analysis is enormous and sometimes difficult to achieve in particular in cases in which the knowledge and understanding of the lifecycle processes are not yet obtained (Layer, et al., 2002).

These analytical techniques can be further classified into five different categories, each will be discussed in detail as follows.

- **Operation-Based Approach**
  This approach is generally used in the final design stages because of the type of information required and is one of the earliest attempts to estimate manufacturing costs. The approach allows the estimation of manufacturing cost as a summation of the costs associated with the time of performing manufacturing operations, nonproductive time, and setup times. Several techniques have been developed to select the alternative manufacturing operations that optimize the machining cost[14]. The cost model proposed by Jung (2002) estimated the manufacturing cost by considering three different times including setup time, operation time, and nonoperation time. Formulation was provided. The total cost was

given by

$$MfgCost = (R_o+R_m)[(T_{su}/Q)T_{ot}+T_{no}]+MaterialCost+FactoryExpenses$$

where $R_o$ is the operator's rate, $R_m$ the machine rate, $T_{su}$ the setup time, $Q$ the batch size, $T_{ot}$ the operation time, and $T_{no}$ the nonoperation time. The model could not be used to evaluate design alternatives because of its availability only in the final stages of design cycle.

Furthermore, Kiritsis et al. (1999) proposed a method for the cost estimation of the machining of parts based on the description of given features and associated alternative manufacturing operations. The proposed methodology was based on Petri nets to determine overall costs, including machining, moving, setup, and tool-change costs. However, getting the optimized results using the proposed methodology was time consuming.

- **Break-Down cost models**
  Unlike the operation-based approach, focusing on the manufacturing costs related to machining, the breakdown method tends to consider all the costs incurred during the product's lifecycle. This means that costs could be associated with material, labour and overhead costs and not just the machining. This requires even more detailed information than the operation-based approach. In addition, the break-down approach is also limited as in general it is more applicable at the final stage of product design processes, when more detail is available. However, the greatest advantages of this method are having a wider costing scope than the operation-based approach and relatively easier to apply without further training in computing or other software programs[11].

  The cost model developed by Son (1991) included labor, machining, tool, setup, space-occupied, computer software, and material costs. The model also separated the raw material cost and labor cost into different categories. The proposed model included *insurance*, *utility*, *maintenance*, *repair*, and *property* costs. The machining cost $C_m$ is, hence, represented in the following equation as:

$$\begin{aligned} C_m = {} & UtilityCost + MaintenanceCost + RepairCost + \\ & + InsuranceCost + PropertyCost = \\ = {} & \sum (C_u T_m + C_{mt} T_{mt} + C_r T_r + aF_k + bF_k) \end{aligned}$$

  where $C_u$ is the utility cost per unit time, $T_m$ the machining time, $C_{mt}$ the maintenance cost per unit time, $T_{mt}$ the total maintenance time, $C_r$ the repair cost per unit time, $T_r$ the total repair time, $a$ the insurance premium, $F_k$ the initial investment, and $b$ the property tax.

  Furthermore, equations for other cost elements including labor, tool, setup, space-occupied, computer software, and material costs were also provided. The requirement of such detailed information restricted the use of the model in the final design stage.

- **Cost tolerance models**

  Part tolerance is one of the most important parameters in manufacturing because it has a significant impact on the manufacturing cost of a product. Material stocks have to undergo a series of manufacturing processes to arrive at the designed shape and accuracy. The accuracy and surface finish of a part are continually improved by the selected manufacturing processes. Thus if the relationship between the tolerance and the cost of producing that tolerance for each manufacturing process is known, a least-cost process sequence may be achieved. A typical cost-tolerance curve shows the manufacturing cost increasing as the tolerance becomes tighter. Several mathematical models have been introduced to describe the cost-tolerance relationship of different manufacturing processes[23].

  Singh (2002) presented a framework for the concurrent design of product and processes considering the criteria of minimum cost, maximum quality, and minimum manufacturing lead time. Three models were presented to jointly design the products and processes. They are the unit cost of production model, the quality model, and the lead-time model. The unit cost model was expressed as follows:

  $$X_0(d, j) = K_i(d, j)[X_i + f(j)] - K_s(d, j)X_s$$

  where $K_i$ and $K_s$ are technology coefficients that can be found from the following equations:

  $$K_i = 1/[1 - SC(d, j)]$$
  $$K_s = SC(d, j)/[1 - SC(d, j)]$$

  $SC$ is the scrap rate given by the following equation:

  $$SC(d, j) = \phi[-d/\sigma(j)] + 1 - \phi[d/\sigma(j)]$$

  where $j$ is the jth manufacturing process selected for producing a product, $X_0(d, j)$ the unit cost with tolerance $d$, $X_i$ the unit raw material cost, $f(j)$ the unit processing cost for $j$th process, $X_s$ the unit salvage value, $K_i$ the technology coefficient (input), $K_s$ the technology coefficient (scrap), $SC(d, j)$ the scrap rate, $\sigma(j)$ the standard deviation, and $\phi(x)$ the cumulative distribution function of probability distribution with the mean equal to 0 and the standard deviation equal to 1.

  The modeling methodology was based on obtaining the optimal tolerances and, hence, setting up the acceptance regions for the design variables meeting certain criteria. The objective of the cost model was to select the process and design variables that minimize the cost function. However, the modeling methodology eliminated the needs for design changes because it considered various design and manufacturing factors at the early stage of the design.

- **Feature-Based cost models**

  The feature-based cost estimation methodology deals with the identification of a product's cost-related features and the determination of the associated costs. Considerable research has been carried out in order to extract and quantify representative product features that contribute to the total cost. These features can either be design related (such as the type of material used for a specific product, geometric details, etc.) or process oriented (i.e., a particular process required for manufacturing the product, e.g., machining, casting, injectionmoulding etc.). The methodology allows the selection of a particular design or manufacturing form feature for design-for-cost (DFC) system users[14].

Taking the advantages of the fast growth of 3D modelling tools, feature-based approaches have become more popular and commercial (Roy and Kerr 2003). Therefore, a broad range of scholars have attempted to estimate the cost of products through their design, process planning and manufacturing process by using this method (Catania 1991, Qu-Yang and Lin 1997). It is found that products consist of standard features in terms of holes, edges, flat faces, flanges etc; hence, the lifecycle costs of the product can be determined by the summation of the cost of each feature with respect to its corresponding manufacturing process (Gayretli and Abdalla 1999). There are several significant advantages of applying this approach to PCE. It not only allows product providers to design and manufacture parts based on design-for-cost target but also costs related to standard parts can be re-used for new products. This means that it is likely to produce an optimised product within the budget and estimate the product cost more efficiently and effectively[11].

However, the approach can have limitations for complex or very small geometric features, especially if machining processes are used to produce these features[14]. Ou-Yang and Lin (1997) looked into the feature-based costing by focusing on the machining-type features and developed a manufacturing cost estimation model based on feature shapes and precision. With the process planning information and geometrical data, the machining time of a feature was estimated. One limitation of their proposed framework was that it only considered conventional machining processes.

- **Activity-Based cost models**
  The ABC system focuses on calculating the costs incurred on performing the activities to manufacture a product. The method was first discussed by Cooper and Kaplan (1988). They presented the ABC system as a useful means to distribute the overhead costs in proportion to the activities performed on a product to manufacture it. The ABC system proved a good alternative to traditional estimation techniques since it provided more accurate product manufacturing cost estimates[14].

  N.S. Ong [15] summarized the ABC fundamentals. ABC uses a two-stage cost allocation process for assigning costs to products. In the first stage, input costs such as utilities, maintenance and salaries are allocated to activities that consume these resources. As the products are routed through the factory, they are allocated costs according to their consumption of the different types and quantities of activities. The total product

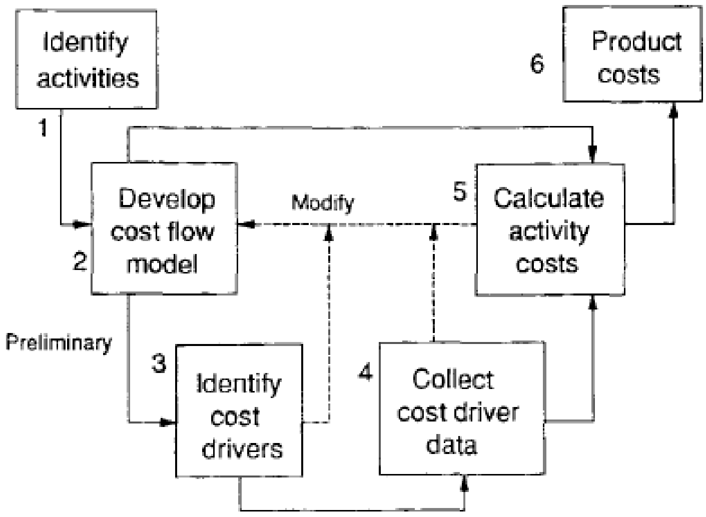


Figure 2.8: Developing the activity-based cost model.[15]

cost is therefore the sum of the costs of all activities required to manufacture the product There are several types of activities. Apart from the traditional unit-level activities whichvary with the volume of output, there are many activities whose costs do not vary with the volume of production but with transactions. These are:

– *Batch-level activities*, which assume that inputs vary in proportion to the number of batches produced, but the costs are amortized (or fixed) for all units produced in that batch; an example is the machine set-up required whenever a batch of products is to be manufactured.
– *Product-level activities*, which assume that inputs are necessary to support the production of each different type of product; an example is the cost incurred in fabricating a harness jig for a new product.
– *Facility-level activities*, which simply sustain a facility's general manufacturing process; an example is the general administration cost.

Three of these types of activities used by the ABC systems contain costs that can be directly attributed to individual products. The fourth type, facility-level activities, contains costs that are common to a variety of products and can only be allocated to products arbitrarily.

The key steps in the development of an activity-based cost model are as follows (see Fig. 2.8):

*Step 1* is to identify the activities involved. This entails a thorough understanding and detailed analysis of the processes, activities and flow of the product. The list should cover manufacturing and manufacturing-supporttype activities.

In *Step 2*, a preliminary cost flow model is developed. This shows the flow of the types of cost into the activities and of activities into products through cost drivers. All costs that can be directly assigned to products (e.g. direct material, direct labour) are also identified. This preliminary cost flow should be revised based on the input from subsequent steps.

*Step 3* is to identify the primary event that initiates the activity and causes cost. The cost driver chosen should reflect the causal relationship between the demand for the output of the activity and the resources consumed to produce it. Usually, after identifying all the cost drivers, it will be necessary to review/change/combine the cost drivers based on: precision required, cost of data collection, commonality and measurability.

In *Step 4*, the data concerning the selected cost drivers must be collected. These can come from historical, observed or estimated figures concerning the level of transactions for the activities. Modification to the cost drivers can be done at this stage if deemed necessary.

In *Step 5*, the cost per unit of the activity's output is calculated. This is called the activity charged-out rate or operation rate. If manual assembly is performed, the direct labour rate is used. If automatic assembly is used, the operation rate would include the labour and machine rates.

Lastly *Step 6*, the product cost is calculated based on the direct allocation of activity costs charged to the product according to the product's consumption of those activities. Costs such as materials which can be directly traceable to the product will be assigned as a direct product cost.

The main benefits this approach brings to companies are better profitability measures, better decision and control and better information for controlling capacity cost (Blocher et al. 2005). Because the ABC approach is able to provide more accurate and informative product costs, this would help companies to better estimate the product profitability, improve product design and manufacturing processes and identify and utilise any unused capacity. ABC provides a clear picture of the behaviour and structure of the indirect costs. This is how for instance overheads can be managed much better. Moreover, it can contribute to better cost price calculations for the benefit of the corporate strategy on the market. Although this approach has several advantages, the main problem is that not all costs have a clear activity which they can be allocated with, such as the costs of a manager's salary, property taxes and facility insurance. Another issue is that it has the probability to neglect some of the product costs during the product's lifecycle, such as the costs of marketing, advertising, and research and development. ABC is a fairly complex system and this is also the biggest drawback of the system. When implementing ABC, a lot of time needs to be spent on defining the activities, the calculation of the cost price and the finding of cost drivers. This requires a company to provide detailed cost information which in turn leads to a complicated process. ABC systems are expensive and they are complicated to maintain and adjust[11].

## 2.4 Decision tree to support model choice

As said before, during the early phases of the design cycle, when limited data are available, qualitative cost estimation techniques are more appropriate and provide a helpful starting point for a detailed analysis at a later stage. For example, the proposed casebased methodology systematically makes use of available past data to generate estimates for a similar new product. One problem linked with such techniques is the limited availability of past data, which is overcome to some extent by making use of the past experience or knowledge of the estimator generally encapsulated in the form of decision rules[14].

Qualitative techniques, therefore, are helpful either in furnishing rough cost estimates or serve as a decision-aid tool for designers or estimators especially during the early phases of design process. However, when the detailed design becomes available, quantitative techniques provide more accurate estimates, which are necessary for factors such as design rationalization, determination of profit margins, etc. The data requirements restrict the use of such techniques in the final phases of design and development process. Techniques such as the ABC systems overcome the problem to some extent by making use of the predetermined activity rates to calculate the total amount of activities consumed to manufacture a product rather than requiring any detailed design and manufacturing information. This, however, requires lead times for individual products in the early design stages, which may be obtained using methodologies such as the case-based approach. Therefore, a combination of the two approaches—the qualitative and the quantitative techniques—could play an important role in developing a cost evaluation system capable of providing useful cost information on various stages of design and development phases[14].

The study of individual techniques also revealed the key conditions under which they can be applied. The conditions for the implementation of these techniques discussed in previous sections are summarized in Fig. 2.9 to form a decision-support model (DSM) for cost estimation methodology selection. The developed model is a helpful tool for estimators in making decisions about selecting a suitable estimation methodology. It can be observed that a particular technique linked with a specific class is more applicable in certain situations[14].

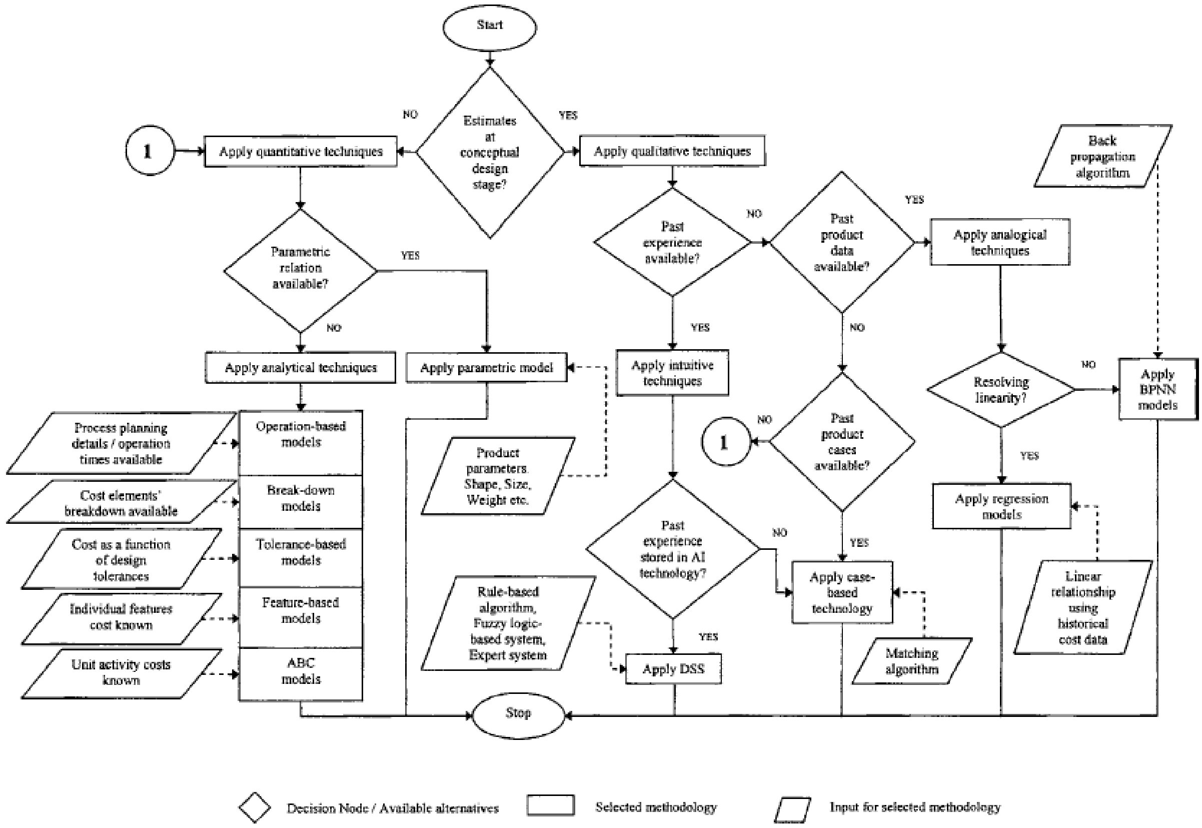


Figure 2.9: Decision-support model for cost estimation methodology selection.[14]

With the advent of computers and the advancement in technology, nonconventional approaches, such as knowledgebased techniques and neural network models, have been applied effectively utilizing past knowledge to predict the future costs in the early design phases. Current trends in cost estimation exploit the feature technology and a simpler trend is based on estimating the costs by calculating the amount of activities performed to manufacture a product. Recent research in the field focuses on getting quicker and more accurate results by developing integrated systems combining two or more approaches. For example, a mix of neural-network approach and feature technology is an emerging trend. Yet another area of ongoing research activities combines rule, fuzzylogic, and feature-based methodologies together. An approach that blends some of these techniques could provide more promising results. For example, there is a need to combine the feature technology with the ABC method to study the effects in detail. An approach dealing with the ABC systems and neural networks at the same time may yet be another research area[14]. The combination of methods varies by application. the new model of estimation adapting better to the available data, provide more reliable results. Subsequently the DSM illustrated here will be used for the case study in question.

## 2.5 Examples in manufacturing industry

The methods illustrated above have been applied in various sectors for cost forecasting. For the construction sector there are several examples such as *Predicting Construction Cost Using Multiple Regression Techniques* (David J. Lowe; Margaret W. Emsley; and Anthony Harding) that describes the development of linear regression models to predict the construction cost of buildings, based on 286 sets of data collected in the United Kingdom. Raw cost is rejected as a suitable dependent variable and models are developed for cost/$m^2$, log of cost, and log of cost/$m^2$. Forty-one potential independent variables were identified. Instead *A neural network approach for early cost estimation of structural systems of buildings* (H. Murat Gunaydın, S. Zeynep Dogan), cost and design data from thirty projects were used for training and testing our neural network methodology with eight design parameters utilized in estimating the square meter cost of reinforced concrete structural systems of 4–8 storey residential buildings in Turkey, an average cost estimation accuracy of 93% was achieved. At last Gwang-Hee Kim, Sung-Hoon An , Kyung-In Kang did *A Comparison of construction cost estimating models based on regression analysis, neural networks, and case-based reasoning* and they noticed that although the best NN estimating model gave more accurate estimating results than either the MRA or the CBR estimating models, the CBR estimating model performed better than the NN estimating model with respect to long-term use, available information from result, and time versus accuracy tradeoffs.

The same methods can also be used to estimate the services costs as Xiao Xi Huang, Linda B. Newnes & Glenn C. Parry demonstrate in *The adaptation of product cost estimation* in which they presented an approach to ascertain whether product cost estimating techniques can be adapted for use in estimating the costs for providing a service techniques to estimate the cost of service.

But in the manufacturing sector the most application cases can be found. Some examples are: *Application of the parametric cost estimation in the textile supply chain* (M. Camargo, B. Rabenasolo, A-M. Jolly-Desodt, J-M. Castelain) in which the parametric methods is applied to estimate the unitary cost of a representative family of wool textile fabrics (this method is widely used in different industrial domains such as aerospace, aircraft, telecommunication); *Cost estimation for general aviation aircrafts using regression models and variable importance in projection analysis* (Xiaonan Chena; Jun Huanga, Mingxu Yia) in fact accurately estimating the development cost of general aviation aircraft plays a key role in devising the best strategy for corporates; *Prediction of total manufacturing costs for stamping tool on the basis of CAD-model of finished product* (M. Ficko, I. Drstvensek, M. Brezocnik, J. Balic, B. Vaupotic) in which the system is based on the concept of case-based reasoning, in the experimental work it was adapted for predicting of tool costs used for tool manufacture on the basis of a theoretic model.

A research has been carried out on application cases as close as possible to the case study in question. In addition to considering the manufacturing sector, the research field has been further narrowed by looking for cases on sheet metal working or automotive products in the design phase. A total of 19 application cases have been collected, none of which however is totally the same as the one in question. In fact, many aim only at predicting the cost of the product quickly and reliably so to reduce the design time and become competitive on the market. The suppliers' point of view has been addressing by Geiger et al. in *Cost estimation for large scale production of sheet metal parts using artificial neural networks*, they used prediction methods to obtain valid supply prices for the submission of offers so could be more simply obtain production jobs from customers.

Many of the application cases found compare the different methods so they could verify which one is the greatest. For the analysis, have been considered all the methods adopted in the cases and then they have been cataloged. In the following Table 2.2 there is a summary of the research.

| **Cost Estimation Model** | **Articles** |
|---|---|
| Case-Based Systems | P.Duverlie and J.M.Castelain (1999); S.Karadgi et al. (2009) |
| Decision Support Sistem | Venkatachalam et al. (1993); S.Karadgi et al. (2009) |
| Analogical Cost Estimation Techinque | R.Roya,S.Colmerb,T.Griggsc (2005) |
| Regression Analysis Model | A. Shtub, R.Versano (1999); Verlinden et al. (2008) |
| Back Propagation neural network Model | A. Shtub, R.Versano (1999); Verlinden et al. (2008); S.Cavalieri, P.Maccarone, R.Pinto (2004); M-Y Chen, D-F Chen (2002); M.Geiger, J.Knolach,F.Backes .(1998); M. Geiger, J.Knolach (2008) |
| Parametric Cost Estimation Techinque | Li Qian, D. Ben-Arieh (2008); S.Cavalieri, P.Maccarone, R.Pinto (2004); R.Roya,S.Colmerb,T.Griggsc (2005); C.G. Hart et al (2012); P. Chwastyk, M. Kotosowski (2013); Farineau et al. (2001); P.Duverlie and J.M.Castelain (1999) |
| Analytical Cost Estimation Techinque | C. Favi, M. Germani, M. Mandolini (2017) |
| Features-Based cost models | P. Chwastyk, M. Kotosowski (2013) |
| Activity-based cost models | Li Qian, D. Ben-Arieh (2008); N.S. Ong (1995); R.Roya,S.Colmerb,T.Griggsc (2005); Li Qian, D. Ben-Arieh (2003); N.S. Ong, L.E.N. Lim (1993) |

Table 2.2: Cataloging of application cases for each cost estimation model

The most authors prefer parametric methods followed by the NN and ABC method for a better estimate, as can be seen from the following Fig. 2.10.

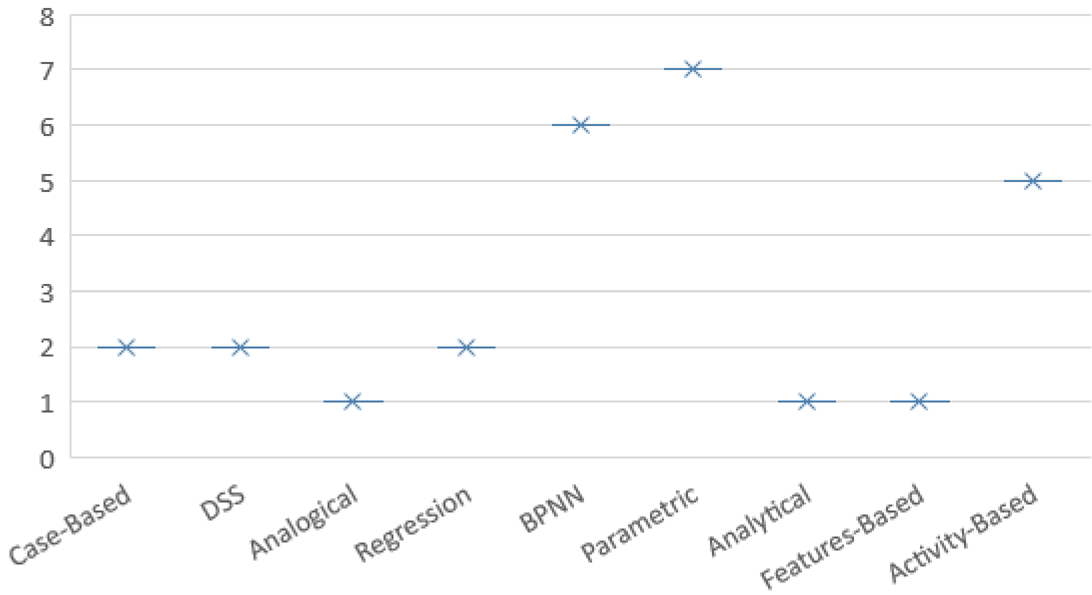


Figure 2.10: Classification of application cases for each cost estimation model

Most cases follow the parametric model but this does not indicate that it is the best. It is simply the most used comparison meter, in fact the different methods are compared with the parametric one because it is the best known, its implementation costs less and it provides good results. The parametric method has been used a lot over the years for these characteristics. Nowadays, however, a new method is being implemented that seems more complex and expensive but provides better results: the NN.

Cavalieri, Maccarrone e Pinto in *Parametric vs. neural network models for the estimation of production costs: A case study in the automotive industry* [5], compared results of the application of two different approaches—respectively parametric and artificial neural network techniques—for the estimation of the unitary manufacturing costs of a new type of brake disks produced by an Italian manufacturing firm. The results seem to confirm the validity of the neural network theory in this application field, but not a clear superiority with respect to the more "traditional" parametric approach: in particular, while the use of a parametric model requires the specification of the analytical expression of the relationship that links input and output, this is not necessary with a neural network. Hence, the ANN is characterized by the possibility to determine autonomously the most appropriate form of the relationship. This can be seen both as a strength and a weakness; indeed[5]:

- the ex ante analysis of the problem is much leaner and faster, and in the case of very complex or innovative problems the outcome is not dependent on the ability of the analysts to find the key independent variables and the most appropriate kind of analytical expression;
- at the same time, the impossibility to know the kind of relationship can be seen as a limit of the neural networkapp roach, since it is not clear

how the results are achieved. In other terms, in the neural network app roach the object of analysis is treated as a "blackbox "; hence, it is impossible to give a theoretical interpretation to the results provided by the tool, especially in the case of unpredicted or (at least intuitively) unjustified values. This fact has often led to some scepticism about this methodology in several application contexts, due also to the difficulty that its "sponsors" face when they are asked to prove the quality of the outcome in case of counterintuitive or questionable results.

Moreover, it could be objected that if the knowledge of the form of the relationship is not needed to implement a neural networkapp roach, it is nevertheless necessary to pre-determine the structure of the network. The answers that can be given to this critical consideration are the following[5]:

- the application contexts of the network structures that have been developed so far (multilayer, Adaptive Resonance Theory or ART, self-organising, etc.) are quite well known, and the identification of the most appropriate structure is then facilitated;

- the software packages for the design of neural networks are generally provided with tools aimed at evaluating the "learning attitude" of the network, and, in case of negative response, at implementing the appropriate modifications.

Another point that is often cited by the users of parametric models is the excellent (or at least satisfactory) quality/ cost ratio. But the implementation cost of a neural networkis generally quite similar to that of a parametric model (the lower costs of preliminary analyses being balanced by the higher costs of developing and testing the ANN). Instead, the higher robustness of the methodology, and the consequent higher propensity to deal with redundant or wrong information enable the elimination or consistent reduction of the activities of data analysis, which are generally very time consuming (and, hence, quite expensive). Another strength of neural networks is related to their flexibility to changes made in the structure of the analysed system once the development of the model has been already completed. For example, if the production process of the firm is modified through the implementation of new technologies, while the parametric model must be completely revised and re-tested, using a neural networkit will be sufficient to conduct a new training program with a new set of data (the structure of the networkmay not even be modified). On the other hand, neural networks are completely data-driven: an adequate set of construction data is then required, while a CER for a parametric model can be also deduced from technical considerations on the production process and on the kind of resources used (as for the typical engineering estimating approach), provided that it can be subsequently validated[5].

In reality many companies create their own personalized method based on their processes and on the historical data available. In this way they try to overcome the limits of a specific method by integrating another. So they get a more reliable and accurate forecasting method but little applicable for other companies. Look for example *An activity-based-parametric hybrid cost model to estimate the unit cost of a novel gas turbine component* (Stephan Langmaak, Stephen Wiseall, Christophe Bru, Russell Adkins, James Scanlan, Andras Sobester) in which the project aimed to find a model that utilized multi-fidelity data from multiple levels of product definition by making use of the synergy effects from using an ABC and parametric model in conjunction.

In conclusion none of the cases seen seeks to price the future of an externally supplied product. In fact, customers do not know all the information and internal costs of the supplier companies regarding their consolidated partnership. Furthermore, often a supplier is chosen, rather than another, not only on the basis of the price of the product but also on the basis of other factors. Price is one of the supplier's choice factors but not the only one. This topic is further explored in the next chapter and it will also be possible to note it within the case study.

# Chapter 3

# Decision making techniques for supplier evaluation and selection

An important ingredient of the competitive game is the type of supplier/customer collaboration in the development of new products. Because a large amount of the firm's manufacturing goes on outside its walls, the relationships with suppliers of critical components are of the utmost importance. Until recently, however, the literature on NPD has rarely dealt with this topic, whereas there has been much description of how Japanese, American, and European firms exhibit very different levels of supplier involvement in the innovative process.

In each sector, the correct evaluation and selection of suppliers is fundamental for progress and development. With the extensive use of business systems and an emphasis on quality improvement concepts, managers seek to go beyond the conventional boundaries of money and material and try to explore the vast new universe of possibilities. In most business processes, it has become essential for companies to turn to a few trusted suppliers who can provide high quality products with minimal lead times and affordable prices. The selection of suppliers has become an important component of the organization's decision-making process and has proven to provide a competitive advantage over competitors, while maintaining strategic and operational constraints. The selection of suppliers involves various criteria including speed, delivery performance, price, quality, reliability, etc. And it often involves selecting one by sacrificing the other. Consider a situation where a supplier supplies goods at cheap rates but is unable to deliver on time. On the other hand, another supplier is supplying the best quality products but delivery performance and prices are not acceptable. Therefore, supplier selection includes that companies must identify the main priorities of selecting the best supplier based on their work style and sector type. Different researchers have proposed extensive decision making techniques to provide a feasible and effective solution to supplier selection problem. There is no single classification for this topic too, but based on the sector type there are different method explained in literature, often mixed with each other[1].

The first part of the chapter aims to highlight the importance of suppliers within the NPD process while in the second are illustrated decision making techniques paying particular attention to the manufacturing sector. The literary review offered in this chapter allows to contextualize the bidding process and to show that there are currently no specific articles that deal with the forecast of supplier prices. Often overlooked for lack of data. Thanks to the construction of the cost forecast model, it will be possible to obtain a comparison benchmark that will allow a better evaluation and selection of suppliers as well as show any inefficiencies of suppliers with which the company already has relationships.

## 3.1 Partnering Models in New Product Development

An important ingredient of the competitive game is the type of supplier/customer collaboration in the development of new products. Because a large amount of the firm's manufacturing goes on outside its walls, the relationships with suppliers of critical components are of the utmost importance. Until recently, however, the literature on NPD has rarely dealt with this topic, whereas there has been much description of how Japanese, American, and European firms exhibit very different levels of supplier involvement in the innovative process. The empirical evidence suggests that Japanese suppliers do four times more engineering work for a specific project than do US suppliers, whereas Europeans lie somewhere in between. In the last two realities suppliers are generally obliged to produce under short-term, arm's length contracts with a marginal role in design and engineering, but in the Japanese context they are strictly integrated in the development process. Some of the major suppliers offer the entire development process, including planning, design, and manufacturing, and their early involvement comes with high degrees of responsibility and extensive communication flow. To better capture the differences among the various strategies and to provide a theoretical framework for the analysis of the case study, we referred to previous contributions on the themes of NPD and procurement. In analyzing how firms involve their suppliers in the innovative process, two dimension should be considered[3]: (1) the timing of their involvement; and (2) the degree of competition among them at the time of their involvement.

- **Timing of involvement**
  The development process is made up of several, identifiable stages, which can be organized *sequentially* or in an integrated, *overlapping way.* In the first case, each stage provides the input to the next one. No stage is supposed to begin before the preceding one is terminated by an abandon/kill decision. In the overlapping model, which is commonly found in Japanese companies, the NPD process is managed by an integrated team employing people carrying out many activities simultaneously. By "timing of involvement," we mean the stage of the NPD process at which the lead manufacturer begins to search for suitable suppliers and make them aware of the project, irrespective of the overall nature of the process-i.e.,

sequential or overlapping. The involvement of suppliers can take place: (1) in the concept stage; (2) in the development stage, after detailed design is completed and technical specifications issued; (3) in the feasibility stage or at the very beginning of the development stage, before detailed design but after the concept design has been completed.

- **Degree of competition among suppliers**
  Referring to the degree of competition among suppliers at the time of their involvement in the NPD process, several situations can be distinguished: (1) because the probability to be selected is the same, an open competition among suppliers exists. The number of suppliers involved may vary from all the potential vendors to a small number of approved suppliers; (2) a certain degree of competition exists, but a small number of suppliers has a greater probability to be selected; (3) a selected supplier already exists and, consequently, it becomes a firm's partner in the innovative project.

By combining these dimensions, three different approaches to the topic of the involvement of suppliers in NPD emerge as pure models (Table**??**): the "traditional," the "Japanese," and the "advanced" models[3]:

- **Traditional model**
  In this model, suppliers are involved after the design is completed and technical specifications issued. The design process is a black box for suppliers and the information disclosed by the leading firm is limited. The lack of explicit involvement in the early stages of the innovative process is normally joined with competitive procedures for supplier selection and order award. Suppliers are requested to quote a price and offer full technical and commercial conditions against technical specifications. In the pure competitive procedure, all potential suppliers are invited. This is not a necessary condition of the traditional model, however. The invited bidders may be a large number (all potential suppliers reported in trade directories or data-bases) or a small number (approved vendor list or qualified suppliers).

- **Japanese model**
  The involvement of suppliers in the NPD normally takes place in the concept stage, before the design of the new product. Collaborative supplier relations are seen as the way to speed the pace of new product introduction and sustainable long-term performance. This is true expecially for first-tier suppliers or primary suppliers, who are responsible for design, development, and sometimes assembly of integrated parts and systems. These suppliers join the firm's meetings at the very beginning of the NPD process, and the different players engage in an interactive pattern of communication whose main dimensions are richness, direction, timing, and frequency. Despite the benefits of this approach, selecting a single source at the very beginning of the development process would not allow the companies to capture new ideas emerging from other suppliers.

- **Advanced model**
  This model balances the benefits of the Japanese model with the access to new technical ideas until the final definition of the product design. The advanced model appears to be the dominant approach in high-tech industries (i.e., the aircraft industry), where a small group of preferred suppliers are involved in NPD before the definition of product specifications. They are requested to invest in development work in order to supply the customer with detailed technical solutions. Technical discussion meetings are regularly held, and all the invited suppliers are requested to demonstrate with simulations, drawings, and computer printouts, the performance of the components, parts, or systems they propose. At the same time, customers frequently ask for additional proposals and new technical solutions. In the advanced model, supplier selection does not take place necessarily at an early stage of the NPD process. All the invited suppliers are supposed to invest in the pre-selection development work, even if only one of them will win.

### 3.1.1 Benefits of Traditional Model

Over the past twenty years, many industrial sectors have undergone major changes in market conditions from both the demand and supply points of view. (Jesper Mommea, Hans-Henrik Hvolb, 2001)

As for the former, the companies have had to face ever more specific requests and ever more restrictive constraints imposed by the new types of buyers upstream of the supply chain. Previously, customers were limited to asking for low prices, high quality and an excellent shipping service. Today, in addition, they expect a shorter life cycle and time to market of the product, a high innovative component and a strong customization (Kotha, 1995; Sanchez, 1997).

The offer was instead influenced by globalization and the increasing competition that companies and their suppliers face in their reference market (Kim Langfield-Smith, David Smith, 2003).

Outsourcing is considered as a form of strategic alliance, particularly when outsourced activity is important for the organization. As described in Table 1.3, several scholars have analyzed the reasons that led to the spread of this phenomenon, from the early nineties to today, both in the private and public sectors.

One of the main reasons that drives companies to outsource is the reduction of operating costs. Managers see outsourcing as an excellent tool to achieve their short-term optimization objectives, imposed by the pressures of an increasingly competitive and constantly changing market.

Another reason that drives companies to outsource some minor or support activities is to be able to focus more efficiently on core activities, having more resources and time available. The outsourcing also gives the opportunity to reduce capital investments and therefore have more liquidity available and allows you to have a more detailed view of the expenses and costs incurred.

| Process Stages | Selected Suppliers | Preferred Suppliers | All Potential Suppliers or Approved Vendors |
|---|---|---|---|
| **Concept stage** | | | |
| Idea generation | | (Informal networking) | |
| Screening | | | |
| Preliminary market evaluation | | | |
| Concept design | Supplier selection/ partnership | Request for information | |
| **Feasibility stage** | | | |
| Preliminary technical evaluation | | | |
| Market research | | Technical discussion | |
| Economic and financial analysis | | | |
| **Development stage** | | | |
| General design | | | |
| Detailed design | | Technical discussion | |
| Make-or-buy analysis | | | |
| Technical specification issue | | | |
| Bidding procedures | | | |
| Supplier selection | | Request for proposal | Request for proposal |
| Prototype delivery | | | |
| **Scale-up stage** | | Supplier selection | Supplier selection |
| **Commercialization stage** | | | |
| | Japanese model | Advanced model | Traditional model |

Table 3.1: Degree of competition among suppliers at the time of their involvement in the NPD process.[3]

| Main reasons identified | Most important references |
|---|---|
| Reducing operating costs | Lacity and Hirschheim (1993b); McFarlan and Nolan (1995); Barthe´lemy and Geyer (2000); Kakabadse and Kakabadse (2002) |
| Focusing on core skills | Quinn and Hilmer (1994); Saunders et al. (1997); Alexander and Young (1996b); Kakabadse and Kakabadse (2002) |
| Reducing capital investment | McFarlan and Nolan (1995); Kakabadse and Kakabadse (2002) |
| More flexibility | Barthe´lemy and Geyer (2000) |
| Accessing to external skills and improve their own | Quinn and Hilmer (1994); McFarlan and Nolan (1995); quality Kakabadse and Kakabadse (2002) |
| Transforming fixed costs into variable costs | Alexander and Young (1996a) |
| Regaining control over internal departments | Lacity and Hirschheim (1993a); Alexander and Young (1996a) |

Table 3.2: Main reasons why companies choose the outsourcing strategy

Finally, the company can resort to outsourcing to acquire from the outside or integrate its skills with new ones, in order to profitably enter new sectors. Through this process, fixed costs are transformed into variable costs and the internal departments over which the company has lost control can be completely reorganized.

The expected results are achieved only by the companies that implement, plan and manage outsourcing in an efficient and organized way taking into account all the possible costs that may emerge and not making short-term objectives prevail over long-term ones (Porter 1994). Firms that underestimate the complexity of the outsourcing process often get more harm than good. Even in these cases, the choice to outsource must be carefully evaluated because the negotiation, contractual, management, transaction costs and all the internal company reorganization costs could be so high as not to be considered such a convenient choice (Bertrand Què Lin, 2003).

### 3.1.2 Benefits from Partnering at the NPD level

This section, based on Bonaccordi and Lipparini, article explores some of the benefits of early involvement of suppliers in NPD, such as reduced development costs, higher quality with fewer defects, reduced time to market, and supplier-originated innovations. In considering that, in the emerging competitive scenario, these aspects have to be pursued simultaneously, and a strategy of closer relationships with critical suppliers could benefit the leading firm in terms of increased predictability of development results and ability to respond to the competition[3].

- **Reduced Development Cost**
  The benefits of early involvement of suppliers are likely to be higher

when industries move toward maturity, because cost effectiveness does not depend on major product design innovations or process technology breakthroughs but on a huge number of small savings in all the details of a product. Nevertheless, by anticipating the involvement of suppliers in the innovative process, all firms can reduce their development costs. It is possible thanks to: early availability of prototypes, standardization of components, consistency between design and suppliers' process capabilities, reduced engineering changes, target price contractual arrangements.[3]

- **Higher quality with fewer defects**
  The increasing relevance of quality for competition has led to a complex evolution of quality control philosophy and techniques. A significant chapter in this evolution is the acknowledgment that the overall quality is strictly dependent on the quality of products, processes, and systems at any point of the vertical chain. Many recent changes in supplier management (quality assurance manual, qualified suppliers, "free pass" techniques, total quality control) are the result of pressures for increased quality. A relationship between these changes and the involvement of suppliers in NPD does not always exist. However, findings from Japanese context demonstrated that closer ties with suppliers are associated with lower reject rates and higher quality levels, thanks to: consistency between product tolerances and process capabilities, refinement of the suppliers' processes, availability of detailed process data.[3]

- **Reduced Time To Market**
  Manufacturing companies are trying to expedite the movement of new technology and products from product concept to marketplace. They tend to focus primarily on products made up of mechanical assemblies and on organizational processes: simultaneous engineering, design for manufacturability, interdisciplinary teams, and statistical tools, such as statistical process control or design-for-assembly techniques. A critical element of shorter cycles lies is knowing how to integrate operations that take place outside the company. The advantages of the suppliers' integration are about: concurrent engineering, earlier identification of technical problems, reduced suppliers' process engineering time, acquisition of suppliers' production capacity.[3]

## 3.2 Supplier evaluation criteria

Supplier or vendor selection decisions are complicated by the fact that various criteria must be considered in decisions making process. The analysis of criteria for selecting and measuring the performance of suppliers has been the focus of many scientists and purchasing practitioners since the 1960's[2].

The majority of research about supplier selection problem mentions Dickson's study[6]. It is based on a questionnaire sent to 273 purchasing agents and managers selected from the membership list of the National Association of Purchasing Managers, which include agents and managers from the United States and Canada. Dickson's study describes the importance of 23 criteria for supplier selection which are classified with respect to their importance observed in the beginning of the sixties. At that time (1966), the most significant criteria are quality of the product, the on-time delivery, the performance history of the supplier and the warranty policy used by the supplier (See Table ??).

| **Rank** | **Criteria** |
|---|---|
| 1 | Quality |
| 2 | Delivery |
| 3 | Performance history |
| 4 | Warranties and claim policies |
| 5 | Production facilities and capacity |
| 6 | Price |
| 7 | Technical capability |
| 8 | Financial position |
| 9 | Procedural compliance |
| 10 | Communication system |
| 11 | Reputation and position in industry |
| 12 | Desire of business |
| 13 | Management and organization |
| 14 | Operating controls |
| 15 | Repair service |
| 16 | Attitude |
| 17 | Impression |
| 18 | Packaging ability |
| 19 | Labor relations record |
| 20 | Geographical record |
| 21 | Amount of past business |
| 22 | Training aids |
| 23 | Reciprocal arrangements |

Table 3.3: Dickson's Supplier selection criteria. [6]

The 23 criteria presented by Dickson still covers the majority of the criteria presented in the literature nowadays, but the evolution of the industrial environment modifies the ranking of these criteria or adds others criteria that are considered important too[6]. Furthermore, there are criteria more important than others depending on the process, so it is not easy to define one exclusive list. The most used criteria in a decreasing sense, are:

- **Quality.** Product quality.
- **Performance Delivery.** The certainty of the right product delivered at the right time in the right quantity.
- **Service.** Follow instructions handling complaints, ease of doing business and quick response.
- **Price/Cost.** Competitive pricing and total cost including price.
- **Lead-time.** The elapsed time from order being placed to delivery.

- **Financial strength.** Cash flow and stability.
- **Flexibility.** Ability to adjust volumes and delivery times.
- **Technical ability.** Modern equipment, ability to follow the development.
- **Development.** Innovation, improvement in order to improve products and reduce costs.
- **Fill rate.** Fraction of orders that are completely filled within the stated lead-time.
- **Production Capacity.** Capacity to increase and decrease volumes.
- **Management approach.** Good relationship and commitment.
- **Geographic location.** Place where the supplier is located.

## 3.3 Decision making approaches

The researchers have used various approaches to solve the complex and uncertain MCDM problems of supplier evaluation and selection. Below we have tried to give a classification that follows that proposed by Agarwal et al. (2011)[1]:

- **Data envelopment analysis (DEA)**
  This approach, considers suppliers and their processes as a system, in which the output (benefit) is identified as the weighted sum of the outputs (e.g. delivery performance, quality, etc.) of the suppliers and the inputs are the weighted sum of inputs (costs). Using the outputs and inputs, the efficiency of the system is determined. Using DEA, the researchers have proposed how to find out the optimal weights to maximize the supplier's performance ratings (efficiency). The method is then used to classify the suppliers as efficient and inefficient.

  Weber (1996) applied DEA for a single product and proposed a model from the organizations to use it for supplier selection for other products as well. In his model, six vendors were evaluated who were supplying some product to baby food manufacturing company. He showed how much reductions in cost and improvement in quality could be achieved while maintaining the delivery performance. Braglia and Petroni (2000) conducted a questionnaire survey with 89 manufacturing firms in Brescia (Europe) and applied DEA to measure the related performance of various suppliers based upon the article of Baker and Talluri (1997). They proposed nine evaluating factors to evaluate the suppliers. Forker and Mendez (2001) proposed the application of DEA to measure comparative efficiency of suppliers. Comparative efficiency was calculated as a ratio of single input to multiple outputs. Narasimhan et al. (2001) came up with proposed evaluating factors to apply DEA for supplier evaluation. Out of the eleven factors considered, there were six inputs, which denoted supplier's capability and five outputs, which symbolized supplier's performance. They classified suppliers into four sections based on performance and efficiency.

Saen (2006) developed a model based on DEA to evaluate technology suppliers on mainly three factors. The idea was to propose a DEA based method for selecting technology suppliers, knowing in advance the nondiscretionary factors from supplier's perspective and the qualitative factor, which ranked them on the scale of five. Seydel (2006) used DEA to solve supplier selection issue. The important thing in this article was that unlike the other approaches, no input was considered in this model. The article used seven point scales to rank the qualitative aspects of the suppliers. Further the article points that the proposed DEA required less effort than simple multi-attribute rating technique (SMART). Talluri et al. (2006) proposed a chance constrained DEA approach to evaluate supplier performance taking into consideration the stochastic performance measures. This study proposed that in order to predict the supplier performance, understanding the variability in vendor attributes is important. The input criteria considered was price, while the outputs were delivery and quality. The comparison of the model with the deterministic DEA highlighted its usefulness. Mondal and Chakraborty (2010) proposed the idea of selecting the flexible manufacturing system in an organization using DEA. Initially, the alternatives were shortlisted on the basis of the best criterion as per Charnes, Cooper and Rhodes (CCR) DEA model and then the shortlisted alternatives are ranked based on the weighted efficiency ranking method of MCDM theory.

- **Mathematical Programming Models**

  - *Linear Programming*
    Talluri and Narasimhan (2003) are the first group of researchers who focused on the importance and implications of performance variability in evaluating different suppliers. The researchers saw the process as a system in which the main objective was to minimize the input items such as cost and to maximize the outputs such as quality, delivery performance, etc. The researchers proposed two linear programming (LP) models so that groups of homogenous suppliers can be easily identified, which provides discriminate choices in final selection.

    Talluri and Narasimhan (2005) designed a linear programming model to help decision makers or buyers select and evaluate different suppliers. The model is based on quantitative measures to select potential suppliers considering the strengths of existing suppliers and to eliminate underperforming suppliers, taking the case of a large, multinational, telecommunications company. The researchers further compared the effectiveness of the proposed model with traditional and advanced DEA, to determine its advantages. Ng (2008) developed a weighted linear programming (WLP) model for supplier selection, using the subjective and mathematical approach to maximize the supplier score. The researcher proposed a transformation technique, which eliminates the need of optimization to solve the weighted linear program.

- *Integer linear programming*
  Talluri (2002) proposed a binary integer linear programming model for evaluating alternative supplier bids. The researcher proposed the use of alternative bid ratings in selecting an optimal set of bids, which satisfy the demand requirements. Talluri (2002) proposed four variations of the model to assist the buyer in making effective decisions in different environments. Hong et al. (2005) developed a model based on mixed-integer linear programming (MILP) for the supplier selection, which not only maximizes revenue but also helps fulfilling customer's needs. The main objective was to find out optimal number of suppliers and order quantity in order to maximize revenue with consideration of variability in the customer needs and suppliers performance. Rajan et al. (2010) proposed supplier selection model for multiproduct, multi-vendor environment based on integer linear programming (ILP) model. The proposed model was validated on agriculture equipment wholesaler.

- *Integer non-linear programming*
  Ghodsypour and O'Brien (2001) used the concept of mixed integer non-linear programming to propose a model to solve the supplier selection problem. The researchers' model was designed to find the optimum number of suppliers and order size to be allocated to each supplier, in order to minimize the overall annual purchasing cost. The article was divided into two groups: single and multi objective.

- *Goal programming*
  Karpak et al. (2001) are the first group of researchers who proposed goal programming (GP) model to evaluate the suppliers. Quality, cost, and delivery performance were the three identified objectives. The model was to find out the optimal quantity of products (ordered), subject to demand and supply constraints.

- *Multi-objective programming*
  Narasimhan et al. (2006) developed a multi-objective programming model to solve supplier selection problem and came out with the optimal order quantity. Five criteria, minimum order size, maximum available supply, stipulate price, quality, and promised delivery-performance levels, were used to evaluate the suppliers' performance. Wadhwa and Ravindran (2007) proposed another multiobjective programming model to solve the supplier evaluation and selection problem, wherein there were three minimization functions: price, lead time, and rejections. To solve the resulted mentioned cases, three solution approaches, weighted objective, goal

programming and compromise programming method, were used to discriminate and compare the solutions.

- **Analytic hierarchy process (AHP)**
  Akarte et al. (2001) identified eighteen criteria, six objective types and twelve subjective, for supplier assessment and divided them into four groups: quality capability, product development capability, manufacturing capability, and cost and delivery. The researchers developed a web-based system to evaluate the suppliers. Muralidharan et al. (2002) developed a five-step AHP-based model, which incorporated nine evaluating criteria for rating and selecting suppliers. People from different departments, such as quality control, purchasing, and stores, were concerned in the selection process. Chan (2003) developed selection model using AHP, which facilitated selection of suppliers. Chan and Chan (2004) used AHP hierarchy to evaluate and select suppliers. Their model consisted of six evaluating criteria and 20 sub-factors. Computations of different relative importance ratings were performed based on the customer requirements. Liu and Hai (2005) used similar approach proposed by Chan and Chan (2004) with a difference that they used Noguchi's voting and ranking method. This method helped manager in voting and in determining the criteria order instead of the weights.

  Chan et al. (2007) proposed an AHP-based multi-criterion decision making approach of supplier selection and their evaluation was performed based on 14 different criteria. They proposed a model to provide a framework to select appropriate suppliers and provided some details on how to deploy organization's strategy for the suppliers. Hou and Su (2007) developed a distributed system to identify appropriate suppliers for components in a mass customization environment. Their method uses dynamic and robust method of evaluating product market position and development directions. Kumar and Roy (2011) proposed a rule based model with the application of AHP to aid the decision makers in vendor evaluation and selection taking the power transmission industry. The article presented a three-step model to calculate the performance scores of various vendors and select the best vendor. The researchers also validated the proposed model taking the data from a multinational transformer company.

- **Case based reasoning (CBR)**
  Choy and Lee (2002) proposed a generic model of CBR integrating customer relationship management (CRM) and supply chain management (SCM) to identify appropriate supplier for the products, services and distribution. Different evaluating criteria were categorized as: quality system, technical capability, and organizational profile. The model was executed for a consumer products manufacturing company, which maintained a database of past suppliers and their attributes. The selection of supplier was performed by fulfillment of the defined specification. Choy et al. (2002), Choy and Lee (2003), Choy et al. (2003a), Choy et al.

(2003b), Choy et al. (2004), Choy et al. (2005) applied the CBR based methodology for supplier selection problem. This approach was similar to the one proposed by Choy and Lee (2002), including the framework for supplier selection. In addition, testing on the data was performed for the same company based on the proposed model.

- **Analytic network process (ANP)**
  Sarkis and Talluri (2002) introduced a dynamic strategic decision model based on ANP (Saaty, 1996) to help decision makers select best supplier for their firm, taking inputs from all managerial levels, from strategic to operational, in the dynamic ever changing environment. The authors identified and applied seven evaluating criteria to evaluate the suppliers. Bayazit (2006) proposed an ANP based methodology, which incorporates feedback and interdependent relationships in evaluating and selecting best supplier for a firm. The researcher identified ten evaluating criteria in the model, classified into supplier's performance and capability clusters. A pair wise comparison matrix was setup to formulate interrelationships among all criteria. Gencer and Gürpinar (2007) proposed an ANP based model for an electronic company for supplier evaluation and selection with respect to various evaluating criteria. The proposed model consisted of forty-five criteria classified under three main criteria cluster.

- **Fuzzy set theory**
  Chen et al. (2006) proposed a hierarchy based MCDM model to deal with supplier selection problem. The researchers proposed the linguistic values, expressed in trapezoidal or triangular fuzzy numbers used to analyze the weights and the rate of the evaluation factors. The proposed model was validated on a high technology manufacturing firm to select key suppliers for components of a new product. Sarkar and Mohapatra (2006) developed a systematic framework to reduce the number of suppliers in order to facilitate the decision makers in selecting the best supplier. They suggested that capability and performance were the major dimensions in supplier selection. The researchers presented the capability-performance matrix that help in arranging the suppliers in decreasing order of preference. In order to validate the framework, a hypothetical case was considered to show how two best suppliers were selected with four performance-based and ten capability-based factors.

  Florez-Lopez (2007) presented an approach to obtain an index of supplier preference and considered fourteen evaluating factors out of eighty-four potential value added attributes. The considered factors were based on the survey of US purchasing managers. The researchers presented a two-tuple fuzzy linguistic model to combine both numerical and linguistic information. Büyüközkan and Çifçi (2011) proposed a novel framework based on fuzzy set theory for solving the multi-criteria decision-making problem under incomplete relations. The researchers proposed the framework for sustainable supplier selection based on some criteria such as time pressure, lack of expertise in the related area and focused on the skill set and capability of the supplier in delivering the products called robust system.

- **Simple multi-attribute rating technique (SMART)**
Barla (2003) proposed a five-stage multi attribute selection model (MSM) for vendor evaluation and selection taking the case of a glass manufacturing company. In the model, seven evaluating criteria of reliability, capability, quality organization, geographic location, financial condition, service level and price were considered. Huang and Keska (2007) presented an integration mechanism to form a comprehensive and configurable metrics arranged hierarchically, which considers product type, original equipment manufacturer (OEM)/supplier and the level of supplier integration. The model was to find the best strategic fit between the firms and the supplier's strategy based on the set of metrics. The model was so developed that the best possible decision could be made based on the chosen and validated set of metrics. The researchers presented a total of one hundred and one metrics for supplier selection.

- **Genetic algorithm**
Ding et al. (2005) proposed a new simulation optimization methodology to facilitate buyers in evaluation and selection of suppliers. The researchers presented a Genetic Algorithm (GA) based optimization methodology. The proposed methodology comprised three basic modules: a discrete event simulator, a GA optimizer, and supply chain modeling framework. The possible configurations of the suppliers were selected and then validated on the basis of the key performance indicators.

- **Criteria based decision making methods**
Almeida (2007) proposed the application of ELECTRE (Elimination Et Choix Traduisant la REalite – ELimination and Choice Expressing the Reality) method for solving the supplier selection problem. The article used ELECTRE for multi-criterion evaluation and used utility function to evaluate different alternatives. Athawale et al (2009) proposed the application of PROMETHEE, Preference Ranking Organization Method for Enrichment Evaluation, to facilitate the buyers in the process of supplier evaluation and selection. The scholars used the qualitative and quantitative criteria and their relative importance to rank various suppliers, helping in better evaluation and selection. The researchers verified the application of PROMETHEE taking the real life data of a company. Athawale et al (2010) proposed the application of PROMETHEE-II in solving the complex MCDM problem of supplier evaluation and selection. The researchers verified the application of PROMETHEE-II taking the real life data of two companies. Zolghadri et al (2011) presented the concept of power based evaluation and selection. According to the article, strong suppliers can exert more power to influence the product development process for their own benefits. The researchers considered the

customer perspective in the dyadic relationship and proposed a method for estimating the relative powers of supplier and buyer.

## 3.4 Other methods

In addiction it is possible to integrate different methods. Thereby, Ramanathan (2007), Saen (2007) and Sevkli et al. (2007) proposed an integrated AHP-DEA approach; Perçin (2006), Kull and Tarulli (2008) and Mendoza et al. (2008) presented an integrated AHP-GP approach; Mendoza and Ventura (2008) proposed an integrated AHP and mixed integer non-linear programming approach; Weber et al. (2000) and Talluri et al. (2008) utilized an integrated DEA and multi-objective programming to develop a new method; Seydel (2005) applied a integrated DEA and SMART; Liao and Rittscher (2007) formulated an integrated GA and multi-objective programming model. The distribution of the articles under various classes of MCDM methods is shown in Fig. 3.1.

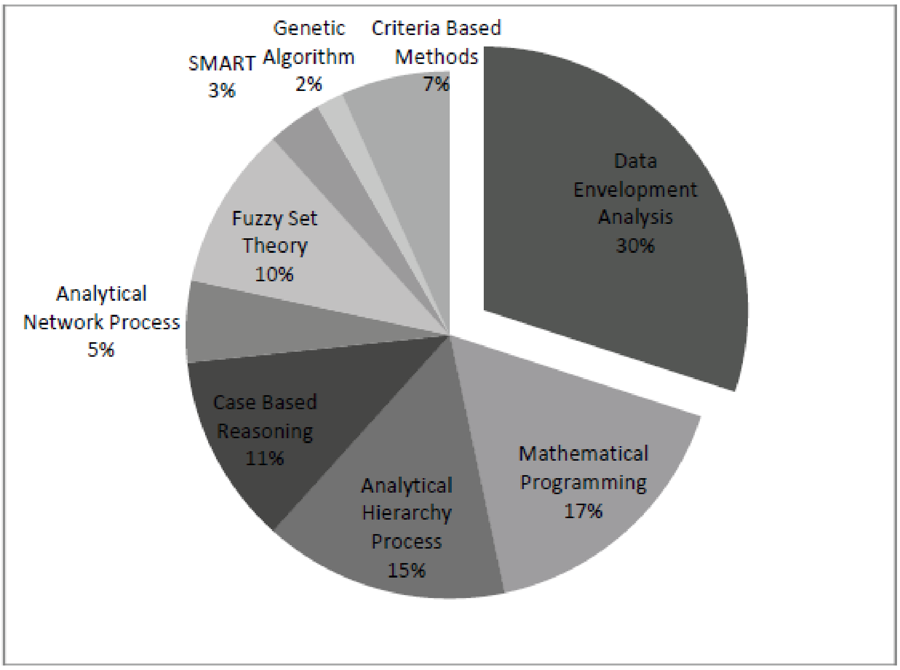


Figure 3.1: The percentage distribution of the number of articles under various MCDM approaches.[1]

The most widely applied methodology was data envelopment analysis (DEA), mainly attributed for its robustness. There is a need to evaluate the suppliers based on the inputs of the strategic, functional and operational levels. The implication of lean manufacturing and popularly used JIT approach has forced the researchers to shift the focus from the efficiency based model to quality based approach. The single criterion approach of the lowest cost supplier is no more accepted in this challenging and continuously changing environment. Thus, price or cost shifted down the line with respect to its importance in evaluating the suppliers, while the quality and delivery performance climbed up the hierarchy. Many evaluating criteria can be derived depending on the requirements of the company. Thus, it is important to analyze and prioritize different selection methods to satisfy stakeholders. Using methods like DEA, AHP, etc. suppliers can be ranked and evaluated to make an optimal supplier selection. Some methods can be beneficial to some specific companies so it is important to evaluate suppliers according to companies' specifications. In addition, AHP is used to evaluate supplier according to different categories to provide consistency in supplier selection. Thus, AHP can definitely aid the researchers and decision makers in meeting the challenging task of the supplier selection problem effectively in the near future.

# Chapter 4

# Introduction to the Application Case

For the last century, the car culture has spread over the entire globe. As much as any other product, the car has shaped not only the global economy but how billions of people live. In Europe alone, the automotive industry accounts for roughly 12 million jobs (including related jobs); in the US, more than 8 million; and in Japan, more than 5 million. For all of its staying power, though, the industry has also seen constant change. Today's cars – with their drive-by-wire electric systems or drive assistants – would have astonished Henry Ford, Ferdinand Porsche, and Kiichiro Toyoda. They would also have been taken aback by the increasingly demanding environmental requirements and the rise of new players, particularly in China. Overall, the global automotive industry is in better shape than it was five years ago, especially in the US, where profits and sales have recovered following the recent economic crisis, and in China, where growth remains strong. This progress will likely continue. By 2020, global profits for automotive OEMs are expected to rise by almost 50 percent. The new profits will come mainly from growth in emerging markets and, to a lesser extent, the US. Europe, Japan, and South Korea will be stagnant in terms of profit growth[13].

This chapter aim to introduce the OEM (Original equipment manufacturer) market point of view, that depend on the evolving of the automotive industry and its market. In fact, the company presented in the case study in question belongs to this varied market, as a supplier of car manufacturers. Hence, the first part of the chapter will focus on current analysis of the sector and its future trends, after which the company will be introduced. In particular, starting from the illustration of the business process in question, it will be possible to identify its difficulties by finding the problem faced in the thesis, then then the objectives that the company wants to achieve. The chapter ends with an example found in the literature of a case study very close to the one in question. It provides an additional guideline to understand the company's goal and possible future developments of the designed cost model.

## 4.1 The Context: The Automotive Sector

The global automotive industry is about to enter a period of wide-ranging and transformative change, as sales continue to shift and environmental regulations tighten. The companies that want to have a successful, long-term future need to get key strategic decisions right in the next decade. The future will not play out the same way for every country or type of car, so the McKinsey's report "The road to 2020 and beyond:What's driving the global automotive industry?" segments the markets accordingly and breaks down the industry geographically as follows: Europe (excluding Russia), North America (US, Canada, Mexico), Japan and South Korea, the BRICs (Brazil, Russia, India, China), and the rest of the world (RoW). It is based on many discussions and interviews with the top management of leading automotive original equipment manufacturers (OEMs) and an analysis of data from the top 17 (by sales) global OEMs, which comprise 80 percent of global sales. Globally, the automotive industry has recovered from the economic crisis. Industry profits in 2012 (EUR 54 billion) were much higher than in 2007 (EUR 41 billion), the last precrisis year, and the prognosis for future growth is even better. By 2020, global profits could increase by another EUR 25 billion, to EUR 79 billion. That is good news, but the benefits will not be distributed equally across all geographies or all types of cars. Instead, some regions and segments will do much better than others. What is most striking about the recent past is how profoundly the source of profits has shifted. In 2007, the BRICs and RoW accounted for 30 percent of global profits (or EUR 12 billion). In 2012, that share rose to nearly 60 percent (EUR 31 billion), as sales in these regions rose 65 percent and outpaced growth in Europe, North America, Japan, and South Korea (Fig.4.1). More than half of this growth came from China (EUR 18 billion)[13].

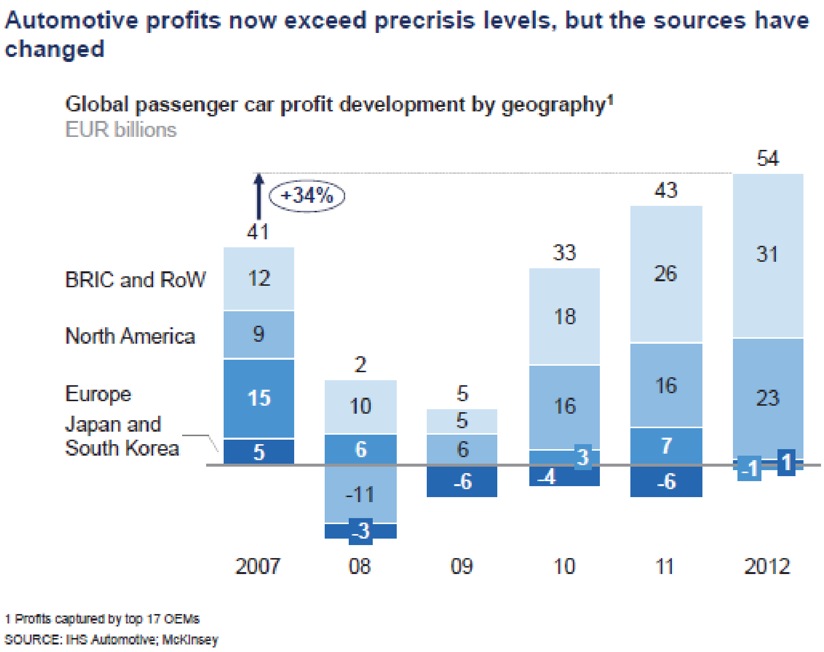


Figure 4.1: Global passenger car profit development by geography.[13]

Europe went in the other direction: in 2007, its automotive industry recorded profits of EUR 15 billion. By 2012, that profit had become a loss of EUR 1 billion. There are two main reasons for the decline. First, fewer people bought new cars. Across the region, the number of new registrations declined by more than four million units over this period, and car sales today are at levels last seen in the early 1990s. Second, Europe's well-developed automotive industry suffers from overcapacity; fierce competition is keeping prices (and therefore profits) down. Japan and South Korea are also looking far from robust. Both markets suffered from the economic crisis, and Japan endured another hit in 2011, with the tsunami-earthquake disasters in March. But in 2012, both countries saw their first profitable year since 2008.

By contrast, North America is in good shape: profits improved from EUR 9 billion in 2007 to EUR 23 billion in 2012. Sales in North America reached 17 million units in 2012 – the most in five years – and are rising again this year. The product mix has also started to shift to higher-value pickups and SUVs. Finally, following some painful balance sheets and labor and non-cost restructurings, the cost structure of leading OEMs has significantly improved, providing a basis for enhanced profitability. Not only did emerging markets (the BRICs and RoW) account for almost 60 percent of worldwide automotive profits in 2012, these regions are poised to significantly outpace growth in established markets over the next seven years. Profit in the BRICs and RoW is projected to grow more than three times as fast as in established markets.

By 2020, emerging markets will account for approximately two-thirds of the total automotive profit, and China will be the driving force (Fig. 4.2). The vast majority of the estimated additional profits (EUR 25 billion) will come from steady sales growth (an estimated 3.8 percent a year, including 4.4 percent for the premium segment). The sources of those profits, however, will be rather lopsided. McKinsey's research indicates that China will account for a little more than half – EUR 13 billion, including EUR 9 billion from the premium segment alone. Other emerging markets will add about EUR 6 billion, while established markets will likely contribute only EUR 4 billion in additional profits, almost all of that from North America. Additional challenges and opportunities could add EUR 2 billion to total profit.

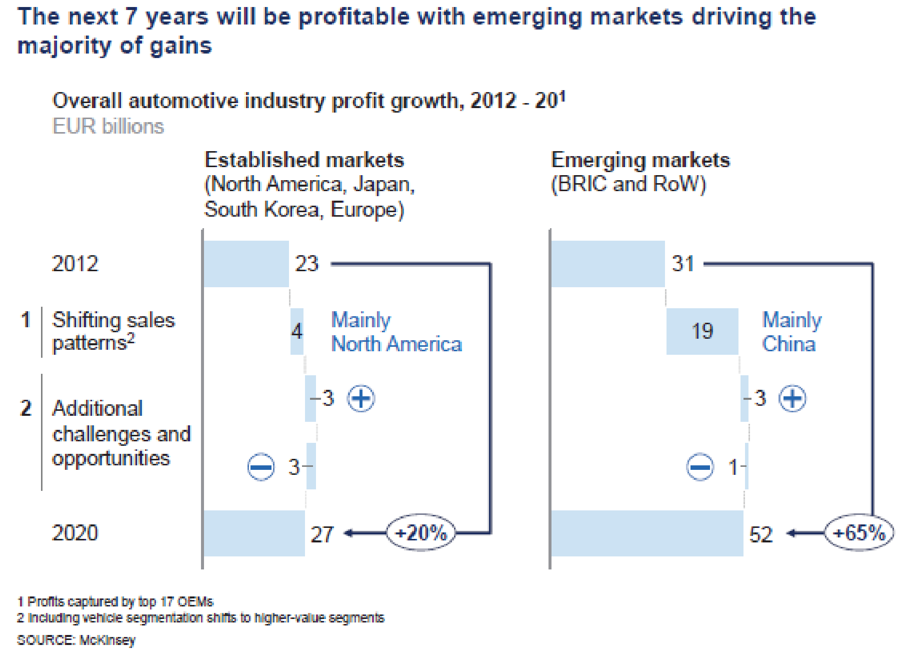


Figure 4.2: Overall automotive industry profit growth, 2012 - 20.[13]

### 4.1.1 The future challenges and opportunities

There are four key challenges that OEMs need to address to get a piece of future profitability. The analysis of this report projects to 2020, but these challenges will shape the industry until at least 2025[13].

- *Complexity and cost pressure.* There will be more platform sharing and more modular systems. At the same time, regulatory pressures will tighten, and prices in established markets are likely to be flat.

- *Diverging markets.* OEMs need to adapt to changing regional and segment patterns of supply and demand with respect to their production and supply base footprints, supply chains, and product portfolios; and the emerging Chinese aftersales market offers new growth opportunities.

- *Digital demands.* Consumers want more connectivity, are focused on active safety and ease of use, and are increasingly using digital sources in making their purchase decisions.

- *Shifting industry landscape.* Suppliers will add more value in alternative powertrain technologies and in innovative solutions for active safety and infotainment; Europe needs to restructure and adjust its capacity to better match demand; and competition is emerging from China.

To capture future growth and find profit from these challenges – and to mitigate their risks – OEMs cannot simply turn to their traditional toolbox. They need to review and adjust their strategic priorities, deploy the appropriate investments and resources, and develop new skills to execute these strategic objectives.

### 4.1.2 How can OEMs benefit from these new challenges and opportunities?

The lion's share of profit growth will come from higher sales. But beyond selling more cars, the industry is changing in more fundamental ways. The research points to nine major imperatives for the automotive industry, especially for OEMs[13].

1. *The price-cost gap narrows.*
   Price and regulatory pressures mean that OEMs in the established markets of Europe, North America, Japan, and South Korea have little margin of error when it comes to making the right decisions on how to differentiate themselves. It is expected that the price-cost gap will narrow, and OEMs will face difficulties in prioritizing among differentiating features and basic customer demands. Therefore, OEMs need to find ways to impose markups for mandated content and to tighten annual cost improvement beyond 3 to 4 percent.

2. *Rising complexity encourages more platforming.*
   Car buyers worldwide are more and more demanding, seeking region-specific features, performance, and styling as well as an element of uniqueness even in mass market products as a way of differentiating and emphasizing individual taste and status. Most automakers respond to this demand with an increasing number of derivatives subject to markups compared with standard models. It is not uncommon to have 20 or even more such "derivatives," as companies seek to profit from different market niches. In effect, derivatives share common non-consumerfacing product elements (e.g., common chassis underpinning, body structures, core components) in order to make differentiation of consumer-facing features profitable. But running more derivatives per platform also increases complexity. To manage this complexity, control costs, prevent cannibalization, and ensure that differentiation is aligned with consumer preference, OEMs need to develop new global platform strategies, including modular concepts. They would have to thoroughly analyze niches where derivatives still might create additional value. However, this would require more sophisticated research on customer preferences and diligent assessments of customer trade-offs and cannibalization effects. Moreover, OEMs need to balance global scale, complexity, and local or segment-specific customer demand. Specifically, they should consider ways to cooperate with other OEMs and how to enhance platform usage across segments, regions, and price levels.

3. *Greening gets more expensive.*
   Carbon dioxide regulation is likely to continue to tighten, and not just in Europe. China, the US, and Japan have also enacted laws to reduce emissions. In Europe, the 2020 target might be reached with the help of advanced conventional technologies, but to meet the overall fleet targets, more electrification could be necessary (especially for premium

players). This will push OEMs to invest more in e-mobility, meaning electrical/hybrid powertrains, including batteries, as well as in lightweight and aerodynamic drag-reducing technologies. Ultimately, electric vehicles may be the answer, though the transition will not happen fast, or soon. In 2020, conventional internal combustion engines (ICEs) will still account for more than 90 percent of cars. OEMs will have to continue developing more advanced ICEs, including cylinder deactivation or variable valve timing and lift. On the other hand, they need to invest in alternative powertrain technologies to meet future emissions targets – without knowing which kind will prevail. Managing these pressures will be a fact of OEM life to 2025 and beyond. One way to lower investment outlays and to drive innovation is to create strategic alliances with other OEMs and preferred suppliers. OEMs could also experiment with alliances with car sharing companies as a way to push EVs into the market, and thus help customers get used to them. Finally, OEMs need to build up their capabilities to anticipate – or at least be prepared for – foreign regulations, especially regarding imports.

4. *The aftersales market in China becomes more important.*
   The new car sales growth in China is slowing but an even more promising, and less obvious, opportunity is the aftersales market, including spare parts, service, used car sales, and financing, which serves as an integral component of brand building and sales funnel management. Aftersales automotive parts revenues on its own could grow from approximately EUR 20 billion in 2012 by 20 percent a year and reach nearly EUR 100 billion by 2020. A strong aftersales network could also enable OEMs to build brand loyalty.

5. *Growth continues to shift.*
   The automotive industry's economic center of gravity will continue to shift, as sales volumes and market share keep moving toward emerging markets. The global sales share of established markets will decline from 50 percent in 2012 to 40 percent in 2020; these will account for only about 25 percent of future volume growth. One major growth opportunity is in smaller vehicles (subcompacts, microcars, and superminis); these already account for more than 30 percent of global sales and could reach more than 30 million vehicles in 2020. More than 60 percent of this market is located in emerging economies, where sales are set to grow 5 to 6 percent a year until 2020. The majority of this growth will be in urban areas, offering OEMs the opportunity to address a large share of growth with relatively few, focused footprint adjustments. Competition in this segment, however, will be intense, as many emerging market players are expanding.

6. *Connectivity becomes more important.*
   Cars on the road are being equipped with danger-warning applications, traffic information services, and a host of infotainment features and increasingly active safety features as well. The number of networked cars

will rise 30 percent a year for the next several years; by 2020, one in five cars will be connected to the Internet. Delivering services through the car is a promising area for future profits and differentiation. To deliver on this, OEMs will have to manage shorter product and service development cycles, such as software and other technology updates. They will also need to build relationships with affiliated firms that build apps tailored to the car. But again, the competition will be intense, particularly if new players from the non-automotive "digital arena" enter the market.

7. *Retail of the future comes closer.*
   In 2012, 70 percent of buyers stated the Internet as a major source for information gathering, displacing brochures, ads, and test reports. Dealerships are still important in decision making and in the customer's overall experiences but less so in the research and product comparison phases. This presents OEMs with contrasting challenges. On the one hand, they need to create a state-of-the-art Web presence that provides customers with a digitally supported purchasing experience based on, for example, comparison tools, car configurators, and other online tools. On the other hand, they need to provide an engaging interaction and compelling experience across all touch points on the customer decision making journey and in the post-purchase experience. This development would require joint investment from dealers and OEMs and intense cooperation to create a seamless experience for the customer throughout the pure online and digitally supported offline channels.

8. *Suppliers add more value.*
   OEMs will have to manage rising production volumes – up to 70 percent in Asia by 2020. That means building a local supplier base, designing an enhanced supply chain, and bolstering supplier capacities. This is particularly important because the imperative to improve green mobility means that suppliers will become more important in terms of how much value they add, especially for the constantly improving ICE but also for the various electrified powertrain alternatives. On the one hand, conventional ICE-powered vehicles have to be optimized with the help of engine control systems, downsizing, and lightweight or automatic transmissions. On the other hand, there are the long-term possibilities of the various electric powertrain alternatives – and these have not been core competencies of most OEMs.

9. *The OEM battle intensifies.*
   Europe is in a particularly difficult position because it is maintaining significant overcapacity, according to the European Automobile Manufacturers Association (ACEA). Moreover, a number of lower-cost brands have recently entered the market, heightening competition further. European OEMs have announced capacity reductions of 750,000 vehicles by 2015. But with regard to how the market is likely to develop, that may not be enough. If OEMs in Europe do not revise their production footprint beyond the announced capacity adjustments, it could be

five years before the industry gets back to its precrisis utilization rate and related profitability levels. Similar challenges apply to OEMs in Japan and South Korea, where capacity adjustments have already been initiated. Closing a plant poses severe challenges on the people side, particularly given Europe's high and prolonged rates of unemployment. The recent history in North America, however, shows the possibilities of restructuring and its ultimate benefits. Though restructuring the industry was painful, sales and profits have rebounded. Capacity is running higher than before the crisis, and almost double that of 2009. Therefore, OEMs in Europe ought to revise their production footprint beyond the announced capacity adjustments.

## 4.2 The Case Company and Objectives

The company analized is Dayco Europe s.r.l. that is a global leader in the research, design, production and distribution of engine transmission systems and aftermarket services for cars, trucks, construction, agricultural and industrial machinery. Also proposing itself as a global leader in system solutions for hybrid electric vehicles thanks to over 100 years of experience in power transmission systems.

The fundamental strengths, which have become the pillars of its identity and the basis of its ability to create value, are: a push for innovation, an instinct to overcome the limits of resistance, orientation towards dynamic systems, services provided with passion.

As already mentioned, Dayco has over 110 years of experience in the supply of products and services, is headquartered in Troy, in the state of Michigan, but has more than 40 other offices scattered in 22 countries around the world that deal with manufacturing and aftermarket, employing more than 4,500 employees, with a turnover of 921 million dollars. In Italy it has two research and development and distribution offices.

The product portfolio is very large precisely to satisfy the needs of every type of car maker, in fact they are currently produced: belts, tensioners, pulleys and Idlers, Belt-In-Oil timing, dampers, decoupiers, vgs, aftermarket kits. In particular, tensioners, pulleys, timing drive tensioners and decoupling are designed and produced in the Italian site under examination. The search for innovative solutions for products and processes has led to more than 260 patented inventions, is continuous and based on: strong intellectual property, customer recognized value, sustainable competitive advantage, focused and aligned resources, standardized product platforms to accelerate replication globally.

The automotive market over the years has increasingly reduced the Time To Market, this has meant that upstream car makers outsourced more and more stages of the production chain, focusing on the core ones. Car makers are unable to take care of the detailed design of every single engine component, therefore they entrust it to OEM companies. It is sufficient that the component meets the general performance characteristics that are desired for the engine. In order to reduce design times and encourage OEM suppliers, tenders are also called quotations, in which the various OEM companies offer their offers that compete with each other. The offers are technical-economic so the quality-price compromise is evaluated. The company that has the winning bid wins the tender and the supply of that component over the years to the car maker. A new project will be included in its portfolio and it can begin its development following the standard phases of project management.

Dayco is therefore an OEM. What for the car maker is an engine component for the OEM is its finished product which in turn is made up of components. In order to be able to produce quickly, in turn, the OEMs turn to other suppliers for part of the components of their finished product. This results in a further listing process between the OEMs and the supplier companies. In fact, in order to present a realistic offer to car makers, OEMs need to know how much the components they purchase from their suppliers will cost. In this way, OEMs adopt the same quotation process as car makers, that is, they request offers from their supplier companies in even shorter times. In particular, Dayco sends the component design to its trusted suppliers and will win the offer with the best price.

Summarizing the core activities of Dayco are reduced to the design and assembly that refer to the R&D and logistics departments.

### 4.2.1 Dayco business process

Dayco operates make to order. The process begins with sending the customer's RFQ to the salesperson. The salesperson evaluates the customer's offer then what the requested product is (the same customer sometimes proposes a target price, the company evaluates its own price, and from the comparison it is possible to see if there is a profit and if therefore the order can be accepted ). The evaluation of the RFQ takes place through a process that follows APQP (Advanced Product Quality Planning) which is divided into 5 phases (after the fifth phase there is production and there ends the task of the Project Manager).

The work done in this thesis focuses on phase 0, also called "RFQ Stage" that provide for six deliverables, as shown below: The deliverables are from a step-by-step procedure for completing Phase 0 is as follows:

- *Step 1 – Entering an APQP Project*
  · The process starts when the Dayco Account Manager is informed of a potential new business opportunity.
  · The Account Manager creates a new APQP Project within a software utilized by Dayco to store deliverables.
  · If there is no formal RFQ provided by the customer, but work will be performed in advance of one, an APQP Project should be created with the designation of Pre-RFQ.
  · Under the scenario of Pre-RFQ, The Account Manager must fill in as much customer information as is known at the time.
  · If the customer provides a formal RFQ, an APQP Project is created with the designation of RFQ.

· Under the scenario of a formal RFQ, the Account Manager must completely fill in the following sections on the "Details" page: Project Details, Commercial Details (except for CAPEX/Tooling) and RFQ Timing. With a formal RFQ, the "RFQ Received" and "Quote Due Date" field information is mandatory.

- *Step 2 – Assigning a Program Manager and his team*
  · Once the APQP Project is created, is assigned a Program Manager to support Phase 0.
  Note: The role of Program Manager in Phase 0 is to support and facilitate the quote process. . . not to complete Phase 0 deliverables. He/she are available to support the Account Manager who owns and is accountable for Phase 0 completion.
  · When the Program Manager is assigned, and the previous step completed, will be include all relevant team members required for the completion of Phase 0.

- *Step 3 – Initial Cost Pack Distribution and Kickoff Meeting*
  · When all team members are assigned, the Account Manager schedules a kickoff meeting.
  · During the kickoff meeting a review of the intended design is performed by Engineering. Information from this review is used, in part, to assess manufacturing feasibility and to assist in populating the Team Feasibility Commitment form (found on a tab within the Cost Pack).

- *Step 4 – Completion of the Phase 0, Pre-Meeting*
  · Prior to the Phase 0, Pre-Meeting, a simple audit will be performed to confirm all required deliverables are uploaded into the software store.
  . After this, all steps and deliverables are approved. These approvals are required to be completed prior to the Phase 0, Executive Review.

- *Step 5 – Upload and Submit Quote to Customer*
  · When the Executive approval is received, a task is sent to the Account Manager to upload the Customer Quote and submit the document to the customer.

- *Step 6 – Update Award Status*
  · The final Phase 0 step is assigned to the Account Manager to confirm one of two scenarios, business award or rejection.

- *Step 7 – Phase 0, Exit*
  · Once new business is awarded by the customer, and the award status is updated, it will perform a final review of the deliverables and complete the Phase 0, Exit.

- *Step 8 – Ownership Change and Transition to Phase 1*
  · When the Phase 0, Exit is successfully completed, it will advance the program to Phase 1 and change the program "Owner" from the Account Manager to the Program Manager.

A summary of the process can be found in the following Fig.4.3:

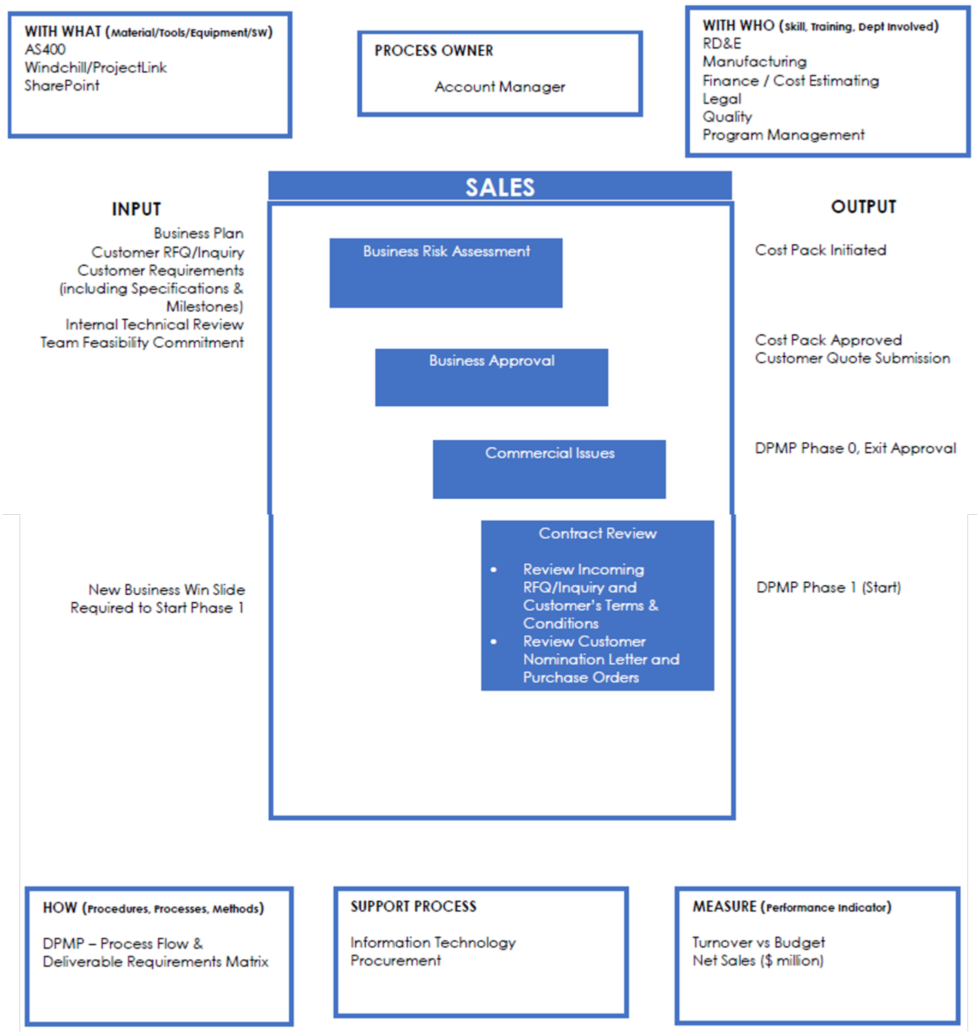


Figure 4.3: Dayco Sales Key Process Flow

### 4.2.2 The bidding problem in Dayco

Particular attention must be paid during Step 3 where the Cost Pack is generated, which is decisive for the Manufacturing Feasibility. The cost pack generation process involves:

- The design of a first possible solution to the CAD of the product requested by the RFQ;
- Breakdown of the product into its components classified by BOM;
- Allocation of the cost to each component;
- Sum of the costs of the components in order to obtain a first rough estimate of the total cost of the product;

- Evaluation of the cost obtained which can be positive or not. If the evaluation is positive, the process ends by generating the Cost Pack. Conversely, if negative, a redesign of the product is considered in order to obtain lower costs, repeating the whole process.

Then the process move on to Manufacturing Feasibility where the price offered to the customer is modeled taking into account the strategy and other business costs.

The bidding problem is part of the Cost Pack generation process. The company outsources its components, then to accurately evaluate their cost, it sends the CAD drawing to its suppliers and then requests an offer. Once the offer for the various components from the various suppliers is received, those with the most competitive price are selected. At this point it will be possible to obtain a more accurate estimate of the cost of the finished product so as to proceed with its evaluation. The collection and selection times of the offers, however, are sometimes too long compared to the time required by the company to respond to the customer's quote (car maker). This makes the company less flexible and competitive, since the time dedicated to the formulation of design alternatives decreases, in chain all the other steps slow down or are carried out with superciality to fall within the two dates, with consequent negative impact on the quality of the final quotation. In general, there is a waste of money if we consider the resources committed for the process, especially in the event that in the end the Manufacturing Feasibility is judged negative, and therefore the project is not carried out in the following steps.

Dayco employees currently estimate the costs of the components by analogy, so that they can evaluate a possible redesign of the product without waiting for the final offers of the suppliers, thus reducing the time. A meeting is called between the Cost Estimator and the Lead Engineer who prepares the BOM of the components. The Cost Estimator does not have a reference database that collects all the past offers of suppliers, but for each component it is based on its own personal experience. Then look in the email for the offers of components that seem similar in geometry to the new designed one, based on the technical differences suggested by the Lead Engineer, it establishes an approximate cost.

In conclusion, the company suffers from the bidding problem analyzed previously, in fact it is unable to obtain a clear and predictive estimate of the price offered by its suppliers. An inaccurate estimate leads to evaluation errors that can affect the redesign of the product with consequent loss of quality and competitiveness in the final formulation of the quotation to the customer. Furthermore, an inefficient use of the resources used occurs and inefficiencies can also be generated in the negotiation phase with the supplier.

The company is ideal for representing a case study that solves the cost estimation problem during the bidding phase. In fact, it has a long history and experience and presents standard processes. The difficulties encountered during the resolution are linked in particular to the lack of data for the families of components considered, since they belong to products that are undergoing major design changes due to the development of electric motors. This entails an even more difficult cost estimation.

The solution of the case study involves the construction of a database that incorporates all the past offers of suppliers, in order to reduce the search time for the Cost Estimator. Subsequently, the proposal of a mathematical model that speeds up the process of predictive estimation of the cost of the components also leads to much more precise and reliable estimation than that obtained by analogy.

## 4.3 An interesting example

During the literary research, an article was found that is very close to the Dayco case. It has been reported below so that it can be used as a benchmark for the case study and as a starting point for possible future developments of the estimation model. The article is wrote by H.S. Wang: "Application of BPN with feature-based models on cost estimation of plastic injection products". The author proposes a cost estimation model for new products based on ANN including the quotations of suppliers together with the geometric parameters among the input data. While the first example limited itself to predicting the prices of supplier quotations, this is much closer to the characteristics present in the case study under consideration in this thesis. The fundamental traits of the work of H.S. Wang are shown below[21].

Plastic injection products have been widely used in various household necessities and high-tech commodities. For getting the bigger target market share and the advantage of leading the product price, the plastic injection product manufacture shall control the cost of the product being developed at the development stage to find out how much percentage of the profit can participate in the price competition. Therefore, this study emphasizes to propose a cost estimation model which is based on BPN (back-propagation network) with feature-based models to dramatically simplify the complex conventional cost estimation procedures and computation parameters requested. Finally, the application of this model is illustrated through a case study of a notebook computer product for cost estimation and the results show that its efficiency and effectiveness in solving the cost estimation problem of plastic injection products at the development stage.

Plastic injection parts in products are used more and more. And with respect to cost estimation, research and development departments in the past could only estimate the final product total cost after getting the quotations of the plastic injection parts after the design stage leading to development cost estimation delay. Moreover, rules of thumb of the engineers are often applied as the cost estimation benchmarks, making the results controversial in terms of accuracy. Although calculation by cost model has the advantage of timeliness, only representative values exclusive of indirect tasks cost and raw materials cost are calculated resulting in inadequate estimation accuracy. The main purpose of this study is to design the cost estimation model for plastic injection products in the initial stage of product R&D by the advantages of BPN, which belongs to monitoring style learning network of the neural networks with advantages such as excellent diagnosis, prediction, simple theory, fast response and high learning precision through the integration of 3D mode features data of price quotations or purchase data on the basis of plastic injection finished product cost-affecting factors test.

The plastic injection product quotations data previously collected are used to set up samples for network learning and testing to verify the feasibility of applying regression network in quotation estimation. After verification, then input the network weights trained into the system program established in this study to estimate the corresponding quotations of the features of the 3D model we designed. The detailed research procedure is as shown in Fig.4.4.

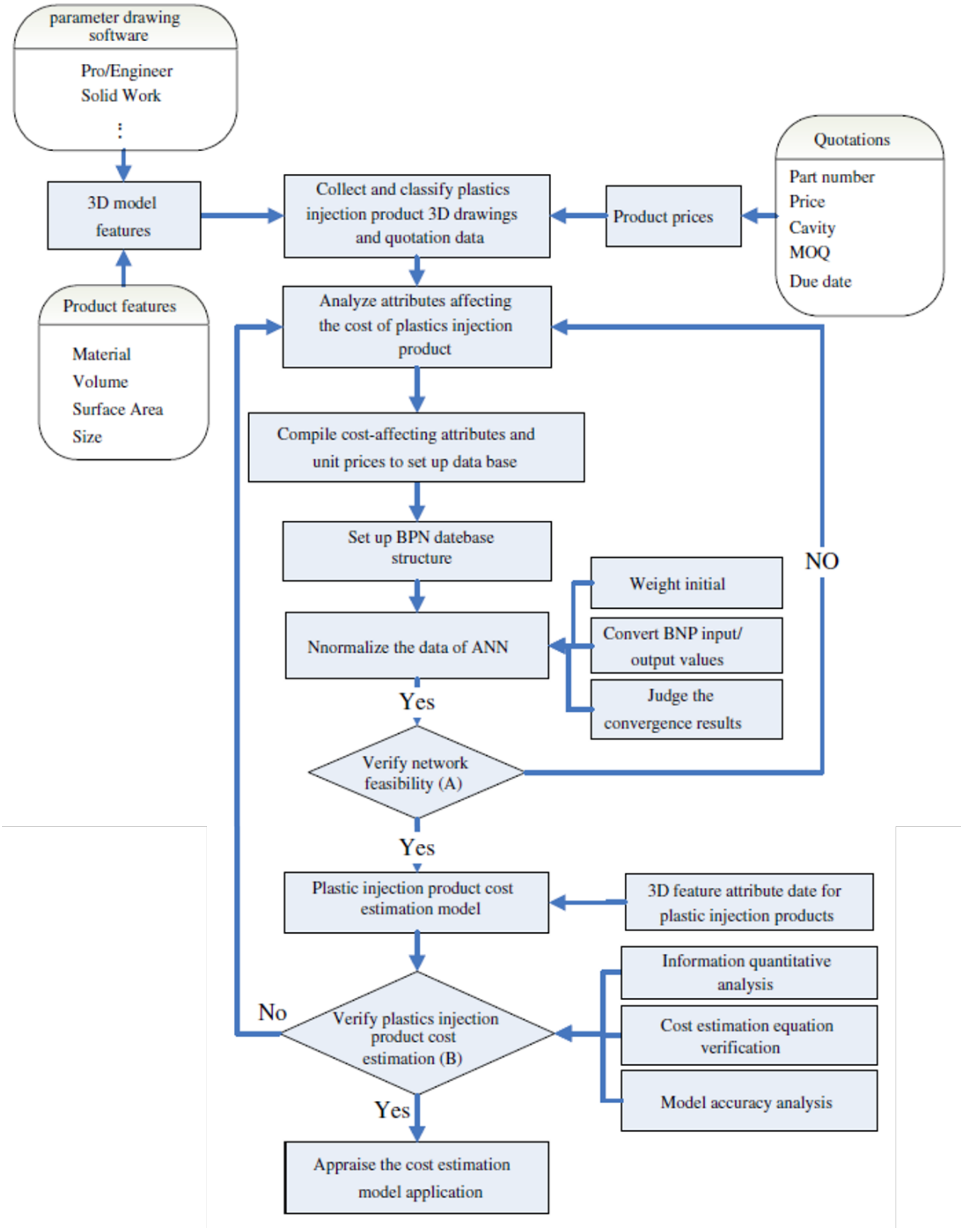


Figure 4.4: Implementation procedures of plastic injection product cost estimation.[21]

As plastic injection products have profits ranging from 20–40% in different industries as well as the manufacturers' tight control of spare parts features drawings and purchase/quotation data, we cannot get large sum of spare parts drawings from various industries and corresponding quotations from many suppliers of different sizes. Therefore, this study only discusses the cost estimation model on the basis of notebook computer industry with one supplier's data collected.

The model in this study is mainly to collect the features data with the product research and development department as the main factor considered. We obtained the price quotations of manufacturers quoted or the purchase prices from the buyers according to material numbers. Moreover, we obtained the cost-affecting items from the drawings, and adjusted according to the plastic injection product manufacturing types.

The difference between the collected reference factors and the present industrial plastic injection cost estimation is as shown in Table 3.6.

| Cost-affecting factors | Traditional industrial cost factors | Cost estimation model experimental parameters |
|---|---|---|
| Raw material cost | Raw material price, product net weight, runner weight, cavity quantity | Product volume, Surface area cavity quantity, product net weight |
| Manufacturing cost | Injection time, injection machine processing fee (Yuan/min), cavity quantity | Projection area, minimum length, width, height and thickness of the product, cavity quantity |
| Quality control fee | (raw material cost + manufacturing cost) 3% | In accordance with spare parts quotations or purchase unit price |
| Cost of Selling | In accordance with company scale | Distinguish in accordance with different suppliers, (this study discuss only one supplier) |
| Profit | 20–40% (depending on different industries) | This study discuss spare parts of notebook computer industry (profit rate is about 20%) |

Table 4.1: Factors comparison between the industry and our cost estimation model.[21]

With the development of CAD/CAM technologies, plastic injection products tend to be streamlined and complex in appearance. However, veteran technologists in the injection product plants will often appraise on the key items of product benchmarks and specific product design specification items. Hence, this study lists the following parameter drawing software (or feature-based 3D software such as Pro/Engineer or SolidWorks) after considering cost-affecting factors data to get the most important item of the product feature model design specifications in addition to referring to the discussion of Wang, Che, and Lin (2005) on the plastic injection product cost estimation parameters. The factors having comparatively bigger effects on cost are found out from plastic injection product as illustrated as follows:

1. Volume: the space the product occupies, it can be found out by the drawing software
2. Material: different materials have different unit prices and mass densities.
3. Product net weight: volume (cm3) $\cdot$ material density (g/cm3).
4. Surface area: the sum of spare parts surfaces.

5. Number of Cavity: number of products for each molding in injection molding process.
6. Projection area : the area of the product in the parting line(cm2), affecting the injection machine selection.
7. Maximum measurements: the minimum length, width and height of the box to contain the product.

In accordance with the cost estimation model parameters in Table 3.6, this study collects the relevant data after distinguishing each spare part's features into material features, form features, and molding conditions as shown in Fig.4.5. Parts of the sample data after collection are as shown in Table 3.7. Make all the parameters quantitative; namely, convert all incalculable data into calculable values. And quantitative data will become the form, which can be easily treated by the system (learning form) with its features.

| P/N | Mat. | Vol. | Surface area | Cavity Qty. | Weight | Thickness | Length | Width | Height | Projection area | Price |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A8355 | ABS | 2592,81 | 4519,44 | 10 | 3,1 | 1,6 | 91,56 | 42,15 | 8,8 | 1757,68 | 1,1 |
| | ABS/PC | | | | 3 | | | | | | 1,2 |
| | PP | | | | 2,3 | | | | | | 0,8 |
| | PC | | | | 3,1 | | | | | | 1,5 |
| | PE | | | | 2,4 | | | | | | 0,9 |
| A0838 | ABS | 84572,21 | 99368,4 | 1 | 104 | 2 | 326 | 277 | 19,1 | 32905,3 | 15,6 |
| | ABS/PC | | | | 99,8 | | | | | | 20,7 |
| | PP | | | | 76,6 | | | | | | 8,8 |
| | PC | | | | 81,1 | | | | | | 9,5 |
| | PE | | | | 101,4 | | | | | | 30,8 |

Table 4.2: Partial lists of part features data. [21]

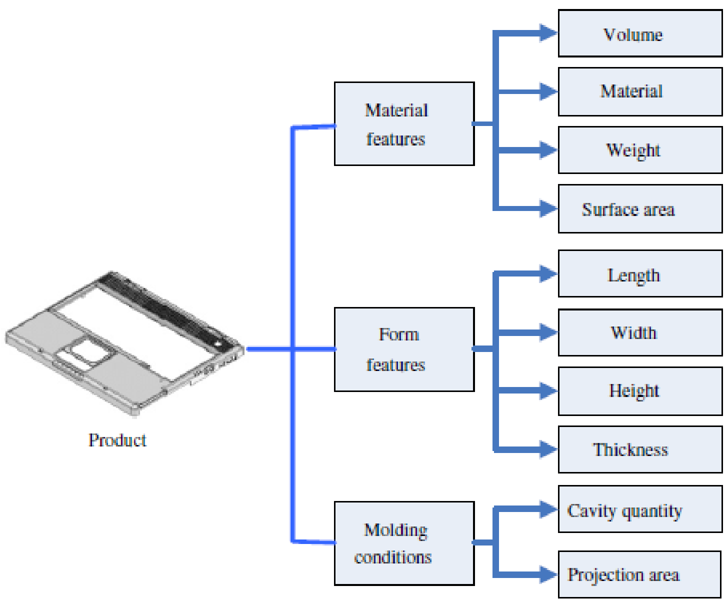


Figure 4.5: Part features structure.[21]

Model construction steps are as shown in Fig.4.6:

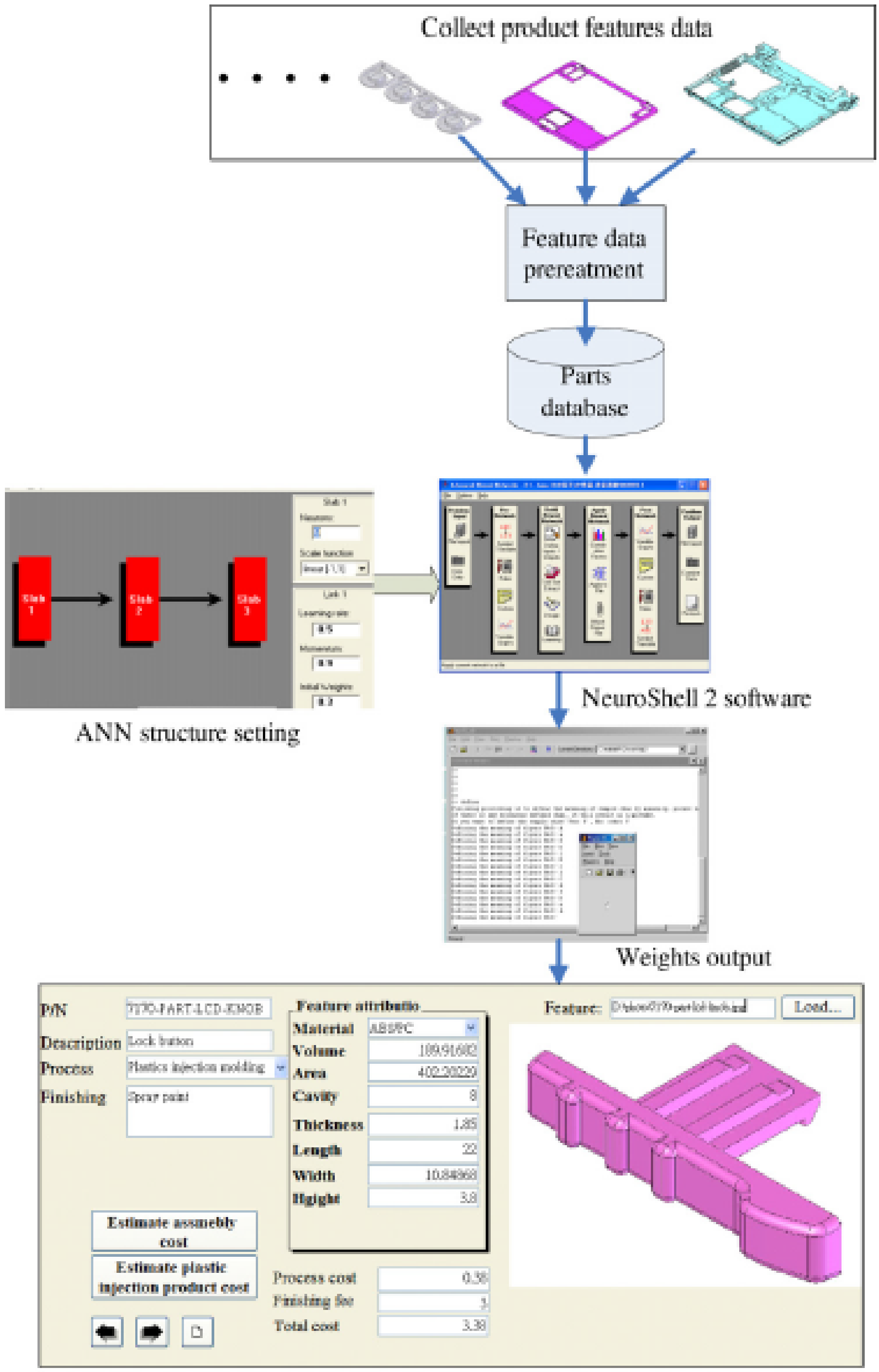


Figure 4.6: Cost estimation model construction for plastic injection products.[21]

Based on the BPN, the cost estimation system proposed in this study was first used to train and test the network with the specification quotation data collected to construct BPN structure proper for plastic product quotations estimation. Finally, BPN structure parameters were inputted to reduce projection area parameters, making it possible for inexperienced engineers to reduce professional judgments of model design. Then, the newly designed injection product specifications was inputted into network to estimate the corresponding quotations with mean absolute error rate reaching less than 1%. Finally, by the user-friendly interface with idiotproof design as well as simple fault control, learners can very easily learn how to operate the cost estimation system within very short time, therefore simplifying the plastic injection product cost estimation procedure. If integrating with other standard components purchase quotations databank, we can timely appraise the final product materials total cost estimation, achieving the purpose of rapid reaction.

# Chapter 5

# The Model Chosen

This thesis aims to create a parametric model that allows a company operating in the automotive sector, starting from its CAD drawings, to predict the possible purchase cost of mechanical components outsourced. The goal is to speed up the economic evaluation phase of a new product which consists in evaluating its feasibility and the hypothetical price to be proposed to the car maker. At the same time, a second objective is to control the efficiency of suppliers and have greater control in the negotiation phase of the price of the purchased component.

In this chapter the methodology applied for the estimation from a theoretical point of view will be illustrated. The family of products chosen for the analysis are the Decouplers, describing their geometry and the reasons for this choice. The final part of the chapter will focus on setting up the model, on data collection and on the variables considered, provided both by the designers 'drawings and by the suppliers' past offers. All this information has been enclosed in a database, which can be updated and improved by the company over time so as to generate an increasingly reliable and precise estimate.

## 5.1 The multiple linear regression model

The company to date has used a rough estimate based on geometric analogies between the components outsourced in the past. Now they want to obtain a much more precise and numerical estimate, whose measurement error is less than that based on the analogy method. The company will have a mathematical tool that can be used by anyone for its intuitiveness and which allows the cost of the component to be obtained with the input data already available at the design stage. The estimation model chosen is the parametric one. Based also on the decision tree seen in Chapter 2, it has been seen that the data made available by the suppliers are such as to allow the construction of a dataset in which the various cost items can be distinguished.

The parametric model consists of identifying regression models where the dependent variable is the cost and the independent variables are all the chosen parameters, they can influence the cost in various ways, in a linear, logarithmic, quadratic manner etc. Through the parametric model it is possible to identify the various relationships between the selected parameters and the final cost. When using multiple parameters, as in this case study, it can be proceeded with a multiple linear regression. Implementing a parametric model means creating a regression model by choosing as independent variables, the parameters that are considered important or significant to describe the dependent variable.

This methodology is not to be confused with the regression model seen in Chapter 2, since in that case the regression operation was applied on the final costs of similar products to predict the value of the purchase cost that would have more likely been able to assume the component considered.

In general, with the regression line, it is estimated to what extent a variable tends on average to increase or decrease when another variable changes. With correlation, on the other hand, the strength of this association is quantified by the Pearson correlation coefficient "r".

Since this model is parametric, assumptions must be satisfied such as:

- The Normal distribution of Variables (especially of the dependent variable);
- The equal variance of the variables (homoskedasticity);
- Independence between independent variables (low correlation).

Before examining the statistical model, it is very useful to draw the relationships between the variables with a Scatter Plot Diagram; in this way it is possible to immediately see the type of mathematical function that best explains the model: linear, parabolic, polynomial, exponential etc.

The equation, if there is a simple two-variable linear regression, becomes:

$$y = \beta_0 + \beta_1 x_1$$

Where $\beta_0$ is the intercept and $\beta_1$ is the angular coefficient. When a regression is made one of the ways to measure the goodness of the model is:

- $R^2$ **DETERMINATION COEFFICIENT.** This value expresses the presence or absence of linear correlation between the variables and expresses the percentage of variance explained by the model. It is a value between 0 and 1. If R square is 0 it means that between the variables there is no linear correlation, if R square is 88% it means that 88% of the variation of the dependent variable is explained by the regression model. In summary, it gives a valid indication of how well a straight line is suitable for describing the relationship between two variables. It must be borne in mind that in multiple regression the $R^2$ must be corrected, in general it tends to increase as the variables increase because there will always be a minimum correlation with the added variable. The correction avoids adding variables that are not significant for the analysis.
- **BETA COEFFICIENT** is the standardized regression coefficient. It is independent of the x and y units, therefore dimensionless.

If we expand the case and consider more than two independent variables, the question becomes more complicated. In fact if the $R^2$ is for example 0.77 it means that 77% of the observed variability can be explained by the variable "X", but if the independent variables are more than two, how do you estimate how much each of them affects individually?

A first approach is to calculate the correlation matrix between all the variables. This matrix can express the relative importance of the variables. The higher the absolute value of the correlation coefficient, the higher the linear association. It is preferable to avoid inserting two strongly interrelated variables (strong collinearity), as these variables contain similar information and it is therefore difficult to distinguish the effects due to each of them individually. Furthermore, if two highly correlated independent variables are considered, there is the problem of overestimating the information they contain (overfitting).

A very useful coefficient in regression analyzes, with which it is possible to estimate whether or not a model has strong collinearity, is the Variance Inflaction Factor:

$$VIF = \frac{1}{1 - R^2}$$

This factor has the purpose of identifying any collinearity of the model. Usually VIF values up to 8 are accepted. Even in multiple linear regression a high $R^2$ and a significant variance indicate that there is a strong linear relationship between the dependent variable and the set of independent variables. The partial regression coefficient for each of the variables are substantially the two-variable regression coefficients adjusted taking into account also the influence of the other independent variables.

This coefficient can be interpreted as the correlation between the independent variable "x" and the dependent variable when the linear effects of the other independent variables have been removed. Inserting many variables is not a good strategy in general, also because the results are difficult to interpret, but it is important not to exclude potentially relevant variables in advance.

The aim is to build a concise model, but one that makes good predictions possible. The best solution is to create a variety of regression models with the same set of variables and select the one that gives the best and most consistent results. In the end, after choosing the most significant variables, a regression model can be proposed with the selected parameters.

In this case study, since three families of components with different characteristics and functions are taken into consideration, it is advisable to create a regression model for each family to avoid that if all the information is considered distorted. In particular, for the Torque Actuator family, a comparison will be made between the different models found which will highlight how it is enough to have only qualitative geometric parameters to obtain a good economic estimate.

### 5.1.1 Parametric model vs. analogous estimation

Both techniques are mainly used for the cost and duration of any project through historical / previous data.

Analogous as the name suggest it means things which are comparable. In the initial stages of the project when there are not aware of much details, it helps to refer to historical data from the project repository, knowledge Database available and check if there is any similar kind of activity done in the past and accordingly estimate the details of new project. Analogous basically uses top-down approach it means it takes bigger picture and analyse risk, cost accordingly instead of narrowing down each task, that's why it takes less time and give a rough estimate of the project. Mostly helpful when there is initial screening of the project. So Analogous estimation can be taken as an expert judgment used for similar projects basis historical data which helps in taking initial decision fast.

While parameter estimation is more accurate estimation techniques compared to analogous estimation as here are taken parameter value to do estimates like cost or duration basis per unit cost/duration. It uses the relationship between variables to provide an estimate of cost/duration. Here unit rate is used and then parameter or variable value is extrapolated for the new project parameter. There are two concepts in the parametric estimation: Regression Analysis: It is a project management technique that helps in establishing statistically relationship between project parameters. It helps to determine the change in the outcome with the probable change in other variables/parameters. Learning Curve: Learning Curve helps in identification that if the same thing is done repetitively then it leads to a reduction in duration /cost or other related parameters and process is improved over time.

Comparative details of Analogous and Parametric Estimation in the follow Table 5.1:

| Analogous Estimation | Parametric Estimation |
|---|---|
| Provides expert judgement based on historical data | Provide calculative parametic values based on historical data |
| Less costly and less time consuming | Take time as need to di calculation to provide unit level cost |
| There is less documentation as no calculation is done | Proper regression analysis is done |

Table 5.1: Analogous estimation vs. Parametric estimation

## 5.2 The Decoupler

Among the products offered in the company portfolio, the choice fell on the Decoupler. It should be noted that the decoupler is the finished product for the OEM company while it is a component for the car maker. It also consists of components designed and assembled by the OEM but purchased in outsourcing.

DDCS is the acronym for Damping Decoupling Compression Spring System, which, in fact, indicates an elastic joint, linked to the FEAD (Front End Accessory Drive) of an engine. The object in question is mounted on the crankshaft of the engine both to reduce vibrations coming from it and to transmit, through a belt revolution, a certain torque to a tensioner or to accessories, such as air conditioning system, alternator or pump water.

The company is developing new Decouplers for electric vehicles, however their design is very distant from the traditional one, this makes it difficult to make them better, especially if done by analogy. Compared to the traditional product, the materials used change and sometimes only the approximate shape of the components remains. The company is focusing on this product due to its propensity for innovation and future evolution, therefore it is being analyzed.

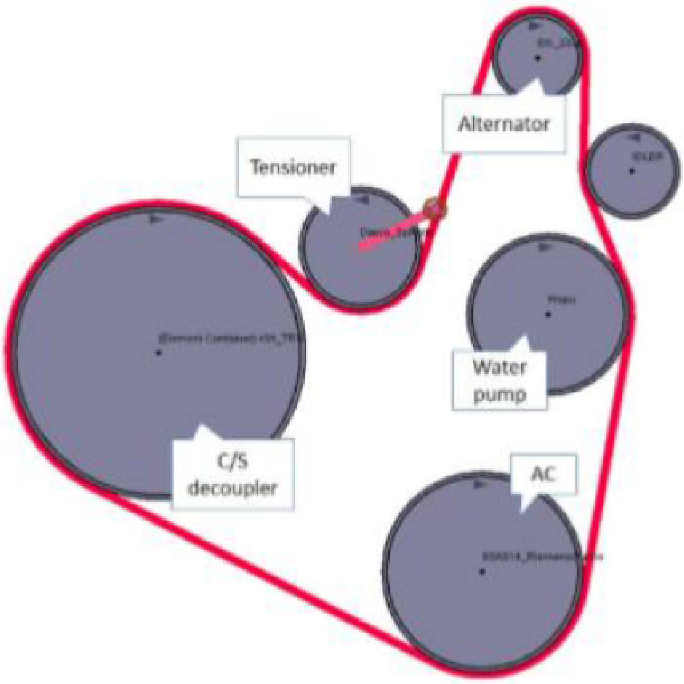


Figure 5.1: Layout of FEAD.

### 5.2.1 Component properties

In the automotive field, belts are defined as those transmission systems for which the torque, made available by the crankshaft, is transmitted to the system outputs, or the accessories. However, it is necessary to premise that the motor does not produce, in any way, a constant output torque but, on the contrary, continuously generates variable torques and, therefore, impulses, which occur especially at low speeds and in the presence of high loads of accessories. By virtue of this, having high inertia of the accessories and variable torques inevitably gives rise to resonance phenomena, which prove to be the cause of noise, vibrations, wear of the tensioners and very high structural loads. To solve these different problems, it was the companies that promoted the introduction of these components.

Figure 5.2: Damping Decoupling Compression System

### 5.2.2 Working principles

The DDCS can be divided into two sub-components:

- A damper, which is made up of two metal pieces, joined together by a rubber compound. This component has the function of damping the torsional vibrations coming from the engine crankshaft. It is therefore identified with the acronym " TVD ", which stands for: Torsional Vibrations Damper;

- A decoupler, designed to filter low-order angular oscillations, which project from the crankshaft onto the FEAD, and which allows the belt, and therefore any accessories related to it, to work, in the most comfortable conditions and optimal.

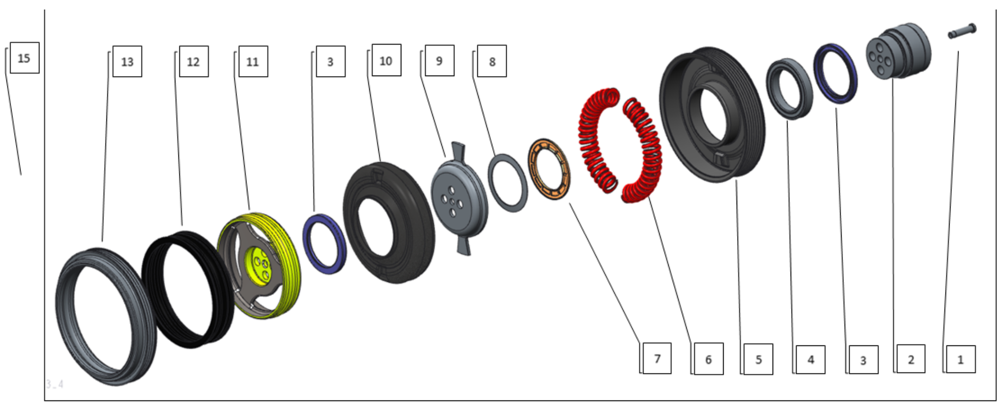


Figure 5.3: Exploded view with related functional groups.

### 5.2.3 Components families description

From the exploded view of Fig.5.3, it is possible to distinguish and, therefore, describe the different components that unite Crankshaft decoupler of various types. In particular, three families of components were chosen for the regression analysis: Pulley, Spring Cup and Torque Actuator. The choice fell on these since they are the components that have the greatest impact on the cost of the Decoupler, they are all molded in sheet metal and maintain approximately the same geometric shape over time.The three components made up three distinct families since they have different functional and geometric properties. For each family, different variants of that component can be identified which develop over time based on the performance required for the decoupler. Below is a small explanation of their functionality:

- **Torque Actuator**
  The torque actuator is an actuator, fixed to the hub with screws, which has the function of compressing the arc springs and, therefore, of transmitting torque.

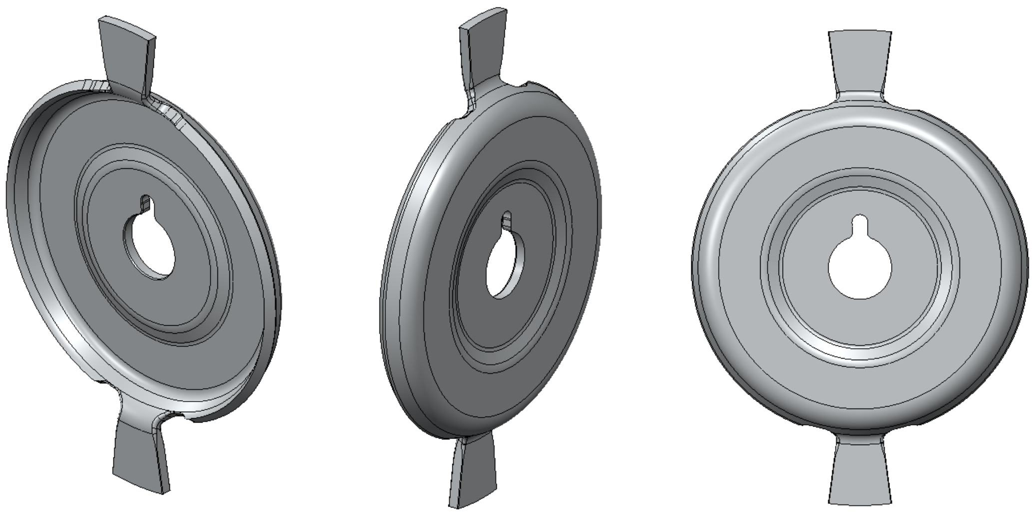

Figure 5.4: Torque Actuator.

- **Spring Cup**
  The Spring Cup is the container that contains and acts as a guide for the two arch springs. This element internally has two physical stops, that is physical constraints, which in fact limit the internal movement of the elastic bodies.

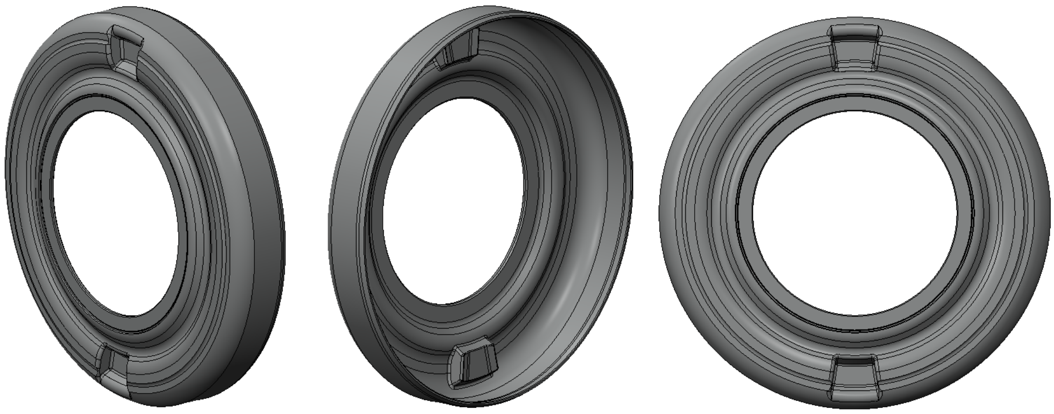

Figure 5.5: Spring Cup.

- **The Pulley**
  The pulley represents the real interface of the component under examination with the belt. Its main function, therefore, is to transmit the torque to the belt. It is keyed to both the bearing and the spring cup.

Figure 5.6: Pulley.

## 5.3 Data Collection and Samples structure

The first work done was data collection. All the offers from suppliers made to the company since the production of the Decouplers began. Due to the lack of data, in order to have a greater number of observations, the following offers were also considered: the offers relating to the products which were not produced either because they did not pass the feasibility test or because the car maker quotation was not won; offers from suppliers who have not won the Dayco quotation because they are not very competitive.

Subsequently, the offers were analyzed, each offer is presented as a small income statement where the sum of the different cost items leads to the final price with which the supplier sells the component. Therefore, the cost items common to the offers of all the suppliers were identified.

The offers were then broken down and reported in a single Excel sheet, the basis for setting up the database which will then be built and supplied to the company to speed up the constification process. The cost items have been identified on the rows of the sheet, while the columns uniquely identify the offer by means of the component code, production volumes and the name of the supplier.

This operation was repeated for the three families identified, therefore three separate Excel sheets were built which identify three different datasets. The observations within the dataset therefore coincide with the offers.

All components have a part number that acts as an identification name with which both the buyer and the supplier refer to a certain type of component; in particular, the first part of the part-number indicates the family to which it belongs while the second is numerical and identifies the specific component. An example is shown in the following Table 5.2:

| | Family Code | Product Code |
|---|---|---|
| Pulleys | WLM | 586 |
| Spring Cup | WQM | 210 |
| Torque Actuator | WQRZ | 845 |

Table 5.2: Dayco families codification.

The number of total observations present within the three datasets are:

| Family | Observations |
|---|---|
| Pulleys | 30 |
| Spring Cup | 27 |
| Torque Actuator | 33 |

Table 5.3: Number of observation for each product family.

## 5.4 The Dataset variables

The transition from an estimate based on the analogy between similar products to a predictive numerical estimate occurs thanks to a parametric model. Despite the good setting of the dataset, it can be seen that the number of observations is limited to obtain a good estimate of the regression. However, it was decided to maintain the parametric model even if the regression will have few variables. This is because it will act as a basis, to which will be added the further observations accumulated over time.

A second step of the work concerns the identification of the variables present within the dataset which will then be used to search for the regression model.

As already mentioned, a part of the variables comes from the cost items of the suppliers' offers, but in particular for the Torque Actuator family, geometric variables were also considered. These variables derive from a qualitative analysis of the CAD drawings of the different variants of the family. This family was chosen because it has the most observations.

### 5.4.1 Cost variables

The cost of a product is made up of different components as shown in the Table. From this Table 5.4 it is clear how the cost is composed of both endogenous components to the product and the production process, as well as exogenous and therefore uncontrollable components.

| Total Purchase Cost | | | | |
|---|---|---|---|---|
| "Endogenous" components | | | "Exogenous" components | |
| Cost of Raw Material | Cost of Superface Treatment | Shipping cost | Cost of Added Value | Cost Consignment Stock |

Table 5.4: Purchase Cost Components.

In detail:

- *Cost of Raw Material (Eur/kg)*
  The cost of raw materials means the cost of steel spent to manufacture the component. This variable is generated by the information of the suppliers, where the net weight of the piece and the cost of product waste are taken into account.

- *Cost of Surface Treatments (Eur/kg)*
  It means the cost to do carbonitriding or galvanization on the steel surface. Surface treatments are not done by suppliers but externally therefore they will have their own transport and packaging costs.

- *Shipping cost (Eur/pcs)*
  The shipping cost is given directly by the supplier.

- *Cost of Added Value*
  In economics the added value (also abbreviated VA), or surplus value, is the measure of the increase in value that occurs in the production and distribution of final goods and services thanks to the intervention of the productive factors (capital and labor) to starting from initial primary goods and resources (Dictionary of Economics and Finance). The Cost of Added Value was calculated as the final cost less the cost of the raw material.

- *Cost Consignment Stock*
  Consignment Stock costs are the costs associated with the supply technology of the same name. They are therefore the costs due to management and financial fixed assets that the supplier must bear.

The determinants identified are influenced differently by the cost variables present in the suppliers' offers, as can be seen from the following table, which also allows a first classification of the cost variables which will then be explained.

| | "Endogenous" components | | | "Exogenous" components | |
|---|---|---|---|---|---|
| Cost drivers | Cost of Raw Material | Shipping Cost | Cost of Surface Treatments | Cost of Added Value | Cost Consignment Stock |
| **1.Input cost** | | | | | |
| Cost of Raw Material (€/kg) | x | | | | |
| Raw Material Quantity (kg) | x | x | x | | |
| Scrap Cost (€/kg) | x | | | | |
| **2.Production volumes** | | | | | |
| Production Volumes per year | | x | x | x | x |
| Batch per year | | x | x | x | x |
| **3.Manufacturing complexity** | | | | | |
| Geometric features | | | x | x | |
| Carbonitriding | | x | x | | |
| Galvanization | | x | x | | |
| Press | | | | x | |
| Deburring | | | | x | |
| Packaging | | x | | | x |
| Set-up | | | | x | |
| **4.Non-produced variables** | | | | | |
| Trasport | | x | x | | x |
| SG&A | | | | | x |
| Profit | | | | | x |
| Currency | x | x | x | x | x |

Table 5.5: Cost drivers.

### 5.4.2 Torque Actuator clustering

For the Torque Actuators, qualitative geometric variables were also identified deriving from an analysis of the CAD drawings of each component belonging to the family. The identification of the geometric variables was made because they are crucial both for the parametric estimate and for that by analogy. They are important for parametric estimation because they influence the cost of the components.

While they are important for the estimate by analogy because they allow the identification of clusters within the family. Each cluster is characterized by particular ranges of values of these variables, leading to the grouping of components similar to each other in terms of geometry and cost. When you have the design of a new component it becomes easier and more immediate to understand what its similar components are and consequently the cost range to which it belongs. In this way it is possible to standardize and speed up the estimation process by analogy. The steps for the clustering of the Torque Actuators are:

1. **Purge of offers**
   For the Torque Actuators starting from the dataset, 33 offers were found. The 33 offers vary according to the volume of production (affects the cost of packaging and transport) and the type of supplier, and they go to outline 13 different products. The first step was to purge the offers. To do this initially, it was taken into account that the suppliers are distinguished according to the type of press used (transfer or progressive), this entails a different cost of mechanical machining. In order to understand which design peculiarities determined a different cost of mechanical processing, it was decided to focus on only one type of supplier (Italian), therefore of the press. The progressive was therefore preferred for the greater number of listed products. From these assessments, the selection of 9 products was obtained.

2. **Identification of the parameters**
   The CAD drawings of the 9 selected products were analyzed, and taking into account the cost items, the design parameters that entail cost changes were identified:

   - *Type of material:* influences the presence of chemical treatments.
   - *Weight:* influences the cost of the material.
   - *External diameter:* affects weight.
   - *Number of holes:* influences the weight, the cost of mechanical processing (cutting) and tumbling.
   - *External shape:* influences the cost of mechanical processing.
   - *Number of steps:* influences the number of steps required for processing, therefore the cost of mechanical processing.

3. **Formation of clusters**
   Five different clusters have been identified on the basis of scatter plots showing the correlation between the different variables. Based on the point cloud, it was possible to identify the 5 different groups.

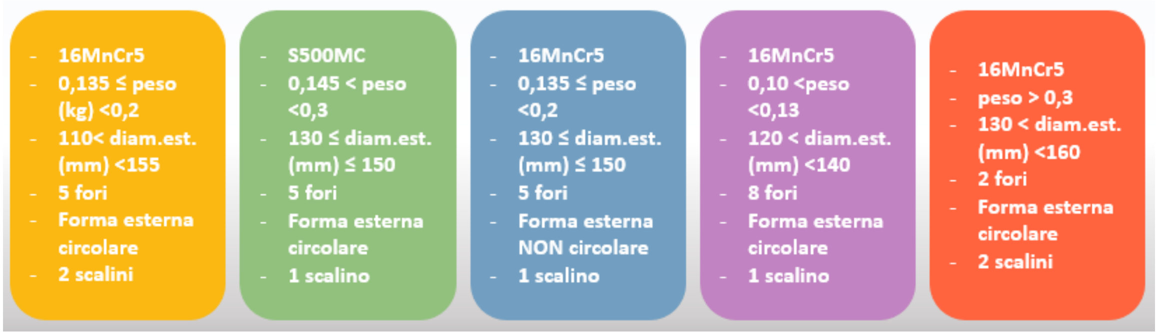


Figure 5.7: Torque Actuator clutering.

4. **Placement of products**
   The fourth step consists in placing the products not present in the progressive supplier offers in the previously identified clusters. The products were placed following the geometric parameters previously identified. For each cluster the products assigned are:


Figure 5.8: Number of components for each cluster.

### 5.4.3 Variables description

The variable you want to predict is called the dependent variable (i.e. the final cost of the component). The variable used to predict the value of the other variable is called an independent variable (all other variables that influence the final cost).

The POTENTIAL variables for the regression analysis are:

- **Volumes_per_year:** quantity of pieces ordered in a year. We need to analyze whether there is an economy of scale, both in linear and logarithmic form.
- **Batch:** quantity of pieces contained in each production lot. This variable can influence the number of setups of the supplier company and their cost.
- **Material_type:** dummy variable indicating the type of steel used for the product. It takes on a different meaning according to the family considered, since different steels are used.
- **Thicknes:** thickness of steel sheet.

- **Raw_cost:** cost of steel (€/ton) purchased by the supplier.
- **Gross_weight:** average gross weight (kg) of the product, that is, before the processing phases.
- **Net_weight:** average weight (kg) of the finished product after the processing phases.
- **Scrap_cost:** material waste (€) due to processing.
- **Treat_type:** type of surface treatment used (carbonitriding or galvanizing). Present statistically significantly only for TA with 0=NoTreat 1=Carbo 2=Zinc.
- **Press_type:** dummy variable indicating the type of press used for sheet metal stamping. With 0= press transfer e 1= press progressive.
- **Lav_mecc:** cost of the molding process (€/kg) regardless of the type of press used.
- **Deburring:** cost of tumbling (€/kg).
- **Pack:** cost of packaging (€/kg).
- **Produc_pz_h:** production of parts at the time of the press.
- **Press_cost_hr:** hourly cost of processing the press for the supplier.
- **Nation:** dummy variable that expresses the nationality the supplier belongs to and therefore from where the products are shipped. This influences the transport costs but also the processing costs. In particular with 0= China 1=Italy/Europe.
- **Washing:** costo del lavaggio (€/kg) del componente.
- **Machining**: cost of further mechanical processing that can be done internally by the supplier or outsourced.
- **Transport:** cost of transporting products. It depends on the origin of the supplier and on the type of agreement established with Dayco (generally of three types FCO, DDP, DAP. In the future, thanks to a greater number of observations, it will be better to use a dummy variable for greater precision).
- **Spinning:** cost (€/kg) of the flow-forming mechanical processing.
- **Press_tons:** tonnage of the press. The tonnage depends on the type of press and determines the hourly production.
- **N_strokes:** numbers of strokes that the press must give to obtain the final piece.

- **Setup_cost**: set-up costs for the data press from the hours dedicated to the cost of the worker engaged.
- **Final_cost**: selling price of the supplier to Dayco.

From the analysis of the Torque Actuators, the following have been added:

- **Ext_diam:** external diameter of the product (mm).
- **N_holes:** number of cavities on the product.
- **Ext_shape:** dummy variable that identifies whether the external shape is circular or not. In particular with 0=NoCircle e 1=Circle.
- **N_rungs**: number of steps.

Each product family has specific characteristics, therefore different variables will be considered for each. The description of the variables used is postponed in the analysis carried out in the next chapter.

It can already be noted that the number of variables identified is much higher than the number of observations. They have also been reported for the correct setting of the model. Over time, as the observations increase, they may be included in the regression based on their significance.

To understand which variables to consider based on current observations, they have been classified into three groups:

| Product | Process | Management |
|---|---|---|
| Material_type | Scrap_cost | Volumes_per_year |
| Thicknes | Treat_type | Batch |
| Raw_cost | Press_type | Produc_pz_hr |
| Gross_weight | Press_tons | Nation |
| Net_weight | Press_cost_hr | Transport |
| Ext_diam | N_strokes | |
| Ext_shape | Deburring | |
| N_holes | Pack | |
| N_rungs | Setup_cost | |
| | Washing | |
| | Machining | |
| | Lav_mecc | |
| | Spinning | |

Table 5.6: Classification of potential variables.

The classification helps to give a methodological approach to the regression model. In fact, it will be possible to perform a regression for each group in order to identify the significant variables, which will then converge in the final model. This process will be implemented for all identified families.

# Chapter 6

# The Application Case: Results

This chapter describes the various stages with which the parametric model was created for the predictive estimate of the price proposed by the suppliers in their offers. The steps for creating the model are:

- Purge of offers. All those unique offers are rejected and due to their peculiarity they constitute outliers.
- The determination of the cost drivers most influential on the cost of the purchased components.
- The development of a predictive type tool, to support negotiation with the supplier which will be the final model proposed.

In the initial part there is a comparison between the different families which shows how, even if they are all sheet metal products, the cost drivers are different. In addition, there is also a comparison between the results obtained with the parametric model and those with the analogy model which demonstrate the efficiency of the mathematical tool.

## 6.1 Comparison between product families

As mentioned in the previous chapter, three product families are considered: Pulleys, Spring Cup, Torque Actuator. From a first analysis of dataset from each product family, through a comparison it is possible to draw interesting considerations. First of all, as reported in the Table 6.1, from the observation of the average values of some variables of greater importance, it emerges that the Torque Actuator compared to the others is much lighter and simpler in geometry.

But the incidence of the cost of the raw material for the products of this family is twice that of the other families. Despite this, there is no impact on the final cost which is lower, about half that of the other two families.

It is also noted that the order volumes for the Pulleys are higher, but the historian shows that they are less frequent. This could indicate from the beginning the presence of economies of scale probably more significant than other families. A further analysis can be made on the significant correlations

| | Pulleys | Spring Cup | Torque Actuator |
|---|---|---|---|
| Average annual quantity (units) | 404.535 | 221.691 | 319.933 |
| Geometric complexity | High | Medium | Low |
| % Incidence of the cost of the raw material on the final cost | 22,13% | 18,50% | 41,91% |
| Net weight (kg) | 0,7663 | 0,4455 | 0,2031 |
| Average final cost (euro / unit) | 3,8261 | 3,3347 | 1,4378 |

Table 6.1: Comparison between product families.

between the variables and the final cost. The Table 6.2 summarizes those common to the three product families.

| | Pulleys | Spring Cup | Torque Actuator |
|---|---|---|---|
| Correlation between annual quantity log and component purchase cost | 53,12%* | 48,29% | 49,7%* |
| Correlation between net weight and purchase cost of the component | 55,64%* | 23,89% | 17,97% |
| * Significant correlations with p-value <5% | | | |

Table 6.2: Significant correlations.

In reality, it emerges that weight and volume have insignificant effect for the Spring Cup, due to the lower volumes and incidence, instead of the Pulleys and in part of the Torque Actuators.

This analysis immediately highlights how the Spring Cup family is very varied, that is, it contains components that are very different from each other. This notable variance is reflected in the search for significant correlations that becomes more complex. Consequently, even the search for the best fit regression model will be more difficult, even more for the limited number of observations.

Torque actuators are confirmed as a family with a less complex and varied geometry. It is these characteristics that make them cheaper than the other two families, despite the high incidence of the cost of the raw material. It should also be noted that the incidence is high because while the final cost for the TA is lower, the cost of the raw material for the three families is similar. So the denominator of incidence for other families is higher than TA and this causes the incidence to drop.

Finally, the Pulleys are the most expensive components, their geometry is in fact the most complex. It provides an empty interior, lateral edges with toothed grooves and the presence of several steps. This entails greater mechanical processing, just think that compared to the Torque Actuator there are more machining steps and the presence of flow-forming. There is therefore justification for the presence of higher volumes, with which economies of scale are attempted.

## 6.2 Multiple linear regression model

### 6.2.1 Torque actuator regression

As anticipated for each family, a first step was to purge the offers from any outliers. Some were easily identified as early as the peculiarity of the offer or its incompleteness, others emerged from the analysis of the distributions of the variables, possible thanks to the reduced number of observations to be verified. The rejected offers were:

- 1 offer not complete due to the lack of geometric variables.
- 3 incomplete offers, where only the final cost is presented without the breakdown into cost items. In addition, too high prices represent outliers.
- 1 offer inconsistent with the other representatives of the same product.
- 2 offers from Chinese suppliers. The two offers for their peculiarity must be considered separately.
- 1 offer since inside it contained an outlier for the mechanical processing item.

In conclusion, there were 25 remaining offers that served as observations for the regression model. Starting from the distribution of the final cost, we can see the three offers proposed by the European supplier, whose prices are not in line with the average.

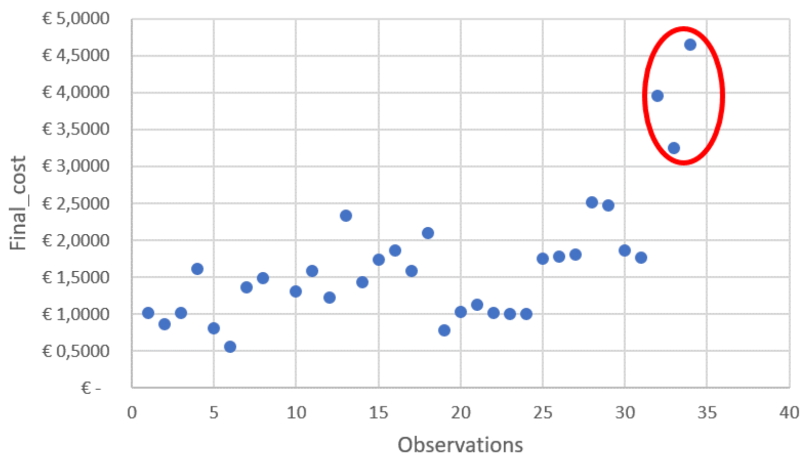


Figure 6.1: Distribution of TA final_cost.

The two offers from Chinese suppliers are in line with the average, but they are not enough to also consider the **nation** variable, which takes into account the different costs for the production of the components outside and the different transport costs. So, a future development of the model could contemplate this opportunity.

For the elimination of further outliers, the scatter plots of each variable related to the final cost were analyzed. The scatter plot on the mechanical molding processing containing the outlier that led to the elimination of the offer between the observations was reported below.

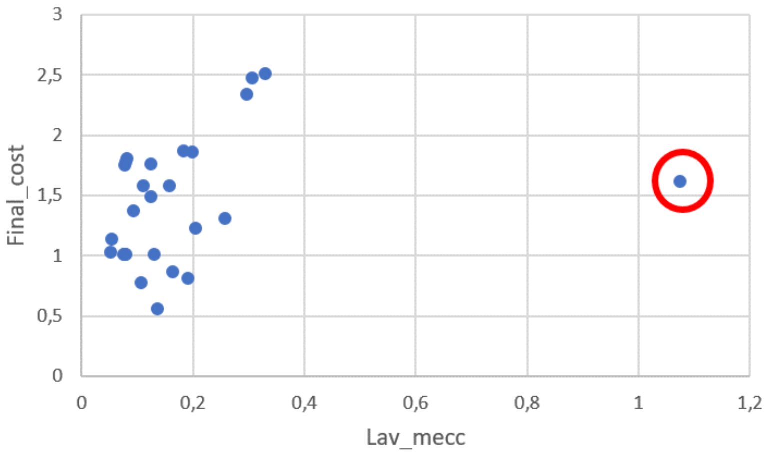


Figure 6.2: Correlation between final_cost and lav_mecc.

In the regression analysis, it will be useful to remove the orders that represent outliers, in order to isolate their effect on identifying a general relationship between the order/product attribute and the final unit cost of purchase. The regression is more reliable if made on relatively homogeneous observations. After the purge step of the offers, we move on to identifying the cost drivers or the variables that affect the final price. Based on the classification in the three groups of variables seen in paragraph 5.4.3, the variables identified for the Torque Actuators are:

| Product | Process | Management |
|---|---|---|
| Material_type | Scrap_cost | Volumes_per_year |
| Thicknes | Treat_type | Batch |
| Raw_cost | Press_type | Produc_pz_hr |
| Gross_weight | Press_tons | |
| Net_weight | Press_cost_hr | |
| Ext_diam | N_strokes | |
| Ext_shape | Deburring | |
| N_holes | Pack | |
| N_rungs | Setup_cost | |

Table 6.3: Classification of variables for Torque Actuator.

It must be underlined that for this family the variable **material_type** indicates with 0=S500MC and 1=16MnCr5. The two types of steel used influence the presence or absence of surface treatments, consequently also the final cost.

As already mentioned, the number of variables is much higher than the number of observations, therefore a selection process must be started in order to implement the model only with really significant variables. The first considerations were:

- The **batch** variable may not be considered because the scatter plot showed that it has the same trend as the **volume_per_year variable**.
- The **gross_weight** and **net_weight** variables both express weight. The gross_weight, however, depends on the efficiency of the supplier company so the buyer is unlikely to know it ex-ante while the net_weight can be obtained from CAD drawings.

Then a descriptive statistic was made where the variables with a very low number of observations were eliminated as they were less influential.

| **Variable** | **Obs** | **Mean** | **Std. Dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| volumes_per_year | 25 | 319.933 | 401.619 | 10.000 | 19.000.000 |
| material_type | 25 | 0,8 | 0,408248 | 0 | 1 |
| thicknes | 25 | 3,58 | 0,31225 | 3 | 4 |
| raw_cost | 25 | 1.089 | 113,3452 | 870 | 1.210 |
| net_weight | 25 | 0,20308 | 0,09149 | 0,101 | 0,36 |
| scrap_cost | 13 | 186,8462 | 54,13847 | 120 | 250 |
| material_cost | 25 | 0,546984 | 0,159681 | 0,3153 | 0,8649 |
| treat_type | 25 | 1,32 | 0,9 | 0 | 2 |
| press_type | 25 | 0,72 | 0,458258 | 0 | 1 |
| press_tons | 14 | 710,7143 | 271,8728 | 250 | 1.000 |
| press_cost_hr | 15 | 83,06667 | 27,67791 | 55 | 120 |
| n_strokes | 13 | 12 | 0,816497 | 11 | 12 |
| deburring | 21 | 0,210938 | 0,180398 | 0,069 | 0,6383 |
| pack | 24 | 0,050042 | 0,070158 | 0,0018 | 0,2047 |
| produc_pz_hr | 25 | 912,24 | 363,8585 | 380 | 1.800 |
| setup_cost | 13 | 415,5385 | 425,5351 | 144 | 1.600 |
| final_cost | 25 | 1,437848 | 0,535311 | 0,563 | 2,5079 |
| ext_shape | 25 | 0,92 | 0,276888 | 0 | 1 |
| n_holes | 25 | 5,12 | 1,833303 | 2 | 8 |
| extern_diam | 25 | 137,98 | 15,25579 | 113,5 | 158 |
| n_rungs | 25 | 1,68 | 0,476095 | 1 | 2 |

Table 6.4: Simple statistics on the variables of the Torque Actuator family.

So, the eliminated variables are: scrap_cost; press_tons; press_cost_hr; n_strokes; deburring; setup_cost. The remaining variables were implemented in the three regression groups, the results are shown in Table 6.5.

By comparing the identified significant variables, it was possible to identify multiple regression, the results of which are shown in the following Table 6.6. The first column of the table indicates the independent variables considered for the regression, in the second the coefficients $\beta_i$ of the variables, and in the fourth the p-value.

Values with a p-value lower than 5% are statistically significant, those with a higher p-value are negligible, therefore it means that the impact that these latter variables have on the final purchase cost is not significantly influential. The positive sign coefficients indicate variables that unfavorably impact the final cost, that is, an increase in the variable also increases the purchase cost.

| | Product | Process | Management |
|---|---|---|---|
| material_type | 0,5057* | | |
| thicknes | -0,33389 | | |
| n_rungs | 0,5978786** | | |
| cons | 1,224175 | 0,4874935° | |
| treat_type | | 0,3029224*** | |
| press_type | | 0,399218 | |
| pack | | 5,412991** | |
| logvol | | | -0,10161 |
| produc_pz_hr | | | -0,00051 |
| R-squared | 0,5697 | 0,6787 | 0,3287 |
| Obs | 25 | 24 | 25 |
| ***p-value<0,1% **p-value<1%* p-value<5% °p-value<10% | | | |

Table 6.5: Regression for TA three groups of variables.

The negative sign coefficients, on the other hand, indicate variables that have a favorable impact on the final cost, which therefore corresponds to an increase in the purchase cost.

| | Coef. | Std.Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| logvol | -0,14366 | 0,044532 | -3,23 | 0,004 | -0,23656 | -0,05077 |
| material_type | -0,39097 | 0,17387 | -2,25 | 0,036 | -0,75365 | -0,02828 |
| treat_type | 0,511585 | 0,082002 | 6,24 | 0 | 0,340532 | 0,682637 |
| press_type | -0,11305 | 0,145181 | -0,78 | 0,445 | -0,4159 | 0,189789 |
| cons | 2,85681 | 0,61511 | 4,64 | 0 | 1,573712 | 4,139908 |

Table 6.6: Torque Actuator regression.

In particular, the variable **logvol** represents the annual sales volume according to a logarithmic function.

The fit obtained shows an $R^2$ of 0,7233, that is, the variables taken into consideration, albeit few, explain a variance of 72,33% which is a good result at a statistical level.

Looking at the Table 6.6, we can draw some important considerations.

The variable that has an unfavorable effect on the final cost of the component, even in a very significant way, is the surface treatment, in line with what has been assumed. The variables that instead have a favorable effect on the final purchase cost are:

- The volumes, albeit in logarithmic form, highlight the presence of economies of scale;
- The type of material, in fact in the case of 16MnCr5 or when the variable assumes a value of 1, the cost has a decrease.
- The type of press, when the press is progressive the costs decrease. Progressive presses have a lower tonnage, this means that the costs for the

setup and to produce the tool suitable for molding cost less than a transfer press. Which instead, has a continuous processing for which the tonnage is greater, even if the hourly production increases.

The results found are summarized in the Table 6.7:

| | **Expected effect** | **Effect estimated by the model** |
|---|---|---|
| material_type | The type of material determines the presence of surface treatments. (there is not a big difference in cost between carbonitriding and galvanizing, by increasing the number of observations this further subdivision can be made in the future). In fact, in the case of S500MC there are no chemical treatments. | The effect obtained is not the expected one |
| logvol | Purchase volumes favorably influence the price. In fact, as the volumes produced by the supplier increase, the volume of the lots also increases, this leads to lower setup costs (the cost is spread over several units) which affect the cost of mechanical processing. Furthermore, the transport and packaging costs are lower. | The expected effect occurs in the model but according to a logarithmic function. There is an economy of scale. |
| treat_type | Depending on the type of surface treatment, there are different effects on the price. In particular, the price increases with carbonitriding. | The expected effect is achieved and also significantly. |
| press_type | The type of press affects the cost of molding. If the press is progressive, its tonnage is lower as well as its hourly production, but at the same time also the tools used for the mold cost less. If, on the other hand, the press is continuous or transfer, the tonnage and the hourly production are higher, but at the same time the tool, given the shape of the press, will also cost more, consequently, also the cost of the printing operation. | Although the variable has no significant impact within the model. It can be seen from the tests carried out that its presence determines a significant cost difference which makes the output values more reliable. |

Table 6.7: Expected effect vs. Estimated effect.

From an initial analysis, the effect of the type of material seems inconsistent with what was expected. However, the overall effect of the variables must be considered or the procedural correlation that binds them must be taken into account.

For the variable on the type of material there is an unfavorable effect of the S500MC compared to 16MnCr5. But when the variable on the treatment is also considered in the sum of the effects, for S500MC there will not be added other unfavorable effects since it is a material that does not require treatment. While for 16MnCr5 there will be treatment, therefore a significantly unfavorable effect will be added. Overall, the sum effect on the final cost is less for S500MC than for 16MnCr5.

The variable on the type of press is insignificant but it is used to determine the cost differences that occur considering different suppliers. This variable includes the costs of molding, set-up and the efficiency of the supplier company. Therefore it is especially useful during the supplier evaluation process.

### 6.2.2 Spring Cup regression

Following the same process, the Spring Cup family was analyzed. The first step was to purge the offers from any outliers. Some were easily identified as early as the peculiarity of the offer or its incompleteness, others emerged from the analysis of the distributions of the variables, possible thanks to the reduced number of observations to be verified. The rejected offers were:

- 7 offers from a European supplier that only show the final cost without breaking it down into cost items. In reality 2 of these bring the subdivision but the prices are equally out of line with the average and therefore eliminated as outliers.

- 1 offer with a price far below the average because it is made with innovative material.

In conclusion, the remaining offers that served as observations for the regression model were 19. Starting from the distribution of the final cost, it is possible to note the offers proposed by the European supplier, whose prices are not in line with the average.

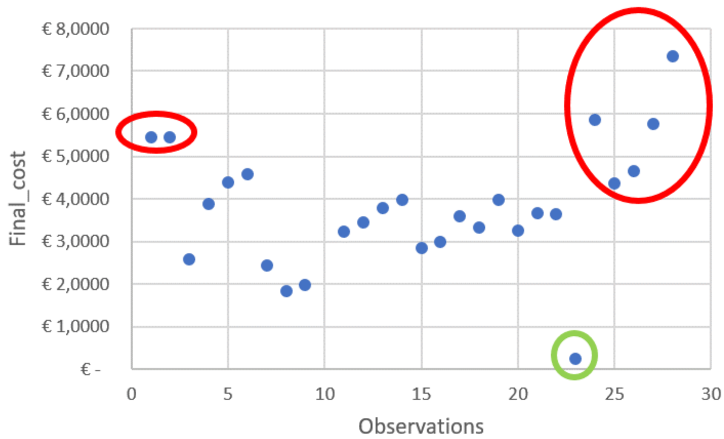


Figure 6.3: Distribution of SP final_cost.

In green is circled one of the latest offers that uses the C75S as a material which is a hardened steel. Its initial raw cost is much higher than the average but does not undergo surface treatments and the mechanical processing has a much lower cost. Overall, the final cost is far below average. This led to an exclusion of the offer as an outlier. But if in the future there are other similar offers, it will be necessary to take them into account in the variable material_type.

After the purge step of the offers, we move on to identifying the cost drivers or the variables that affect the final price. Starting first from the classification seen that also allows us to identify the peculiar variables for this family:

| Product | Process | Management |
|---|---|---|
| Material_type | Scrap_cost | Volumes_per_year |
| Net_weight | Machining | Batch |
| Raw_cost | Press_type | Produc_pz_hr |
| | Press_tons | Nation |
| | Press_cost_hr | Transport |
| | N_strokes | |
| | Washing | |
| | Pack | |
| | Setup_cost | |

Table 6.8: Classification of variables for SP.

The **material_type** variable in this case indicates with 0=DC04/QSTE420MC and 1=S420. In reality, the offers for DC04 and QSTE420MC are unique, but they have been merged by defining a single category for their common characteristics.

The **batch** and **gross_weight** variables will not be considered for the same reasons seen for the TA. Although there are two thicknesses for the S420 material, they do not entail a difference in cost. So, the **thicknes** variable will not be considered.

The material undergoes surface treatments, in particular nitrublack or carbonitriding but due to the limited observations for carbonitriding, the **treat_type** variable cannot be considered.

Then a descriptive statistic was made where the variables with a very low number of observations were eliminated as they were less influential (Table 6.9).

It was decided to eliminate all variables below 19 observations in order not to further weaken the final regression, namely: scrap_cost; n_strokes; washing; pack; transport; press_cost_hr; press_tons; setup_cost; produc_pz_hr.

The remaining variables were implemented in the three regression groups, the results are in Table 6.10.

Given the limited number of observations, it was decided to consider only two variables. For each identified regression, only one variable manages to be significant. The same effect is also had in the overall model, obtained by comparing the identified significant variables in pairs, shown in Table 6.11.

For this regression, the fit is very low, in fact $R^2$=0,2279. The variable that remains most significant is the material_type. From the scatter plot that links the final cost with the type of material, in fact, it is clear how a range of values of the final cost is absorbed by the material DC04.

| **Variable** | **Obs** | **Mean** | **Std. Dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| volumes_per_year | 18 | 221.691 | 214.222 | 10.990 | 700.000 |
| nation | 19 | 0,842105 | 0,374634 | 0 | 1 |
| material_type | 19 | 0,894737 | 0,315302 | 0 | 1 |
| raw_cost | 19 | 1 | 0,079589 | 0,5 | 1 |
| net_weight | 19 | 0,445474 | 0,118218 | 0,22 | 0,71 |
| scrap_cost | 16 | 0,189625 | 0,076275 | 0,026 | 0,25 |
| press_type | 19 | 0,421053 | 0,507257 | 0 | 1 |
| n_strokes | 13 | 8 | 0,408248 | 7 | 9 |
| washing | 8 | 0,099475 | 0,00715 | 0,0901 | 0,11 |
| machining | 19 | 0,983526 | 0,218358 | 0,1565 | 1 |
| pack | 15 | 0,054653 | 0,027623 | 0,024 | 0,105 |
| transport | 14 | 0,11745 | 0,077287 | 0,0194 | 0,3304 |
| press_cost_hr | 14 | 124,7143 | 66,39095 | 60 | 240 |
| press_tons | 16 | 860 | 217,5929 | 500 | 1.000 |
| setup_cost | 15 | 917,2381 | 515,4111 | 350 | 2.024 |
| produc_pz_hr | 14 | 737,1429 | 399,7493 | 514 | 2.100 |
| final_cost | 19 | 3,334747 | 0,750072 | 1,835 | 5 |

Table 6.9: Simple statistics on the variables of the SP family.

| | Product | Process | Management |
|---|---|---|---|
| material_type | 0,891587*** | | |
| net_weight | 1,335168 | | |
| cons | 1,942229*** | 1,536411** | 4,748076** |
| machining | | 1,592558*** | |
| press_type | | 0,551032 | |
| logvol | | | -0,14131 |
| nation | | | 0,298965 |
| R-squared | 0,1967 | 0,0465 | 0,2642 |
| Obs | 19 | 18 | 19 |
| ***p-value<0,1% **p-value<1%* p-value<5% °p-value<10% | | | |

Table 6.10: Regressione for SP three groups of variables.

| | Coef. | Std.Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| material_type | 0,965436 | 0,275965 | 3,5 | 0,003 | 0,380416 | 1,550455 |
| press_type | 0,406138 | 0,309518 | 1,31 | 0,208 | -0,25001 | 1,062287 |
| cons | 2,299931 | 0,265562 | 8,66 | 0 | 1,736965 | 2,862898 |

Table 6.11: Spring Cup regression.

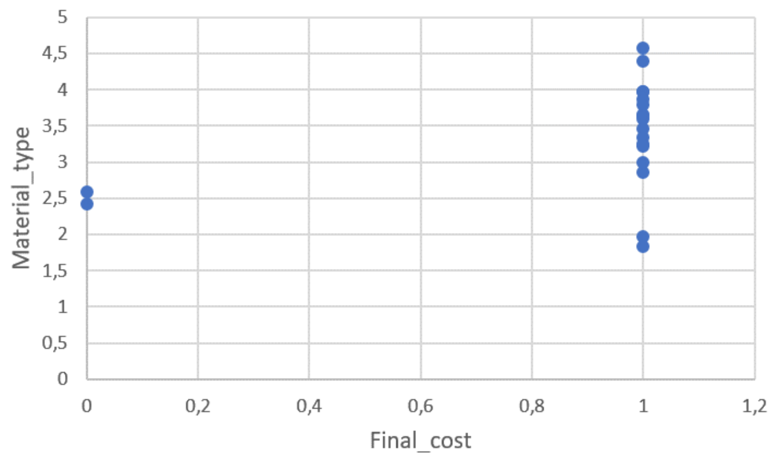


Figure 6.4: Correlation between final_cost and material_type.

Also for this family, the cost variance given by the variable on the type of press used by suppliers is preserved.

### 6.2.3 Pulley regression

Finally, the same procedure was applied to Pulleys. The first step was to purge the offers from any outliers. Some were easily identified as early as the peculiarity of the offer or its incompleteness, others emerged from the analysis of the distributions of the variables, possible thanks to the reduced number of observations to be verified. The rejected offers were:

- 5 offers from a European supplier that only show the final cost without breaking it down into cost items. In reality 1 of these brings the subdivision but the price is equally out of line with the average and therefore eliminated as an outlier.
- 1 offer from a Chinese supplier that contained machining and spinning outliers.
- 1 offer inconsistent with the others regarding the same product.
- 2 offers from a Chinese supplier that only shows the final cost without breaking it down into cost items.
- 2 offers regarding the same product that undergoes a very expensive galvanizing surface treatment and therefore must be analyzed in its peculiarity.

In conclusion, the remaining offers that served as observations for the regression model were 19. Starting from the distribution of the final cost, it is possible to note the offers proposed by the European supplier, whose prices are not in line with the average.

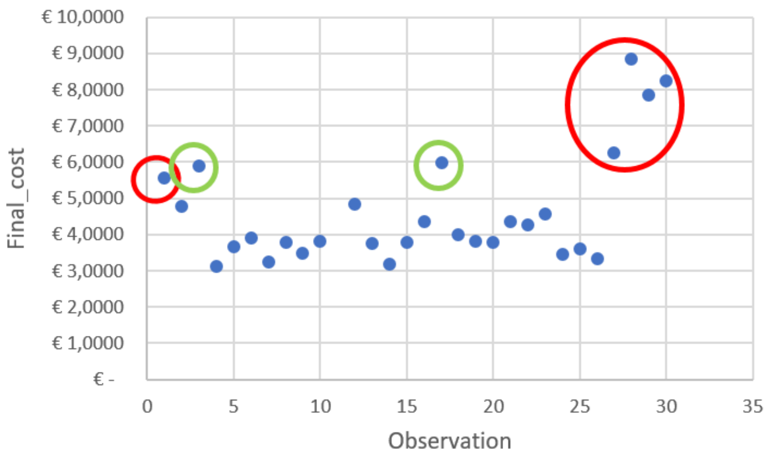


Figure 6.5: Distribution of Pulley final_cost.

The two offers that describe the same product are circled in green. If you analyze the distribution of the different variables, you can see that their out of average cost is due to the galvanizing treatment, therefore they are considered as outliers.

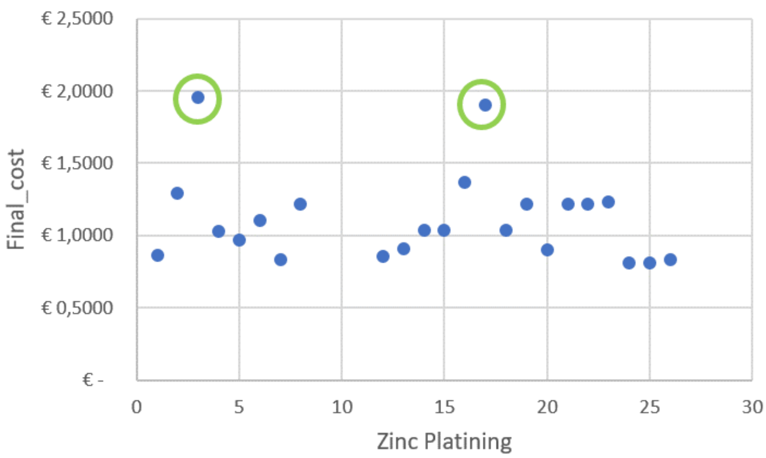


Figure 6.6: Distribution of Zinc Plating.

Continuing the analysis of the distributions of the variables, another outlier emerged due to the offer of an uncompetitive Chinese supplier, as can be seen from the following graphs:

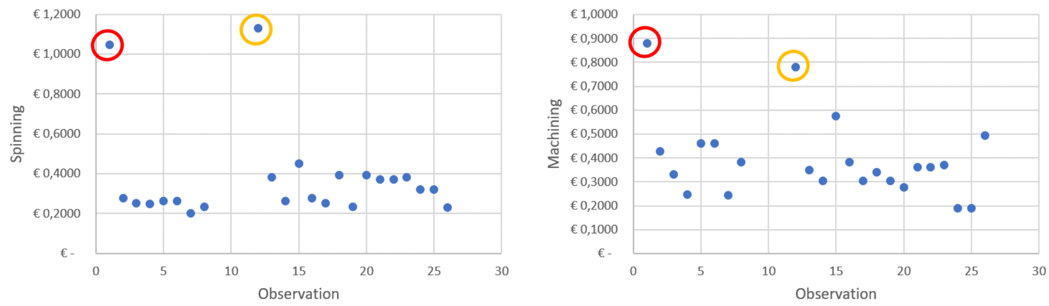


Figure 6.7: Correlation between final_cost, spinning and machining.

After the purge step of the offers, we move on to identifying the cost drivers or the variables that affect the final price. Starting first from the classification seen that also allows us to identify the peculiar variables for this family:

| Product | Process | Management |
|---|---|---|
| Material_type | Scrap_cost | Volumes_per_year |
| Net_weight | Machining | Transport |
| Raw_cost | Lav_mecc | |
| | Pack | |
| | Press_cost_hr | |
| | N_strokes | |
| | Spinning | |

Table 6.12: Classification of variables for Pulley.

For pulleys there is only one Chinese supplier, this means that some variables such as **press_tons** and **produc_pz_hr** are constant, therefore not considered. Furthermore, since there are no offers for the two types of press, the variable **press_type** cannot be considered. Over time, Dayco has tried to look for other Chinese suppliers to free itself from the only one with whom it has lasting relationships. For this reason 3 different offers appear, but they have proved to be not very competitive.

The material used is unique therefore the **material_type** variable is not considered.

The **batch** and **gross_weight** variables will not be considered for the same reasons seen for the TA.

There is only one type of surface treatment or galvanizing, therefore the **treat_type** variable is not considered.

There is another European supplier (the same of the TA and SP) but also in this case the prices are out of line. In general, this supplier is considered because with its offers it supplies other Dayco offices in Europe. If more information could be obtained from its offers, the **nation** variable could be fed. For the moment, however, its offers must be considered separately where only an estimate can be made by analogy.

Then a descriptive statistic was made where the variables with a very low number of observations were eliminated as they were less influential.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| volumes_per_year | 15 | 404.535 | 597.025 | 16.829 | 1.895.112 |
| thicknes | 19 | 0,31579 | 0,671038 | 0 | 2 |
| raw_cost | 19 | 623,6521 | 147,2919 | 62 | 826 |
| net_weight | 19 | 0,766316 | 0,121263 | 0,56 | 0,991 |
| scrap_cost | 19 | 79,39947 | 30,31752 | 35 | 141 |
| lav_mecc | 19 | 0,315184 | 0,081863 | 0,1304 | 45 |
| machining | 19 | 0,353574 | 0,101814 | 0,19 | 0,5739 |
| spinning | 19 | 0,320847 | 0,066855 | 0,2315 | 0,4783 |
| press_cost_hr | 16 | 9,75 | 0,447214 | 9 | 10 |
| n_strokes | 16 | 9,5 | 1,549193 | 6 | 12 |
| pack | 19 | 0,129426 | 0,060851 | 0,0222 | 0,22 |
| transport | 18 | 0,280606 | 0,076213 | 0,1739 | 0,4522 |
| produc_pz_hr | 18 | 300 | 0 | 300 | 300 |
| final cost | 19 | 3,8261 | 0,469711 | 3,1281 | 4,7879 |

Table 6.13: Simple statistic on the variables of the Pulley.

It was decided to eliminate all variables below 19 observations in order not to further weaken the final regression, with the exception of the volume for the verification of the presence of economies of scale. The eliminated variables are: press_cost_hr; n_strokes. The remaining variables were implemented in the three regression groups, the results of which were:

| | Product | Process | Management |
|---|---|---|---|
| thicknes | 0,2422528** | | |
| net_weight | 1,480979** | | |
| cons | 2,614638*** | 2,431983** | 1,615808** |
| machining | | 2,231129** | |
| pack | | 4,676396*** | |
| logvol | | | 0,1903108** |
| transport | | | 0,087884 |
| R-squared | 0,3993 | 0,4537 | 0,3363 |
| Obs | 19 | 19 | 14 |
| ***p-value<0,1% **p-value<1%* p-value<5% °p-value<10% | | | |

Table 6.14: Regression for Pulleys three groups of variables.

Given the limited number of observations, it was decided to consider only two variables. The significant variables identified were then compared in pairs to identify the final model, shown in Table 6.15.

The fit for this regression is better than that for the Spring Cup but still not as high as that for the TA, it is equal to $R^2$=0,6754.

The most significant variables are **logvol** and **net_weight**, for which the final cost has a linear trend as can also be seen from the scatter plots (Fig. 6.8).

| | Coef. | Std.Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| logvol | 0,215468 | 0,041183 | 5,23 | 0 | 0,125737 | 0,305199 |
| net_weight | 2,489598 | 0,830483 | 3 | 0,011 | 0,680131 | 4,299064 |
| cons | -0,6081 | 0,952176 | -0,64 | 0,535 | -2,68271 | 1,466518 |

Table 6.15: Pulley regression.

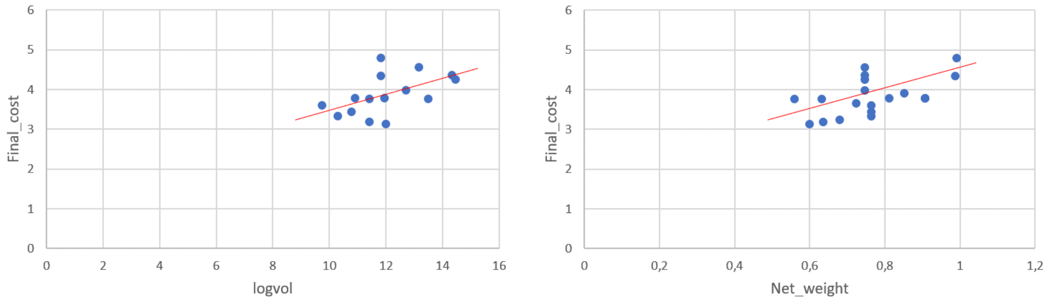


Figure 6.8: Correlation between final_cost, net_weight and logvol.

In general, both for the Pulleys and for the Spring Cups, the very limited observations do not allow an in-depth analysis that also includes the study of CAD drawings, leading to low fit. By inserting the geometric variables, in the future, you can certainly have better results.

## 6.3 Residue Analysis

Once the regression model has been identified for each product family, it is advisable to perform some residue tests to have further confirmation of the validity of the model. In particular, it is useful to analyze the distribution of residues graphically since it allows to evaluate, a posteriori, if the hypothesized model is correct. If so, the errors should be distributed normally.

The calculation of the residues is carried out with the following formula:

$$Residues = ActualPurchaseCost - EstimatedPurchaseCost$$

$$Residual\% = \frac{ActualPurchaseCost - EstimatedPurchaseCost}{ActualPurchaseCost}$$

In this paragraph, since the methodology is the same for all product families, we have focused on that of the Torque Actuators, the analysis can be easily replicated with the same steps to the other families.

The graphical results of the analysis of the distribution of residues for the family considered are shown in Fig. 6.9.

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Residues | 25 | -4,90E-10 | 0,281568 | -0,43134 | 0,456844 |

Table 6.16: Statistic of residues.

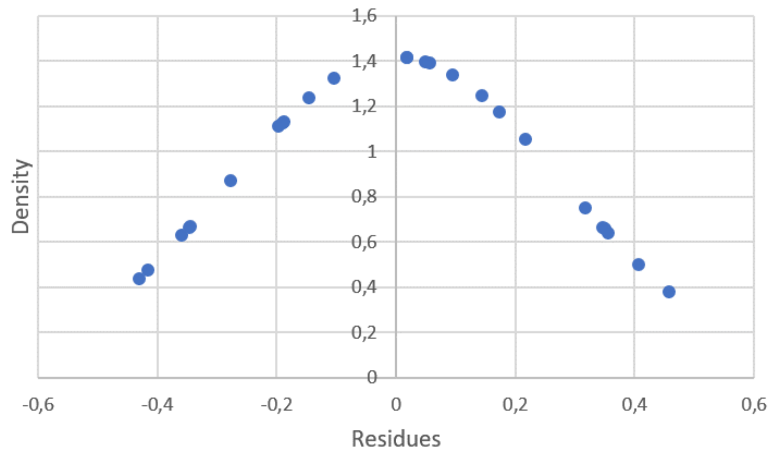


Figure 6.9: Distribution of residues.

From the graphs, the residues are normally distributed, in addition, the average percentage value of the error on the purchase cost is very quite low equal to about 28%. Fig. 6.10 shows the scatter plot that relates the residues to the final purchase cost. The trend of the residuals with respect to the dependent variable does not show a slight heteroskedasticity.

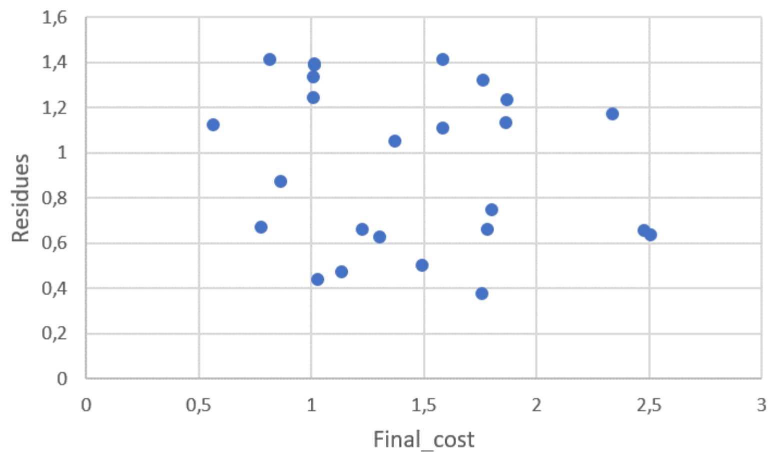


Figure 6.10: Correlation between final_cost and residues.

Since the regression model has a high coefficient of determination, all positive residual values indicate potential inefficiencies in purchases, or at least the presence of possible unobserved cost determinants, which may have caused a statistical error.

## 6.4 Comparison between Parametric and Analogous estimation

Dayco currently does not apply the estimate by analogy following a standardized process. When the cost of a new component is assessed, the Cost Estimator on the basis of his personal experience identifies the existing component whose characteristics are closer to those of the new one. The final cost is calculated based on how different they are.

E.g. taken the WQRZ597 which differs from the WQRZ602 (always belonging to the first cluster therefore, judged similar) mainly for the greater weight that negatively affects the cost. The external geometric shape is very similar except for a small difference between the depth of the steps, which however is not significant. The reference data for the WQRZ602 are:

| **WQRZ 602** | |
|---|---|
| Material_type | 1 |
| Treat_type | 2 |
| Volume_per_year | 10.000 |
| Net_weight | 0,138 |
| Prezzo press_progr | 1,8644 |
| Prezzo press_transf | 2,3387 |

Table 6.17: WQRZ 602 variables.

while those that the Cost Estimator knows ex ante of the WRZ597 are:

| **WQRZ 597** | |
|---|---|
| Material_type | 1 |
| Treat_type | 2 |
| Net_weight | 0,198 |

Table 6.18: WQRZ 597 variables.

For the same type of press and volume per year, a proportion is made between prices and weights, which identifies a final price for 597 of approximately € 2.67 for press_progr and € 3.36 for press_transf.

The calculation made is approximate and lacking in methodology, leading to an even greater estimate error. To make the error minor and standardize the estimation process by analogy, a tool was created on Excel with a user-friendly interface that allows to calculate the final cost of the new component on the basis of the input data that the company knows ex-ante , or before the arrival of the supplier offer, based on the CAD drawings.

The tool is based on the 3 datasets created for the regression model but calculates the final cost by following the cost items according to the income statement. In particular, the input data entered are:

| Input Data | |
|---|---|
| Net weight Kg (according to the drawing) | |
| Family Type | |
| Steel Type | |
| Country of cost evaluation | |
| Country of delivery | |
| Volume (parts per year) | |
| Press Type | |
| Surface Treatment | |

Figure 6.11: Input data for database.

While the output ones follow the income statement scheme present in the suppliers' offers:

| Output Data | | |
|---|---|---|
| **Currency** | **Euro** | **USD** |
| Material Cost | #N/D | #N/D |
| Surface Treatment Cost | #N/D | #N/D |
| Machining Phase Cost | #N/D | #N/D |
| Press Phase Cost | #N/D | #N/D |
| Washing Phase Cost | #N/D | #N/D |
| Spinning Cost | #N/D | #N/D |
| Duburring Cost | #N/D | #N/D |
| **Total Manufacturing** | #N/D | #N/D |
| SG&A (Total Manufacturing cost*0,07) | #N/D | #N/D |
| Profit (Total Manufacturing cost*0,16) | #N/D | #N/D |
| Packaging (Material Cost *0,05) | #N/D | #N/D |
| **Total FCA Price** | #N/D | #N/D |
| Transportation Cost | #N/D | #N/D |
| Duties,Taxes | #N/D | #N/D |
| **Total DDP Price** | #N/D | #N/D |

Figure 6.12: Output data of database.

Each cost item was calculated on the basis of the average values obtained by combining the various input data. Thanks to a simple and intuitive interface, this file can also be used by designers for a first rough estimate of the entire finished product in order to evaluate any redesigns. In addition, this tool speeds up the estimate by analogy and provides values based on mathematical calculations, making the estimate a methodological and standardized process with reduction of the error committed. In fact, if the final cost of the WQRZ597 seen in the previous example is recalculate, the result is:

| Input Data | |
|---|---|
| **Net weight Kg (according to the drawing)** | 0,1980 |
| **Family Type** | Torque_Actuator |
| **Steel Type** | 16MnCr5 |
| **Country of cost evaluation** | Italy |
| **Country of delivery** | Italy |
| **Volume (parts per year)** | 10k - 50k |
| **Press Type** | Transfer |
| **Surface Treatment** | Zinc Platining |

Figure 6.13: Input data for WQRZ 597.

| Output Data | | |
|---|---|---|
| **Currency** | **Euro** | **USD** |
| Material Cost | 0,46456 | 0,53425 |
| Surface Treatment Cost | 0,5 | 0,575 |
| Machining Phase Cost | 0 | 0 |
| Press Phase Cost | 0,23 | 0,2645 |
| Washing Phase Cost | 0 | 0 |
| Spinning Cost | 0 | 0 |
| Duburring Cost | 0 | 0 |
| **Total Manufacturing** | 1,19456 | 1,37375 |
| SG&A (Total Manufacturing cost*0,07) | 0,08362 | 0,09616 |
| Profit (Total Manufacturing cost*0,16) | 0,19113 | 0,2198 |
| Packaging (Material Cost *0,05) | 0,02323 | 0,02671 |
| **Total FCA Price** | 1,49254 | 1,71642 |
| Transportation Cost | 0,02239 | 0,02575 |
| Duties,Taxes | 0 | 0 |
| **Total DDP Price** | 1,51493 | 1,74217 |

Figure 6.14: Output data for WQRZ597.

while for progressive a final cost of € 1.6739 is obtained.

The values obtained through this tool were compared with those obtained with the parametric model.

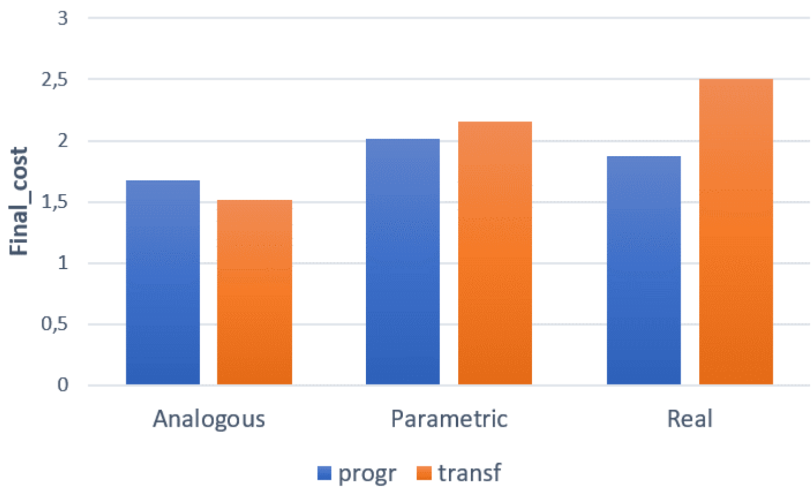


Figure 6.15: Comparison between models.

The graph generally shows how the parametric model is more reliable than the estimate by analogy. For the progressive press, both the parametric and analogical models show an error of about 20% compared to the real cost. The parametric model has a cost in excess while the analogous is in default. The estimate is good because you have enough offers from the same supplier.

For the transfer press there are fewer offers available. The model that is most affected is that by analogy where the error is greater. This is due to the presence in the real offer of machining costs of approximately 0.64 cents which are not provided for in the analogous model. The machining item was excluded in setting up the model since there were only two offers that contained it and the designers were unable to understand its relationship with the CAD drawing. The impact on the final cost given the presence of this cost item is mitigated in the parametric model.

# Conclusions

The information asymmetry present during the bidding phase involves payment by the customer of the supplier inefficiencies. The customer is also bound to the supplier for the waiting times for receipt of the offer, which prevent him from redesigning the final product.

This thesis provides a tool to support the customer to free himself from the supplier, obtaining a predictive estimate of the cost of the component he will purchase externally. He will no longer have to wait for an offer from the supplier but will predict the cost based on his CAD drawings. This leads to a reduction in the information asymmetry, in fact the customer manages to notice any inefficiencies on the part of the supplier, benefiting the entire negotiation process which also becomes faster. In addition, it manages to evaluate any redesigns of the finished product so as to be able to obtain a higher quality product, which responds better to market needs, making it more competitive.

By analyzing the past literature and observing the types of data available, it was considered appropriate to choose a top-down model as the first approach. More precisely, a parametric model was used in this thesis. It consists of a multiple linear regression analysis on a dataset with a sample of purchase offer observations. Through this statistical tool, the main cost drivers and the ways in which these affect the final cost have been determined. Once the regression line with the coefficients of each parameter has been determined, it is possible to estimate the final purchase cost for any part number entered in the model. A different parametric model was proposed for each product family; it would not have been appropriate to present a single one, since the product families are different from each other and this could have distorted the results.

The limitation encountered during the setting of the model concerns the scarcity of the number of available observations, sometimes not even statistically significant.

This implies that the variables used to set up the model are very few, therefore the explained variance is low. The model becomes even less reliable for those families with complex geometry and very variant between one product and another, as in the case of the Spring Cup, where in fact the worst fit is obtained. Conversely, for the Torque Actuator and Pulleys family being the most standardized geometry, the fit is better.

This limitation led the company taken as a case study to use a predictive estimate based on analogy. However, the estimation process is neither standardized nor follows a methodological rigor.

The second result obtained with this thesis was to standardize the estimation process by analogy making it more efficient and decreasing the estimation error that was committed, through the creation of a user-friendly interface that based on the data collected in the database performs calculations mathematicians, allowing their use also to designers.

It has also been shown that clustering can also simplify the estimation process by analogy. The clusters are discriminated by ranges of values assumed by the geometric variables which result in different final cost ranges. In particular, the family with simpler and less variant geometry, i.e. the Torque Actuator, was analyzed.

The results obtained with this method overcome the limitations encountered with the parametric method. In fact, comparing the two models, it turned out that the parametric model offers more reliable results for families with simple geometry and with few variations while they are very high for the Spring Cup. So, to overcome the variance given by this family, the analogue method can be utilized which also highlights which are the most significant geometric variables in determining the final cost and then they can be used in the parametric model.

By increasing the number of observations available in the future, the parametric model can be perfected leading to even more reliable results for this family with considerable variance. For the moment, in order to reduce the estimation error, it is convenient to compare both models.

Thanks to the setting obtained with the parametric model, it will be possible in the future to develop a model of neural networks to obtain an even more reliable predictive estimate. Currently an experimental approach could follow the guidelines offered by the article by Chun Ching Lee, C. Ou-Yang "A neural networks approach for forecasting the supplier's bid prices in supplier selection negotiation process" which solves a case study very similar to that under exam. The authors start from a poor database, which they enrich with observations generated by simulations, in this way they manage to create a model based on neural networks that allows a much more accurate estimate even in the presence of geometric variability.

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