\

Pedro Alcântara Arvelos

When to make or buy?

A framework for make-or--buy decision making

Master thesis in Production Engineering

Dezember 2014

Acknowledgments

Going back to school after many years of professional life was an exciting experience specially considering my shift from Civil to Production Engineering. Sitting in the class room, attending lectures, working on the various tasks and preparing for exams like in the past has helped me to get back some habits of reading, studying. However this would not have been possible without the understanding of my working colleagues and the support of my family during the last two years

I have learned about many new subject matters and I would like to thank all of my professors and colleagues for their contribution to this almost two-year learning process.

To Professor Pedro Cunha I leave special thanks for being my thesis supervisor, whose knowledge and guidance proved to be very important to this work.

Abstract

The purpose of this study was to develop a make-or-buy framework that could be applied when the make-or-buy issue arises. The framework was developed after a literature review and it is based on a two-phase model which has in the external environment the trigger for the make-or-buy process. The first phase starts with three different value disciplines – customer intimacy, product leadership and operational excellence, which form the value discipline of the customer. To the value disciplines there are six objectives associated: cost, quality, variability, flexibility, time and human capital. In the second phase, three options are available: Make, Make and Buy and Buy. The structure of the model was designed so that the Analytic Hierarchy Process (AHP) methodology could be applied in ranking the considered criteria. A three phase implementation procedure was also developed in which a multi-functional team ranks each all the criteria.

The framework was implemented in a company that operates in the automotive sector. Although the practical application did not follow the proposed steps in the implementation procedure, it was determined that the best option was to make the product instead of buying or even making and buying. The obtained results demonstrated coherency between the results obtained in each level, as the judgments made were subjected to a consistency check throughout the process. However, a larger empirical research is suggested to assess the model's utility and applicability in real-world make-or-buy decision making situations. This would be accompanied by workshops in the companies where the framework would be implemented, as well as by the development of a software tool to facilitate the application of the AHP methodology.

Keywords: Make-or-buy decisions, Outsourcing, Sourcing, Decision making, Structured framework.

Resumo

O âmbito deste estudo foi o de desenvolver uma metodologia de apoio à tomada de decisão quando o problema de “make-or-buy” surge. A metodologia foi desenvolvida após uma revisão à bibliografia existente e tem como base um modelo de duas fases que onde o ambiente externo vai desencadear o processo de “make-or-buy”.

A primeira fase tem início com três diferentes disciplinas de valor – proximidade com o cliente, liderança do produto, e a excelência operacional, que formam a disciplina do valor para o cliente. A estas disciplinas de valor estão associados seis objetivos: custo, qualidade, variabilidade, flexibilidade, tempo e o capital humano. Na segunda fase estão disponíveis três opções: Fazer, Fazer e Comprar, e Comprar. A estrutura do modelo foi desenvolvida de forma que o Analytic Hierarchy Process (AHP) pudesse ser aplicado na classificação dos critérios considerados. Foi também desenvolvido um procedimento para a implementação de três fases, onde uma equipa multifuncional classifica os todos os critérios.

A metodologia foi implementada numa empresa que opera no setor automóvel. Apesar da aplicação prática não ter seguido os passos do procedimento de implementação, determinou-se que a melhor opção era a fazer o produto em vez de comprar ou mesmo fazer e comprar. Os resultados obtidos demonstraram coerência em cada nível, uma vez que os julgamentos/decisões tomadas foram sujeitas a uma verificação de consistência ao longo do processo. No entanto, é sugerido um maior estudo empírico para avaliar a utilidade do modelo e a sua aplicabilidade em situações reais de tomada de decisão de “make-or-buy”. Este estudo seria acompanhado por “workshops” nas empresas onde a metodologia seria implementada, bem como pelo desenvolvimento de software que facilite a aplicação da metodologia de AHP.

Palavras-chave: Decisões “make-or-buy”, Externalização, Produção interna, Tomada de decisão, metodologia estruturada.

Index

List of Figures

List of Tables

List of Abbreviations and Acronyms

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
CBR	Case-Based Reasoning
CI	Consistency Index
CR	Consistency Ratio
DA	Discriminant Analysis
DM	Decision Maker
ELECTRE	Elimination Et Choix Traduisant la Realité
MAA	Multi-Attribute Analysis
MADM	Multi-Attribute Decision Making
MCDM	Multiple Criteria Decision Making
MEW	Multiplicative Exponential Weighting
MODM	Multiple Objectives Decision Making
PA	Product Architecture
R&D	Research and Development
RI	Random Index
ROCE	Return On Capital Employed
SAW	Simple Additive Weighting
SSM	Strategic Sourcing Model
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

List of Symbols

λ	Matrix eigenvalue
λ_{max}	Matrix's maximum eigenvalue
Σ	Sum
A_i	Alternative *i*
A_{NxN}	Square matrix of dimension *N*
B_i	Attribute *i*
b_{ij}	Entry *b* of the *i*-th row of the *j*-th column in a generic matrix
C_{ij}	Sum of the c elements in each column of a generic matrix
c_{ij}	Entry *c* in the *i*-th row of the *j*-th column of a generic matrix
Ev	Eigenvector of the matrix
Ev_{ij}	Entry *Ev* in the *i*-th row of the *j*-th column of a matrix's eigenvector
m_{ij}	Measure of performance of the alternative in the *i*-th row of the *j*-th column
n	Number of criteria used in decision making
Pv	Priority vector of the matrix
Pv_{ij}	Entry *Pv* in the *i*-th row of the *j*-th column of a matrix's priority vector
w_j	Weight of the *j* attribute
X_{ij}	Entry *x* in the i-th row of the j-th column

Chapter 1

Introduction

In this chapter, the make-or-buy issue is presented, as well as the purpose of this study. The developed framework and its implementation procedure are also presented along with the case study that was conducted.

1.1. Introduction and developed work

A make-or-buy decision consists of the act of choosing between manufacturing a product in-house or outsourcing its production to an external supplier. Companies have finite resources and cannot always afford to have all manufacturing technologies in-house (Cáñez et al., 2000). Thus, a company, essentially, makes the comparison between the costs and other benefits of producing a product or product component internally in relation to purchasing it from an external supplier. A company may choose to produce in-house when, traditionally, the benefits of outsourcing a given product or product component are low, i.e., when one or more of the following conditions are observed:

- The cost of buying is superior to the cost of producing in-house;
- The company has an excess of production capacity;
- The suppliers may not be reliable.

In order to make this decision, the company assumes that it possesses the appropriate techniques, equipment, as well as access to raw material, and also the capacity to meet its own quality standards. In the last decades, with the increase of outsourcing, the decision to make-or--buy has become the one that managers have to deal with more often. However, the decision of producing an item instead of buying it entails risks. A company that decides to make instead of buying, risks losing access to alternative sources of design flexibility, and also to the technological innovations that a specialized supplier can offer. When buying, a company risks losing its own design capability and becoming dependent on the supplier.

The factor cost was initially viewed as one of the most important factors to be considered in a make-or-buy decision (Balakrishnan, 1994; Padillo and Diaby, 1999). With the development of new studies, researchers understood that a make-or-buy decision had also a strategic component and that cost, and the availability of the production capacity were not the only factors to be considered (Welch and Nayak, 1992; Probert, 1996, McIvor et al., 1997, McIvor and Humphreys, 2000; Cáñez et al., 2000; Platts et al. 2002; Water and Peet, 2007; Holcomb and Hitt, 2007; Park and Ro, 2011; Puranam et al., 2013). In view of the fact that a make-or-buy decision is considered to have a great impact on a company's strategy, as strategic decisions make use of considerable corporate resources, have long-term consequences, and are in many cases extremely difficult to reverse (Ketelhöhn, 1993), then a structured framework should be used to assure that all decisions made are in the company's best interest.

The purpose of this study was, after a literature review regarding the issue of make-or-buy decisions, to develop a make-or-buy decision making framework. The framework is divided into two phases that, in order to implement the Analytic Hierarchy Process, are distributed along five hierarchic levels. In Phase 1 the Value Discipline of the Customer (Treacy and Wiedersema 1997) and the Performance Objectives are defined. The Value Disciplines, the importance of which is assessed in Level 1, refers to three ways in which a company can outperform their competition by producing a different kind of customer value, namely:

- Operational excellence;
- Product leadership;
- Customer intimacy.

The Value Disciplines of the Customer will be further detailed when Phase 1 of the framework is presented.

Regarding the Performance Objectives, six objectives were identified – Cost, Time, Flexibility, Quality, Variability, and Human Capital. The importance of each one is determined in levels 2 and 3 and is influenced by the position that the company wishes to assume in relation to its customers, each time the make-or-buy issue arises.

In Phase 2, which includes levels 4 and 5, the decision whether to in- outsource is taken followed by determining of the type of relationship to establish with the supplier. In this model, the option "supplier" is considered for simple short-term contracts, while the option "partnership" is for a long-term relationship. In each level a comparison matrix is computed and the priority vector of the corresponding attributes is assessed. It should be noted that a short-term contract is considered to have the duration of a product's lifecycle while the designation long-term partnership is adopted when a range of products is to be developed between the client and the supplier.

Regarding the practical application, the implementation procedure was designed so that the majority of a company's main functions could take part in the process. The functions that were considered are the ones displayed in Fig. 1.1.

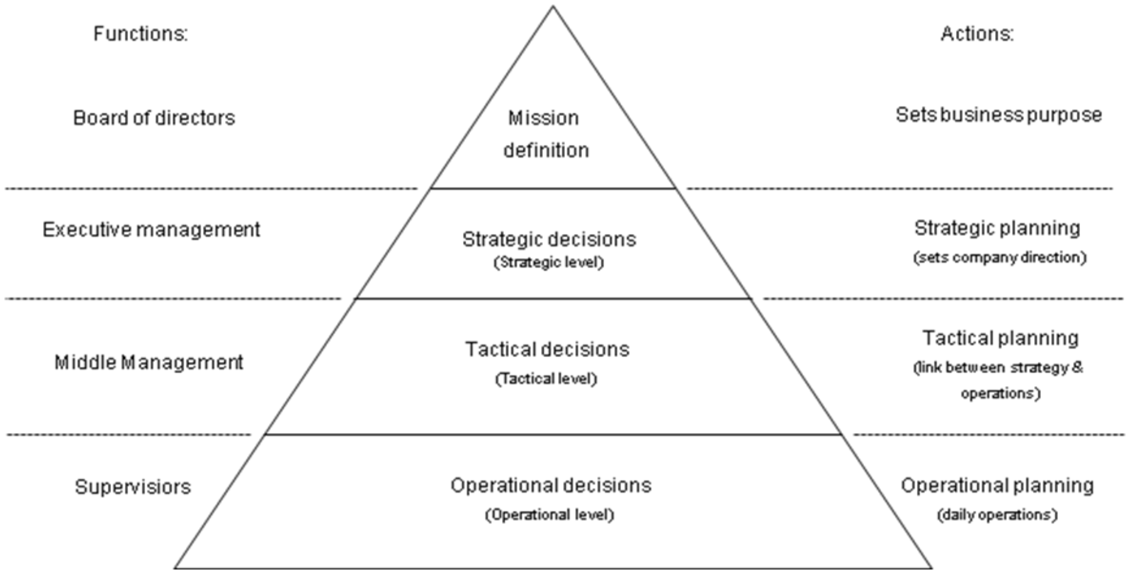

Figure 1.1. Management pyramid

The process is divided into 3 phases, allowing the different team members to participate only at a given stage where their expertise is most needed:

- Phase 1: Preparation phase – The project team is selected and briefed;
- Phase 2: Data collection – The data necessary to perform the make-or-buy analysis is gathered and its rating carried out by performing 2 workshops;
- Phase 3: Analysis and supplier relation selection – After obtaining the priority for each of the three options – Make, Buy, or Make and Buy, and if the priority vector indicates that the best ranked option is to buy or to make and buy, then the decision has to be made regarding the relation with the supplier.

However, due to the fact that this is an academic study, it was only possible to assemble a one man team, which led to the decision of, in Phase 2, performing just one workshop instead of the initial two.

Although the practical implementation procedure differed from the proposed methodology, coherency between the results obtained in each level was observed, which was to be expected as the judgments made were subjected to a consistency check during the process. The final result indicated that the best option was to make instead of buying or making and buying, which is also consistent with previous decisions made by the company, regarding the same type of products.

The framework was designed to be applied to all types of production or production strategies, however it is still necessary to implement it in different industries to assess its effectiveness and eventual improvements.

The existing literature has presented some approaches that allow standardizing the make-or-buy decision process. As this subject has proven to be complex and the literature extensive, it was decided to divide this study into five chapters. Chapter 1 introduces the make-or-buy subject and the objectives of this study. Chapter 2, which is divided into 4 subchapters, presents a theoretical review. The first subchapter presents a review of make-or-buy models and approaches. The models and approaches are organized chronologically, thus making it easier to understand the evolution of the work that has been done, so far, by other researchers. The third subchapter presents the attributes that a make-or-buy decision making model should address and, in the third and fourth subchapter the Multiple Criteria Decision Making Models (MCDM) and the Analytic Hierarchy Process (AHP) are, respectively, presented and their usefulness to the make-or-buy issue demonstrated. In Chapter 3 a two phase framework is developed and presented. Each of the two phases are detailed and integrated in a decision making hierarchic structure, based on the AHP which is also presented. This framework presents, besides the option of making or buying, a third option – making and buying, which is new to these types of frameworks. A proposal for the implementation procedure, based on the work developed by Platts et al. (2002) is also presented. In Chapter 4, a case study where the developed framework was applied is presented. The case reports a company that operates in the automobile branch and received a contract to deliver a part produced by injection of Polyurethane (PU) Foam in a closed tool. Due to its characteristics the traditional production process was thought to be expensive, driving the cost to non-competitive values. This proved to be a good opportunity to apply the methodology as the company was equating buying instead of manufacturing. On completion of the process, the results indicated that, despite the high investments costs, making the part is still better than outsourcing its production.

In the final chapter, the conclusions are presented along with a proposal for further developing the work developed in this study.

Chapter 2

Make-or-Buy: Where do we stand

In this chapter, the make-or-buy models and approaches, that were found to be more relevant, are presented. The main areas and attributes that a make-or-buy decision making model should consider, in the author's opinion, are identified. Due the multidisciplinary nature of this subject, the Multiple Criteria Decision Making theory (MCDM) and Analytical Hierarchy Process (AHP) are presented and demonstrated their usefulness to the make-or-buy issue.

2.1. Trends

During this literature review two different make-or-buy trends were identified. The first trend, which is essentially concerned with the strategic side of outsourcing, considers the following factors:

- Cost
- Core activities
- Product architecture
- Relation with suppliers

The traditional costs analysis, based on the Transaction Cost Theory (Williamson, 1975), may influence the decision of which activities should or should not be outsourced. Core activities should remain in-house while the non-core can be outsourced. According to Prahalad and Hamel (1990) a core competence should be kept in-house instead of surrendering core competencies in favour of external suppliers. However, this aspect cannot be dissociated from the cost reduction, as mentioned by Quélin and Duhamel (2003) that state that a firm can outsource a core activity that requires a heavy investment, as long as the supplier/service provider covers that cost. Concerning product architecture, Parka and Young (2006), based on the knowledge-based view, argue that when product architecture changes, a company that adopts a pseudo-make strategy (a company designs a product but outsources the manufacturing process) will probably demonstrate better product performance than a firm that follows a pure make or buy strategy. The relationship with suppliers is critical and when a company lacks knowledge and/or skill in an important area, it can benefit from the knowledge exchange between internal and external suppliers. Thus a strategic partnership can bring benefits for both.

The second trend, like Water and Peet (2006) mention, is more prescriptive in nature. As Platts et al. (2002) state, the make-or-buy process can be carried out systematically and analytically by means of a structured methodology. However, considering exclusively the aspects above mentioned can be somewhat narrow-minded, as there are other important issues to be considered, namely, both qualitative and quantitative information. In subchapter 2.1 a review of eight existing make-or-buy frameworks is made, in which factors such as cost, time, quality, technology and manufacturing processes, supply chain management and logistics, and support systems, among others, are identified. The frameworks developed by Cáñez et al. (2000) and Water and Peet (2006), already consider quantitative measures to facilitate the assessment of priorities between the different factors. Water and Peet (2006) even developed an AHP model to support the decision making process. This idea was also chosen to be incorporated into the framework developed in this study.

2.2. Models and approaches

From the literature review, it was possible to assess the evolution of the make-or-buy approaches over the last two decades. The advances made have been substantial. Welch and Nayak (1992) suggested a conceptual framework that intended to enhance the traditional cost analysis by considering strategic and technological factors. Their model, the Strategic Sourcing Model (SSM), consists of three main dimensions:

i. Process technology's role in competitive advantage – Assessing if outsourcing factors that are involved in the development and introduction of new products, such as research and development (R&D), design, engineering, manufacturing, or assembly, will be prejudicial to their firm's competitive position;
ii. Maturity of the process technology across industry – Companies should evaluate the maturity of the process technology across all industries;
iii. Competitors' technology position – This analysis involves a structured benchmarking approach that should take into consideration the differences that may exist from industry to industry.

This model results in a three by nine matrix, which will allow deciding which strategy to adopt: "make", "marginal make", "develop internal capability", "buy", "marginal buy", or "develop suppliers".

Later on, Probert (1996), describes the development of a ten step systematic approach to formulating a make-or-buy strategy. Similarly to Welch and Nayak (1992), Probert (1996) analyses the manufacturing technologies used by the business, as he considers the technological factor the centre of the methodology, namely the competitiveness with which they are deployed, and their importance to the success of the business. The methodology was reported to be applied to six engineering manufacturing businesses which reported positively in terms of its effectiveness, with projected business results improvements of 10% to 40% in return on capital employed (ROCE) and 30% to 60% stock/lead-time reductions. However, Probert (1996) stated that the determination of the key issues confronting the business, the relationship between product architecture (PA) and the manufacturing technologies, and the evaluation of make in/buy out options, are all areas for further development.

McIvor et al. (1997), with the intention of illustrating that the make-or-buy is a strategic decision and has implications for the general corporate strategy of the organization, propose a four stage conceptual framework for evaluating make-or-buy decisions based on three main criteria:

i. Core competences;
ii. Capabilities (e.g. : internal versus external);
iii. Cost (e.g.: internal versus external).

In the first stage the core activities are defined. This stage is very important, as McIvor et al. state, companies have mistakenly given away their core competences by reducing internal investment and choosing outside suppliers. This action would not result in the enrichment of the necessary skills needed to continue future product leadership. They argue that sourcing decisions can have an impact on, among other factors, the core activities of the organization. In the second stage the appropriate value chain links are profiled. Through a structured benchmarking approach, similarly to what Welch and Nayak (1992) propose, companies should assess their core activities capabilities in relation to potential suppliers' and competitors' capacity. In the third stage where the total cost analysis is processed, the traditional cost assessment is replaced by a careful measurement of all the actual and potential costs involved in outsourcing a given activity, internally or externally. The final stage, an analysis of potential suppliers for partnership is made. The company may decide to establish a partnership relationship with a supplier, as it is possible to develop core competences by learning from a partner. However, this involves the exchange of information, risks and rewards, thus the importance of a proper analysis.

McIvor and Humphreys (2000), present a five stage hybrid computer-based system approach, designed to assist in the make-or-buy decision, which employs both case-based reasoning (CBR) and decision support system components that include a multi-attribute analysis (MAA) and a sensitivity analysis. The system evaluates the suppliers' capabilities based on technological and organisational profiles, followed by the measurement of the acquisition costs.

In the first stage the key performance categories that are required to specify the technical capability categories, are identified, while in the second stage the technical capability categories are analysed. The objective is to identify in rank order the suppliers that are technically competent in their ability to supply the item. The internal and external capabilities are compared in the third stage with the best-in-class on the range of criteria identified. The suppliers that have been identified in the third stage as being technically capable, have their organisations analysed in the fourth stage where the relevant characteristics used in establishing a close collaborative relationship with a supplier are analysed. The fifth and final stage (total acquisition cost analysis) considers all the current and potential costs involved in the purchasing process, from initial conception, such as collaborating with a supplier in the project phase, through to the use of the completed product by the final customer (McIvor and Humphreys, 2000).

The results indicate that the system supports the procurement function in evaluating the make--or-buy decision and has led to improved communication with suppliers as well as within the multi-functional procurement team. Reference is made to the cross-functional team that was responsible for the definition and selection of the model attributes, but neither the participants nor the role they played in the company are detailed. However, Moschuris (2008), in an attempt to assess the degree of involvement of organizational participants in the make-or-buy process, conducted a study which led to the conclusion that, although varying among companies, the technical, the production and the financial functions, and an ad-hoc make-or-buy committee are mainly involved. These variations depend on organizational characteristics such as the size of the company and operations technology, as well as on the characteristics of the item/service such as type and commercial uncertainty.

Cáñez et al. (2000) developed a framework for the make-or-buy decision process where they suggested four areas to cluster relevant factors to be considered in make-or-buy decisions:

i. Technology and manufacturing processes;
ii. Cost;
iii. Supply chain management and logistics;
iv. Support systems.

It also identifies five performance measures: *cost savings*, *capacity utilisation*, *time-to-market*, *quality* and *flexibility*. These performance measures that are closely linked to the triggers or reasons for undergoing in a make-or-buy process, intend to allow the evaluation of the extent to which the targets suggested by the triggers are achieved (e.g., cost saving – cost saved).

In the case studies performed, Cáñez et al. (2000) observed that the companies which applied the framework demonstrated cost reduction and improved quality. Thus, a four phase implementation procedure was proposed. In the first phase, *Preparation phase*, a multi--disciplinary team is selected and informed about the part or family of parts to be considered. The second phase, *Data collection phase*, consists of the data collection by means of three workshops where the principles of the multiple attribute decision making (MADM) are applied. The *collected data* is then, in the third phase (Data analysis phase), analyzed in order to score each of the choices, where the highest score indicates the best option. In the final phase, *Feedback*, a feedback session, between the researcher and the multi-disciplinary team is planned to discuss the process. The use of a questionnaire is also planned in order to ensure that key issues are taken into consideration.

Based on the framework and on the implementation procedure developed by Cáñez et al. (2000), Platts et al. (2002), described the development of a make-or-buy decision making process and reported on its application inside a manufacturing company. The make-or-buy process, which was conducted by a facilitator, is composed of three phases. In the first phase, *Preparation*, the multi-disciplinary project team is selected and the part or family of parts or process to be considered is identified and described. The second phase, *Data collection*, requires the specification, the gathering and the weighting of the factors influencing the performance of in-house and external suppliers. These weightings are, during the third phase, *Analysis and Results*, combined to give a score which gives an indication of the relative advantages of making or buying when considering several factors.

Even though the frameworks presented so far have demonstrated improvements in the make-or-buy decision making process, they lack in strategic content and are mainly descriptive in nature. Water and Peet (2006), present a three-phase model, consisting of a decision hierarchic structure of five levels, which allows the Analytic Hierarchy Process (AHP) to be incorporated into the model. This strategic framework, influenced by the work carried out by McIvor (1997) and Platts et al. (2000), integrates the relationship that a company has with its customers to determine which activities may be considered as core or non-core. Unlike other models, Water and Peet (2006) do not include a trigger, as they consider the fact that the management of an organization is willing to consider outsourcing to be sufficient. Three different fields, operational excellence, product leadership and customer intimacy, are distinguished to which five performance objectives apply, e.g. speed, quality, cost, flexibility and reliability. In addition to the Financial area, as well as Supply Chain Management and Logistics, Support Systems and Technology & Manufacturing, which are considered by Platts et al. (2002), the areas of Engineering, R&D and Human Resources, are included in the second phase.

Water and Peet (2006) highlighted the fact that, after the decision to outsource is made, it is important to select the proper supplier relationship, as the company will no longer control the production process, the expected goals to be achieved are still the same. Although the AHP facilitates the structuring of the make-or-buy decision process, the issue of supplier choice still needs to be further investigated in terms of programming, as well as the lack of empirical evidence regarding its effectiveness.

Puranam et al. (2013) state that instead of making or buying, firms often make and buy the same part or product, and argue that “explaining the mix of external procurement and internal sourcing for the same input requires a consideration of complementarities across and constraints within modes of procurement” (Puranam et al., 2013). Thus, they proposed an integrated framework that allows the decision maker to decide how much to make and how much to buy, given a set of external factors, by explaining how complementarities and constraints instigate plural sourcing and form the optimal combination of internal/external sourcing. In terms of complementarities, the ones that are considered in the model are incentive and knowledge complementarities. While incentive complementarities promotes competition by, e.g., the threat of backwards integration or outsourcing, and “increasing” performance, knowledge complementarities, promotes innovation between internal and external suppliers through collaboration and knowledge sharing. Regarding constraints, Puranam et al. consider scale diseconomies and lock-ins “constraints to external sourcing, like the bargaining power of unions and government regulations”.

It is also suggested that while factors that confer a cost or benefit advantage to one of the modes of procurement (such as transactional hazards) push towards a pure sourcing model, constraints push firms away from corner solutions while complementarities pull towards equal usage of the two sourcing modes (Puranam et al., 2013).

This analysis offers an analytical basis for explaining how much firms make and buy, which is very useful in the work that will follow this literature review.

In Table 1, a summary of the described approaches is presented.

Table 2.1. Summary of the make-or-buy approaches described in this study

Authors	Year	Key factors	Possible improvements	Practical demonstration of the benefits of the models
Welch and Nayak	1992	Strategic Sourcing Model - Model consisting of three main factors: Process technology's role in competitive advantage; Maturity of the process technology across industry; Competitors' technology position.	Consider more factors other than technology. Develop a practical application of the model.	No
Probert	1996	A ten step strategic make-or-buy methodology Considers the technological factor as the centre of the methodology and its importance for business success.	Assessment of key issues confronting the business, the connection between PA and the manufacturing technologies, and the evaluation of in-house production or external acquisition options.	Application of the model in six engineering manufacturing businesses. They reported positively in terms of its effectiveness, although no performances measures are presented.
McIvor et al.	1997	A four step conceptual framework based on three main criteria: Core competences; Capabilities (e.g.: internal versus external); Cost (e.g.: internal versus external).	Develop a practical application of the model.	No
McIvor and Humphreys	2000	A five stage hybrid computer-based system approach, designed to assist in the make-or-buy decision which employs case-based reasoning (CBR) and decision support system components that include a multi-attribute analysis (MAA) and a sensitivity analysis. The system evaluates the suppliers' capabilities based on technological and organisational profiles, followed by the measurement of the total acquisition costs.	The model should include a mechanism for integrating the total acquisition cost into the decision-making process.	The system prototype developed was customised, refined and tested in a multinational company. The system is capable of evaluating suppliers' capabilities based on technical and organisational profiles.

Authors	Year	Key factors	Possible improvements	Practical demonstration of the benefits of the models
Cáñez et al.	2000	A framework with four relevant make-or-buy areas: Technology and manufacturing processes; Cost; Supply chain management and logistics; and Support systems. It also identifies five performance measures: Cost savings, Capacity utilisation, Time-to-market, Quality and Flexibility.	The author states that feasibility, usability and utility are to be addressed during the implementation procedure.	Three in-company case studies were performed which showed a cost reduction and improved quality. An implementation procedure is proposed.
Platts et al.	2002	A three phases make-or-buy decision making process: Phase 1 - Preparation, the multi-disciplinary project team is selected and briefed; Phase 2 – Data collection, requires the specification, the gathering, and the weighting of the factors influencing the performance of in-house and external supply; Phase 3 – Analysis and results, the weightings of phase 2 are combined to give a score which gives an indication of the relative advantages of making or buying when considering several factors.	The facilitator should be replaced in order to guarantee that no implicit knowledge has been held. The authors also suggest that the way process stages fit together should be improved, the costing exercise developed and the ratings definitions made clearer. The spreadsheet macro should also be made more user friendly.	Application in an industrial case that allowed understanding that the framework is feasible, useful and practicable.

Authors	Year	Key factors	Possible improvements	Practical demonstration of the benefits of the models
Water and Peet	2006	A three-phase model, consisting of a decision hierarchy of five levels, which allows the AHP to incorporate into the model. Phase 1 consists of the determination of the value the company wants to represent to its customers and markets (value discipline) and the performance objectives; In Phase 2 the relevant value-creation areas and their capability factors are defined. In the third and final phase, the type of relationship with the supplier(s) is defined. If the buy option is chosen, then the option can be buying directly from the supplier or of establishing a partnership with the supplier.	The supplier choice needs to be further investigated in terms of programming. The authors also mention the lack of strategic and purchasing professionalism, the restrictions of AHP and lack of empirical evidence are areas that require possible improvements.	The model is illustrated by the example of a shipyard in the Netherlands that must decide whether to outsource the construction of hull components or continue to execute that task itself.
Puranam et al.	2013	Propose an integrated framework to explain how complementarities and constraints allow making empirical predictions about sourcing, i.e., to decide how much to make and how much to buy.	The mechanisms that generate complementarities or constraints (e.g., knowledge transfer, administrative diseconomies of scale, etc.), would benefit from "independent formal treatment" (Puranam et al., 2013, pp. 1158).	No

In summary, the make-or-buy approaches reviewed above are helpful in shaping the make-or--buy methodology that will be developed during this study, as some of them are designed to address this type of decisions that requires trade-offs between relevant factors.

2.3. Make-or-buy attributes

Decision making in the manufacturing environment is a strategic issue (Chryssolouris, 1992). From the literature review (Welch and Nayak, 1992; Probert, 1996; McIvor et al., 1997; McIvor and Humphreys, 2000; Cáñez et al., 2000; Platts et al., 2002; Water and Peet, 2006), and taking into consideration the words of Chryssolouris (1992) who states that decisions regarding manufacturing systems, besides requiring a technical understanding and expertise, also require the ability to satisfy certain business objectives. Thus, it can be concluded that a combination of both engineering and management disciplines is required. The decision-making exercise can be put into practice in the manufacturing environment, if the appropriate procedures are made available to the decision makers (Chryssolouris, 1992).

Thus, there are four classes of manufacturing attributes that should be considered in a decision-making exercise, namely:

- Cost;
- Time;
- Quality;
- Flexibility.

For the make-or-buy decision making framework it was decided to consider, additionally, two more attributes – *Variability* and *Human Capital*.

It is relevant to consider that those attributes can differ when the process space or the product space is considered. In Fig. 2.1. the interrelationship between the first four attributes when it comes to *process attributes* is demonstrated, while Fig. 2.2. demonstrates the same kind of interrelationship but, since it concerns *product attributes*, the fourth dimension – “Flexibility”, is replaced by “Variability”. Since the optimization of these attributes, simultaneously, is not possible, then the outcome of a make-or-buy decision will be governed by trade-offs between the different attributes. This will require the evaluation of each attribute, quantitatively and qualitatively. The more precisely defined these are, the easier it is to trade them off, thus, making it easier to reach a sound decision (Chryssolouris, 1992).

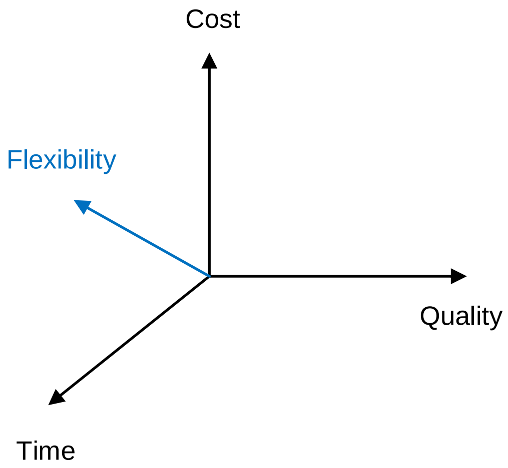

Figure 2.1. Process attributes space (adapted from Chryssolouris, 1992)

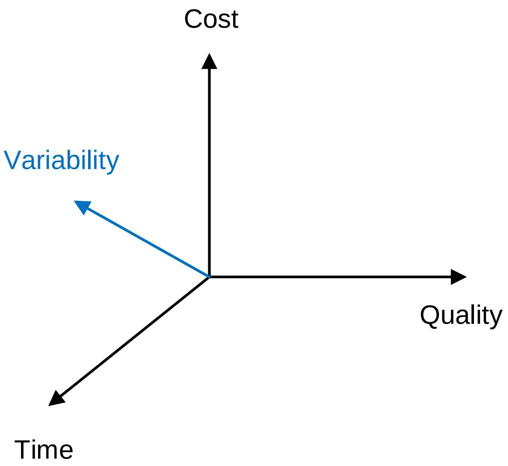

Figure 2.2. Product attributes space (adapted from Chryssolouris, 1992)

The attributes above mentioned, from now on referred to as objectives, will be briefly discussed and, in the next chapter, their respective indicators identified. Thus an objective is an attribute that will be maximized or minimized according to the strategy to be followed.

2.3.1. Cost

A company benefits from determining the cost of producing products or services provided that information will allow them to make pricing decisions to determine if a product should be discontinued or initiated, and other product related decisions. Costs related to manufacturing include a number of different factors which can be broadly classified into the three categories:

- Direct materials – This cost includes the raw materials for producing the product, or that become part of the finished product, and can be easily be traced back to it.

- Direct labour – The direct labour needed for operating the equipment and facilities – the cost of workers who are physically involved in converting raw materials into a finished product.
- Overhead – This refers to indirect factory-related costs that incur during manufacturing. This can be divided into two additional categories:
  - Variable overhead – Indirect production costs that vary as the quantity produced also varies:
    - The energy required for the performance of the different processes. Depending on the industry, this cost may be insignificant compared to other factors, while in others it may assume a financial burden of the manufacturing system.
  - Fixed overhead – Indirect production costs that do not vary as the quantity produced varies:
    - Maintenance. This includes labour, spare parts, etc., needed to maintain the equipment, facilities and systems.
    - Equipment and facility costs. These include the cost related to the equipment necessary for the manufacturing processes, the facilities, and the factory infrastructure.
    - Salaries. Besides the production line workers, the salary cost of the remainder company workers must also be accounted for.

The investment cost, needed to assemble a new production line or adapt an existing one to a new product must also be accounted for.

This objective was, in the early make-or-buy models, the preponderant factor to choosing when to make or when to buy, thus its inclusion in this study's framework is unavoidable.

2.3.2. Time

According to Chryssolouris (1992), time objectives, in manufacturing systems, refer to:

- The speed at which a manufacturing system can respond to changes, e.g., design, volume demand;
- The speed at which a system can manufacture a given product – this is usually expressed as the production rate of the system.

In some way, production rate affects all other types of attributes. Higher production rates normally result in lower cost but also at the cost of an eventual decrease in the level of quality. In addition, the flexibility of the system may also suffer an impact when high production rates are sought out and the resort to automation is necessary, Chryssolouris (1992).

This objective is, in the author's opinion, associated with the remainder, of extreme importance and could not be left apart in the developed framework, as it affects all others.

2.3.3. Quality

The quality of a product, broadly related with customer satisfaction, is often difficult to define in quantitative terms, since customer satisfaction depends not only on the actual features of a product, but also on its feasibility, maintainability, and host of other factors that are often subjective and thus difficult to quantify. However, customer satisfaction can be traced back to two major factors at the origin of a product: its design and manufacture.

In manufacturing, quality typically refers to how well the production process meets the design specifications of a product, i.e., a given set of different characteristics and properties. The quality of a product is an aggregate of the quality of individual features and properties.

Since manufacturing quality reflects the meeting by the manufacturing process of established expectations within tolerances, it is important to note that such tolerances may be over- or under-estimated. An overestimation of tolerances leads to unnecessary cost during product manufacture and unnecessary pressure on the manufacturing system, while an underestimation of tolerances may lead to a malfunctioning product.

Measuring quality is critical for manufacturing, since it reflects the performance of the production process as a whole, and facilitates the establishment of trade-offs between quality and other manufacturing attributes.

2.3.4. Flexibility

Being recognised as one of the most useful tools, flexibility has become a critical component to achieving a competitive advantage in today's current market place (Jain et al., 2013). It is defined as the ability of a product or a production system to change or adapt with the lowest penalty in time possible, effort, cost and/or performance, thus, quickly and economically. This allows the creation of products that meet the demands of a diversified customer base.

Chryssolouris (1992) summarizes flexibility into three main forms:

- Product flexibility: Enables the same equipment in a manufacturing system to produce a diversity of products in small lot sizes and to be used across several product life cycles.
- Capacity flexibility: Allows a manufacturing system to adjust the production volumes of different products to changes in volume demand while, at the same time, remains profitable.
- Operation flexibility: Refers to the production of a set of products or parts, by resorting to

> different machines, materials, operations and sequences of operations which, in turn, results from the flexibility of individual processes and machines (including the flexibility of the manufacturing system's structure itself).

However, in order to be properly considered in a make-or-buy decision making process, it should be properly defined in terms of its indicators.

2.3.5. Variability

Environmental uncertainty and increased competition are some of the main triggers that have led to changes both in products and in processes (Correa and Gianesi, 1994; Jain et al., 2013). Managing these changes, or variations, has proven to be one of the most important priorities, at all levels of manufacturing, if a company intends to provide the variety demanded by the market, while remaining profitable, maintaining the levels of quality, responsiveness and adaptability (ElMaraghy, 2005). The variability of both products and processes of a manufacturing system can be seen from two different perspectives:

i. Variation due to variety of parts or products produced;

ii. Variation in production volume, specifically lot-size variation.

In order to stay competitive, it is essential to manage the variability of products and processes, in order to diminish the problems associated to the new products' design and production, thus similarly to the other attributes, variability will be included in the framework.

2.3.6. Human Capital

Most of the current models (Probert, 1996; McIvor et al., 1997; Cáñez et al., 2000; Platts et al., 2002, Puranam et al., 2013) ignore the importance of the Human Resources (HR) value in influencing a company's competitive position. However, Water and Peet (2006) recognize that importance by agreeing with the conclusions of Lepak and Snell (1999). Lepak and Snell, by combining the arguments from transaction cost economics, human capital theory and the resource-based view, argue that when the potential of the human capital is identified, developed, and then strategically deployed, a company may be able to gain a competitive advantage. Thus, employee skills related to core activities should be developed and maintained in-house. Prahalad and Hamel (1990) have also recognized that people are a company's most precious asset.

The author of this study agrees with the decision of Water and Peet (2006) and Prahalad and Hamel's (1990) opinion, of including this attribute in their model and decided to include it also.

From the above, it can be concluded that the make-or-buy decision making process is based on performance requirements, which specify the values of the relevant manufacturing attributes (Chryssolouris, 1992). It also "involves many interdependent and interwoven aspects and criteria.

Both quantitative and qualitative elements play a role as well as uncertainty and incomplete information" (Water and Peet, 2006, pp.259). Such complexity requires a model that can consider simultaneously, different levels of decision variables and multiple objectives in the analysis and solution of some problems.

When Padillo and Diaby (1999) first introduced the term multiple-criteria to a make-or-buy decision making model, they noted that the multiple criteria decision making (MCDM) methodology could be implemented into the model. In the next subchapter, the MCDM method is presented.

2.4. Multiple attribute decision making methods (MADM)

When it comes to decision making "there is a need for simple, systematic, and logical methods or mathematical tools to guide decision makers in considering a number of selection criteria and their interrelations" (Rao, 2006). The purpose of such tools is to find the most suitable combination of criteria, after the identification of the selection criteria.

The multiple attribute decision making (MADM) methods fit in the category of the multiple criteria decision making (MCDM), which "refers to making decisions in the presence of multiple, usually conflicting, criteria" (Hwang and Yoon, 1981).

As Hwang and Yoon state, there are four words that are widely used in the MCDM literature (*attributes*, *objectives*, *goals* and *criteria*). As there are no universal definitions of these terms, they made some distinctions which were adopted in this study, namely:

- Criteria: A criterion is the basis for evaluation, as it is considered a measure of effectiveness. It can emerge in the problem as a form of attributes or objectives.
- Goals: Goals, or targets, are a priori values or levels of aspiration. These are to be either achieved, surpassed or not exceeded, and can be referred to as constraints because they are designed to limit and restrict the alternative set.
- Attributes: Performance parameters, components, factors, characteristics, and properties are all synonyms for attributes. An attribute should provide a means of evaluating the levels of an objective. A number of attributes can characterize each alternative, chosen by the decision maker's (DM) conception of criteria.
- Objectives: An objective is something to be pursued to its fullest, and indicates the direction of the change desired.
- Decision matrix: A MADM problem can be expressed in a matrix format (also known as decision table). A decision matrix in MADM methods has four main parts, namely:
    - (a) Alternatives;
    - (b) Attributes;
    - (c) Weight or relative importance or priority of each attribute (*i.e.*, weight);

(d) Measures of performance of alternatives with respect to the attributes.

In which each part is identified as follows (see Table 2.2.):

- Alternatives, A_i (for i = 1, 2, …, N);
- Attributes, B_j (for j = 1, 2, …, M);
- Weights of attributes, w_j (for j = 1, 2, …, M); and
- Measures of performance of alternatives, m_{ij} (for i = 1, 2, …, N; j = 1, 2, …, M).

Table 2.2. Decision table in MADM methods (extracted from Rao, 2006)

	Attributes					
	B_1	B_2	B_3	-	-	B_M
Alternatives	(w_1)	(w_2)	(w_3)	(-)	(-)	(w_M)
A_1	m_{11}	m_{12}	m_{13}	-	-	m_{1M}
A_2	m_{21}	m_{22}	m_{23}	-	-	m_{2M}
A_3	m_{31}	m_{32}	m_{33}	-	-	m_{3M}
-	-	-	-	-	-	-
-	-	-	-	-	-	-
A_N	m_{N1}	m_{N2}	m_{N3}	-	-	m_{NM}

Although the problems of MCDM are widely diverse, Hwang and Yoon (1981), state that they share some common characteristics:

- Multiple objectives/attributes: Each problem has multiple objectives/attributes. A DM must generate relevant objectives/attributes for each problem setting.
- Conflict among criteria: Multiple criteria usually conflict with each other. For example, in designing a car, the objective of higher gas mileage might reduce the comfort rating due to smaller passenger space.
- Incommensurable units: Each objective/attribute has a different unit of measurement, e.g., safety may be indicated in a nonnumeric way and cost in Euros.
- Design/selection: Solutions to these problems are either design the best alternative or to select the best among previously specified finite alternatives. The MDCM process involves designing/searching for an alternative that is the most attractive for all criteria (dimensions).

The domain of alternatives will allow MCDM problems to be subdivided in two types –

continuous and discrete. MCDM problems can be broadly categorized into two groups:

i. Multiple objective decision making (MODM), which have decision variable values to be determined in a continuous or integer domain, with either an infinitive or a large number of alternative choices. The best alternative should satisfy the decision maker's constraints, preference and/or priorities.

ii. Multiple attribute decision making (MADM), has a discrete and, usually, limited number of predetermined alternatives. "The alternatives have associated with them a level of accomplishment of the attributes (not necessarily quantifiable)" (Hwang and Yoon, 1981, pp. 3) based on which the final selection of the alternative is made, with the help of both inter- and intra-attribute comparisons. The comparisons may involve explicit trade-offs that are appropriate for the problem considered.

Table 2.3 shows the differences of the features between these two groups.

Table 2.3. MADM vs MODM (Hwang and Yoon, 1981)

	MADM	MODM
Criteria (defined by)	Attributes	Objectives
Objective	Implicit (ill defined)	Explicit
Attribute	Explicit	Implicit
Constraint	Inactive (incorporated into attributes)	Active
Alternative	Finite number, discrete (prescribed)	Infinite number, continuous (emerging as process goes)
Interaction with DM	Not much	Mostly
Usage	Selection/Evaluation	Design

"Given the decision table information and the selected decision-making method, the task of the DM is to find the best alternative and/or to rank the entire set of alternatives that maximizes his/her satisfaction, with respect to more than one attribute" (Rao, 1986, pp 27). All the elements in the decision table must be normalized to the same units, since, as mentioned above, each attribute may have a different unit of measurement. That will allow all possible attributes in the decision making process to be considered.

Regarding the choice of the MADM method to use, the selection itself is a problem, as different methods (e.g.: Elimination Et Choix Traduisant la Realité – ELECTRE, Technique for Order of Preference by Similarity to Ideal Solution – TOPSIS, Multiplicative Exponential Weighting – MEW, Simple Additive Weighting – SAW, Analytic Hierarchy Process – AHP, and Analytic Network Process – ANP), are introduced for different decision situations, several authors have outlined procedures for selecting the most appropriate MADM method.

Thus, considering that a make-or-buy framework will have to consider objective and subjective attributes, it was decided to choose the Analytic Hierarchy Process, once it was designed to reflect the way a person thinks, and has the ability to deal with objective and subjective attributes, especially when these represent an important part of the decision making process. These characteristics are briefly presented in the next subchapter.

2.5. Analytic Hierarchy Process (AHP)

Developed by Thomas Saaty (1980), the AHP reduces the study of even formidably intricate systems to a sequence of pair-wise comparisons of properly identified components, by providing a simple multiple criteria methodology that allows the evaluation of alternatives (Saaty, 1990b). It breaks up a decision-making problem hierarchically, into a system of objectives, attributes (or criteria), and alternatives. An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. Each level of hierarchy is analysed independently and the results combined as analysis progresses. The judgments made can be refined through a continuous application of a feedback process, where each application leads to a refinement of the judgments. The AHP includes and measures tangible, non-tangible, quantitatively measurable, and qualitative factors (Saaty, 1990b). The subjective judgements of different individuals also make up an important part of the decision making process.

The ability to handle real decision situations that involve subjective judgments, multiple decision makers, and the ability to provide measures of consistency, makes AHP a useful methodology. The basic procedure to carry out the AHP method consists of the following steps:

1. <u>Structuring a decision problem and criteria selection</u>

The first step is to decompose a decision problem into its constituent parts. A simple AHP model has three levels (Fig. 2.3.) – a goal or objective at the top level; the attributes or criteria at the second level; and the alternatives at the third level (more complex models with more levels can be formulated).

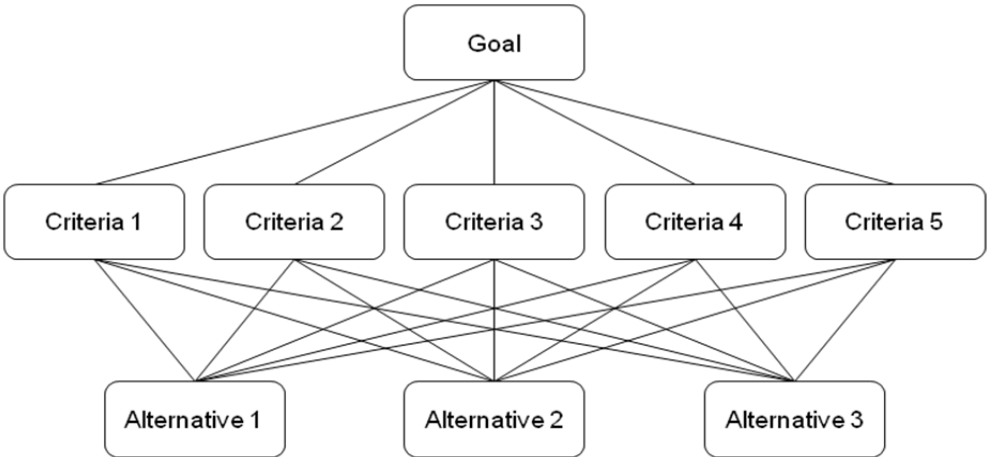

Figure 2.3. A generic AHP model

Arranging all the components in a hierarchical form provides a global overview of the complex relationships and helps the DM to assess whether the elements in each level can be compared precisely. The elements in each group are assumed to be independent. "*An element in a given level does not have to function as a criterion for all the elements in the level below. Each level may represent a different cut at the problem so the hierarchy does not need to be complete*" (Saaty, 1990a).

2. <u>Priority setting of the criteria by pair-wise comparison</u>

For each pair of criteria, the DM should respond to a question such as *"Of the two criteria being compared, which is considered more important by the DM with respect to the overall goal?"* Rating the relative "priority" of the criteria is done by assigning a weight between 1 (equal importance) and 9 (extreme importance) to the more important criterion, whereas the reciprocal of this value is assigned to the other criterion in the pair (refer to Table 3.2 for details). The relative weights are then normalized and averaged in order to obtain an average weight for each criterion.

3. <u>Pair-wise comparison of alternatives on each criterion</u>

For each pairing within each criterion the better option is awarded a score, again, on a scale between 1 (equally good) and 9 (absolutely better), as the other option in the pairing is assigned a rating equal to the inverse of this value. Afterwards, the ratings are normalized and averaged.
Comparisons of elements in pairs require that they are homogeneous or close with respect to the common criterion; otherwise significant errors may be introduced into the process of measurement (Saaty, 1990a).

4. <u>Obtaining an overall relative score for each option</u>

In this final step, the criteria weights are combined to produce an overall score for each alternative. The process of weighing and adding is executed until the final priorities of the alternatives in the bottom most level are obtained, for each element in the level below contributes with its weighed value to obtain the overall or global priority.

In the next chapter, the development of the make-or-buy framework is presented. From the literature review, it was noticed that a make-or-buy decision implies the analysis of different criteria and of the relations between them. Rao (2006) states that when it comes to decision making there is a need for a simple, systematic, and logical method or tool to guide the decision makers in considering a number of selection criteria and their interrelations. Thus, the framework is initially defined and detailed in its graphical representation, according to recommendations of Miles et al. (2014) and after the identification of the selection criteria and of the most suitable combination among them, then the hierarchic levels that were found to be needed to fully characterize a make-or--buy decision situation, and allow the use of the AHP method are presented. The AHP will allow the measurement of tangible, non-tangible, quantitatively measurable, and qualitative factors (Saaty, 1990b).

Chapter 3

Framework development

On completion of the literature review, a two phase framework, based on the ideas developed by McIvor et al. (1997), Cáñez et al. (2000), and Water and Peet (2006) was developed with a structure that allows the use of the AHP technique. This technique allows reducing the complexity of the decision-making process.

3.1. A two phase framework

As seen in Chapter 2, several authors, for over 20 years, have been developing models to support the make-or-buy decision that consider several factors such as cost, time/speed, technology, quality, flexibility, reliability, and human resources (Welch and Nayak, 1992; Probert, 1996; McIvor et al., 1997; McIvor and Humphreys, 2000; Cáñez et al., 2000; Platts et al., 2002; Water and Peet, 2006, Puranam et al., 2013). Probert (1996) highlights the importance of technology in influencing business key success factors such as quality, cost, delivery and flexibility. However, according to Water and Peet (2006), in order to arrive at a sound make-or-buy decision, many judgements and decisions have to be made, namely the definition of:

- The strategic goals;
- The objectives; and the objectives' indicators;
- The determination of the most suitable kind of relationship with a supplier when an activity or process is to be outsourced.

To note that, as the supplier selection process consists of a strategic choice, with specific aspects that need to be considered, it will not be addressed in detail in this work.

In addition, Miles et al. (2014) state that a framework should explain, graphically or in narrative form, the key factors, variables and the presumed interrelationships among them. Thus, it was decided that these three groups of decisions should be grouped in a two phase model, as can be seen in Fig. 3.1., which considers the external environment as the trigger for the make-or-buy analysis.

The two phases are defined as follows:

Phase 1: Determine the value discipline of the customer and the performance objectives

Phase 2: Determine whether to outsource or in-source

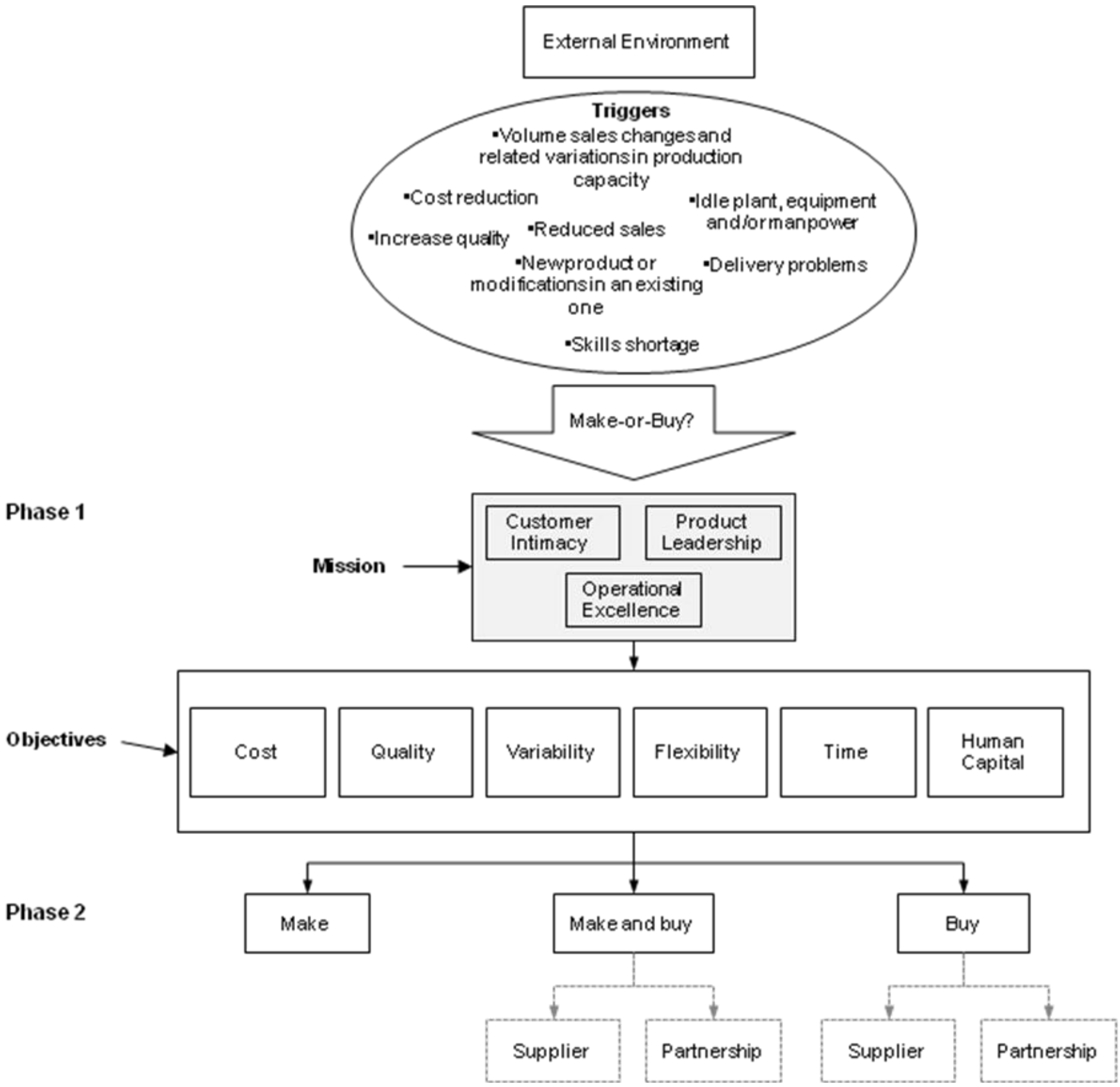

Figure 3.1. A two-phase model for the make-or-buy decision process

3.1.1. Phase 1: Determine the value discipline of the customer and the performance objectives

Probert (1996), in his model, considers the technological factor as the centre of the methodology and its importance for a competitive position, while McIvor et al. (1997), base their model on the assessment of the core competences, capabilities, and a broad cost analysis, that alerts the decision makers to the strategic issues of a make-or-buy decision. Later, Cáñez et al. (2000) developed a model in which the external environment activates the trigger for the make--or-buy process. Despite the evolution of the make-or-buy models, Probert (1996), McIvor et al. (1997) and Cáñez et al. (2000), as Water and Peet, state, "*do not recognise the company's strategic position but especially focus on the value the company wants to represent to its customers and market*" (Water and Peet, 2006, pp.263).

Water and Peet (2006) recognised the importance of incorporating a company's strategic position as they integrated, in their model, the ideas of Treacy and Wiersema (1997) that state that a company must find unique value that only it can present to a particular market. Thus, in this phase, the concept introduced by Treacy and Wiersema, to which they called "value disciplines" (Fig. 3.2.), refers to three ways in which a company can outperform their competition by producing a different kind of customer value, namely:

- Operational excellence: Offers reliable low price products that can be obtained by the client with the least inconvenience;
- Product leadership: Offers the latest product – it's all about product performance;
- Customer intimacy: The company knows their clients' needs and buying habits and offers products that meet exactly their expectations, thus cultivating long term relationships.

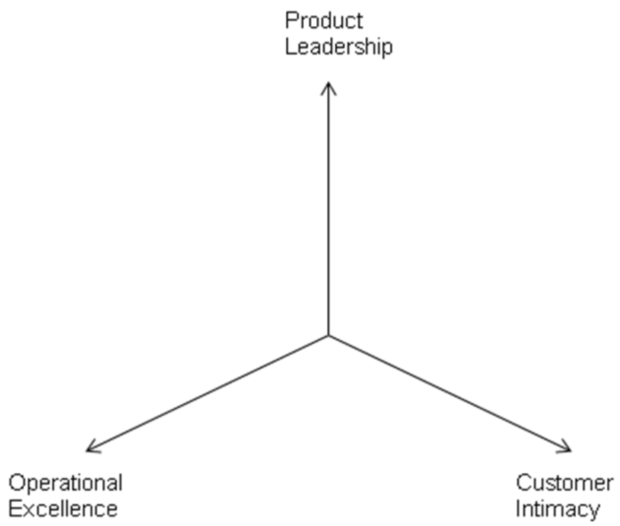

Figure 3.2. The three value disciplines

Although Treacy and Wiersema (1997) argue that pursuing a value discipline is not the same as choosing a strategic goal, the selection of one will have a large impact on what a company does. However, instead of considering just one of the value disciplines at a time, Water and Peet (2006) argue that in order to survive, a company should consider all three value disciplines and not just one as Tracy and Wiersema (1997) defend. Thus, the strategic position of organisations will be a miscellany of the three value disciplines, which need to be ranked, as one of them will be more important than the other two (Water and Peet, 2006).

In this study, as mentioned in the previous chapter, it is defended that a company can identify six objectives that should be considered in a make-or-buy process – cost, time, flexibility, quality, variability, and human capital (these objectives were already detailed in the previous chapter). The importance of each one will be influenced by the position that the company wishes to take in relation to its customers, each time the make-or-buy issue arises.

After the strategic position of the company, regarding the product under analysis is assessed, and its influence over the six objectives, the company will be able to decide whether to outsource, insource, or both.

3.1.2. Phase 2: Determine whether to outsource or in-source

The idea behind outsourcing the development of the design process, and/or of the production of a given product or part is, on one hand, to gain access to new knowledge, experience, and technology, and, on the other hand, to allow the company's resources to become available, making possible to concentrate its efforts and capabilities on core activities. However, if it is decided to outsource a given activity (core or not), a company should previously address a number of issues concerning the maintenance of the knowledge and experience (design skills, management skills, production, etc.), as well as the fact that the company should maintain control over the new product development and design process, which will contribute to the maintenance of its competitive position.

In their model, Water and Peet, argue that the benefits of outsourcing are defined in accordance with the type of product that will be outsourced and with the value discipline of the customer. Kraljic (1983) identifies four types of products (Fig. 3.3.), which Olsen and Ellram (1997), describe and suggest how to manage the relationship associated to each type:

- Leverage: These types of products, besides being easy to manage, are strategically important to the company. The goal is to create a supplier relationship based on mutual respect in order to communicate future requirements, and obtain a low total cost.
- Non-critical: This category includes products that are easy to manage and have a low strategic importance. The goal is to reduce the number of suppliers and of duplicate products/services in order to reduce administrative costs. The supplier relationship should basically manage itself.
- Strategic products: The products that fall into this category are difficult to manage and strategically important to the company. These products are better managed by establishing a close relationship with the suppliers, by promoting their involvement and joint development of products and services. In this situation, a supplier should be seen as an extension of the company.
- Bottleneck: The products in this category despite having a low strategic importance are difficult to manage. The goal is to lower the production costs, by involving the supplier in a value analysis, or eventually, by standardizing the products or even by finding replacements, if possible.

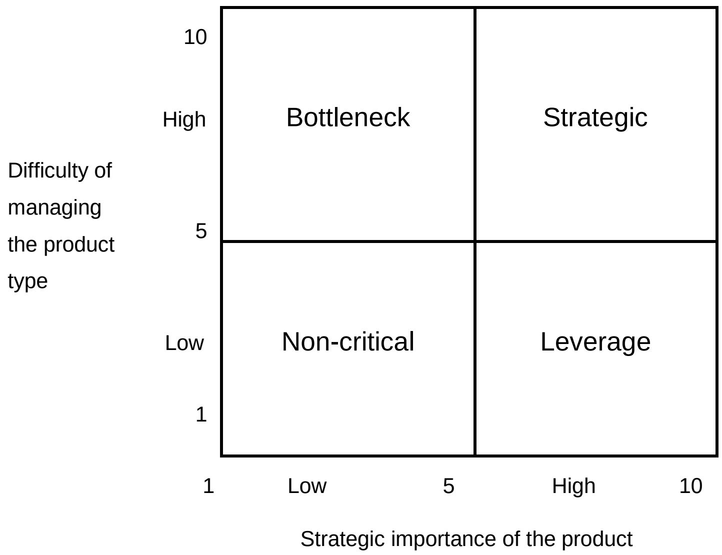

Figure 3.3. Portfolio model (adapted from Ollsen and Ellram, 1997)

The value discipline of the customer also needs to be taken into consideration when establishing a relationship with a supplier, as these objectives influence the company’s strategic position and can allow the exploitation of the supplier’s capabilities.

Varadarajan and Cunningham (1995) argue that a strategic alliance promotes the partition of resources and skills by the cooperating companies in order to achieve common goals, linked to the strategic objectives, as well as particular goals of the individual partners. In Table 3.1, some of the reasons that motivate the establishment of a partnership are identified.

Table 3.1. Motives underlying entry of companies into partnerships (extracted from Varadarajan and Cunningham, 1995)

Product-related motives:

- Fill gaps in present product line;
- Broaden present product line;
- Differentiate or add value to the product.

Product-market-related motives:

- Enter new product/market domains;
- Enter or maintain the option to enter evolving industries whose product offerings may emerge as either substitutes for, or complements to, the firm's product offerings.

Market structure modification-related motives:

- Reduce potential threat of future competition

Resource use efficiency-related motives:

- Lower manufacturing costs;
- Lower marketing costs.

Skills enhancement-related motives:

- Learning new skills from alliance partners;
- Enhancement of present skills by working with alliance partners.

Although one of the most common motives for establishing a partnership is of learning from their partners (i.e., internalizing over time the distinctive capabilities/skills of the alliance partners), Varadarajan and Cunningham (1995) point out that, at the same time, companies should safeguard their own distinctive skills from being internalized by their partner. The risk of losing market share should not be neglected. Strategic alliances can be seen as a new form of competition in which the partner that learns the fastest would be able to dominate the relationship as well as to renegotiate the terms of the alliance in its favour (Varadarajan and Cunningham, 1995).

From the above, it was decided to include, in this phase, three options: Make; Make and Buy; and Buy. Associated to the options of Make and Buy, and Buy the following options were introduced:

i. Selecting a supplier to whom a product or part of a product will be outsourced;

ii. Establishing a partnership with a supplier.

These concepts and ideas will be integrated in a decision making hierarchic structure based on the AHP. This model offers the possibility of choosing between outsourcing or in--house production, or even both. Regarding other models, the last option is new, although Puranamn et al. (2013), in their framework, have created the analytical basis for making empirical predictions about when plural sourcing (making and buying) is likely to be optimal. However their work still requires further development before it can be incorporated into this framework.

3.2. The AHP format

The AHP methodology integrated with the decision making model, developed in this study, results in the following 5 levels framework that will be presented. In Fig. 3.4., Level 1 and 2 are presented.

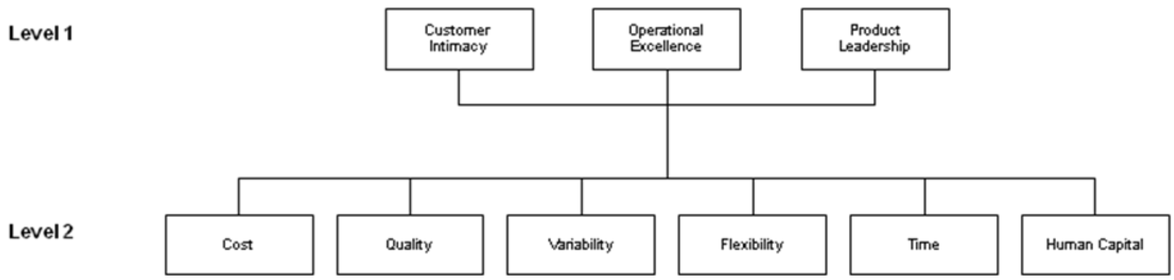

Figure 3.4. The first two hierarchical levels of the developed framework in the AHP format

A detailed description of each level and the steps to be followed, according to the AHP methodology, will now be given.

In Level 1, the three value disciplines – Customer Intimacy, Operational Excellence and Product Leadership, are arranged in a matrix of [3x3] dimension and their relative importance with respect to the market is determined, by performing pair-wise comparisons. The comparisons and judgments are captured using a rating the scale developed by Saaty (1990b) – refer to Table 3.2 for details. Saaty (1990b) also suggests that the questions to be asking when comparing two different criteria are of the following kind: of the two criteria under comparison, which is considered more important by the DM with respect to the overall goal?

Table 3.2. The fundamental scale of absolute numbers (Saaty, 2008)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed (doubt)
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j* , then *j* has the reciprocal value when compared with *i*.	
1.1 – 1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

The comparison matrix is formed with the pair-wise ratios whose rows give the ratios of the weights of each element with respect to all others, thus forming a square matrix A_{NxN} (where b_{ij} denotes the comparative importance of objective i with respect to objective j). The main diagonal entries of the matrix are all 1, as a criterion that is compared with itself is always assigned the value 1. Each entry b_{ij} of the comparison matrix is governed by three rules, or constraints: $b_{ij} > 0$; $b_{ji} = 1/b_{ij}$, for $i \neq j$; and, when $i = j$, $b_{ij} = 1$. An example is given in Fig. 3.5.

$$
\begin{array}{c} \text{Criterion} \\ \\ \\ A_{NxN} = \\ \\ \\ \\ \end{array}
\begin{array}{c} \\ B_1 \\ B_2 \\ B_3 \\ - \\ - \\ B_N \end{array}
\begin{array}{c}
\begin{array}{ccccccc} B_1 & B_2 & B_3 & - & - & B_N \end{array} \\
\begin{bmatrix}
1 & b_{12} & b_{13} & - & - & b_{1N} \\
b_{21} & 1 & b_{23} & - & - & b_{2N} \\
b_{31} & b_{32} & 1 & - & - & b_{3N} \\
- & - & - & - & - & - \\
- & - & - & - & - & - \\
b_{N1} & b_{N2} & b_{N3} & - & - & 1
\end{bmatrix}
\end{array}
$$

Figure 3.5. Comparison matrix

After the first step, which is to compute the comparison matrix, the next step is to normalize the comparison matrix. The relative normalized weight of each objective is found by dividing each entry in the column by the column sum to provide its normalized score. The sum of each column in the normalized matrix is 1. In mathematical terms the procedure is as follows:

i. Considering a matrix of pair-wise elements:

$$
\begin{bmatrix}
c_{11} & c_{12} & c_{13} \\
c_{21} & c_{22} & c_{23} \\
c_{31} & c_{32} & c_{33}
\end{bmatrix}
$$

Figure 3.6. Generic square matrix

ii. The sum of the elements in each column of the matrix is given by (3.1):

$$
C_{ij} = \sum_{i=1}^{n} c_{ij} \tag{3.1}
$$

iii. The normalized matrix is given by (3.2):

$$
X_{ij} = \frac{c_{ij}}{C_{ij}} \Rightarrow \begin{bmatrix}
X_{11} & X_{12} & X_{13} \\
X_{21} & X_{22} & X_{23} \\
X_{31} & X_{32} & X_{33}
\end{bmatrix} \tag{3.2}
$$

After the normalized matrix has been calculated the next step is to rank the importance of each of the criteria by determining the priority vector, *Pv*. This is done by calculating the average of each line, i.e., calculating the geometric mean of the *i*-th row (see 3.3).

$$Pv_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \Rightarrow \begin{bmatrix} Pv_{11} \\ Pv_{21} \\ Pv_{31} \end{bmatrix} \tag{3.3}$$

Where,

X_{ij} corresponds to the entry in *i*-th row of the *j*-th column;

n corresponds to the number of columns of the matrix.

The final step is to perform the consistency analysis. The purpose of this analysis is to assure that the original ratings were consistent. To do so, the following should be done:

i. Calculate the consistency measure:

This is done by multiplying the *i*-th row and the column of the average of the rows and then dividing by the average of the *i*-th row (see 3.4). This results in the matrix's eigenvector, *Ev*. The following example considers the matrix in Fig. 3.6 and in (3.2).

$$\begin{aligned} Ev_{11} &= \frac{1}{Pv_{11}}\left(C_{11}Pv_{11} + C_{12}Pv_{21} + C_{13}Pv_{31}\right) \\ Ev_{21} &= \frac{1}{Pv_{11}}\left(C_{21}Pv_{11} + C_{22}Pv_{21} + C_{23}Pv_{31}\right) \Rightarrow \begin{bmatrix} Ev_{11} \\ Ev_{21} \\ Ev_{31} \end{bmatrix} \\ Ev_{31} &= \frac{1}{Pv_{11}}\left(C_{31}Pv_{11} + C_{32}Pv_{21} + C_{33}Pv_{31}\right) \end{aligned} \tag{3.4}$$

The average of vector (3.5) provides the maximum eigenvalue, λ_{max}.

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} Ev_{ij}}{n} \tag{3.5}$$

Where,

Ev_{ij} corresponds to the entry in the *i*-th row of the *j*-th column of the matrix's eigenvector.

n corresponds to the number of columns of the matrix.

On page A.2 of Annex 1 a step-by-step example of the consistency check can be found.

ii. Calculate the Consistency Index, CI:

With the value of the λ_{max} determined, it is possible to calculate the consistency index, CI, as shown in (3.6).

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3.6}$$

The smaller the value of CI, the smaller is the deviation from the consistency, which measures the actual intensity with which the preference is expressed through the sequence of objects under comparison. By using Table 3.3 the Random Index, RI, is determined according to the number of criteria used in decision making.

Table 3.3. Random index (RI) values (adapted from Saaty, 1990b)

n	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,51	1,52	1,54	1,56	1,58	1,59

iii. Calculate the Consistency Ratio, CR:

The Consistency Ratio is determined by (3.7) (Saaty, 1990b).

$$CR = \frac{CI}{RI} \tag{3.7}$$

A value of CR less than 0,1 is considered acceptable because human judgments need not be always consistent, and there may be inconsistencies introduced because of the nature of scale used.

In Level 2, each pair of the performance objectives – Cost, Quality, Variability, Flexibility, Time and Human Capital, is compared to each of the value disciplines, i.e., with the elements of immediate upper level, resulting in three matrices of [6x6] dimension. Then, for each of these three matrices, the steps described above, namely the pair-wise comparison, the normalisation of the comparison matrix, and the consistency check, should be repeated. At the end of Level 2 the weight of each of the PO will be obtained.

The priority vector of each matrix is calculated and the resulting three priority vectors are put into a matrix of 6x3. The product of this matrix with the calculated priority vector of the three value disciplines will result in the ranking of the objectives again with respect to the market.

In Fig. 3.7, Level 3 is presented. In this level the indicators for each of the performance objectives are identified. Similarly to the assumption made by Water and Peet (2006), it was also assumed in this study that the indicators are independent among them. Although matching a number of likely indicators for each objective is possible, and an adjustment in order to best fit to a specific make-or-buy problem can be made, only a few, as an example, are presented.

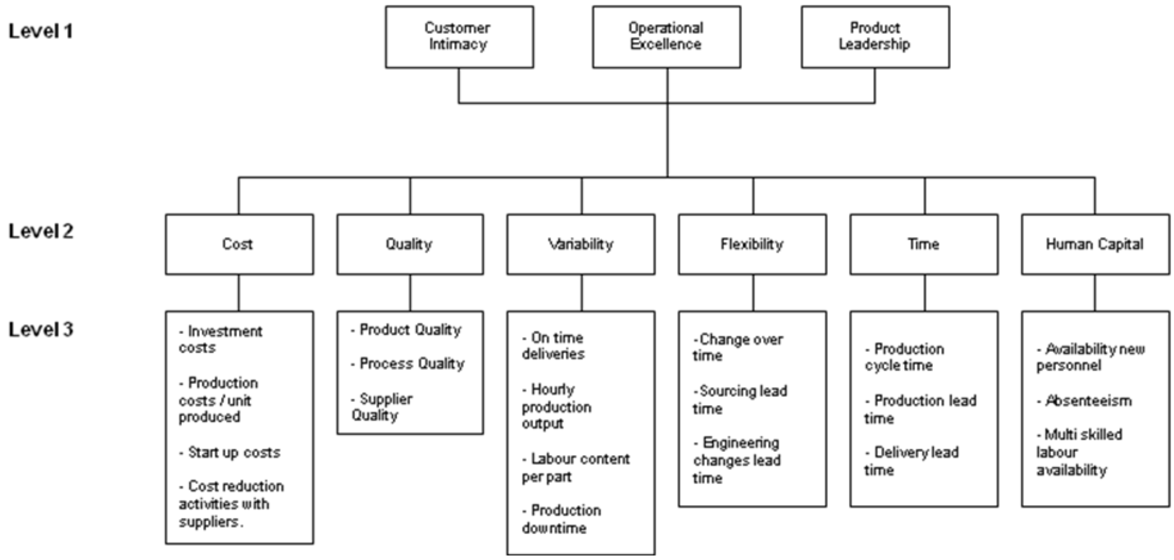

Figure 3.7. The hierarchical structure with the objective indicators identified

The next step is to make a similar comparison between each set of indicators, which will result in six matrices with the following dimensions: [4x4]; [3x3]; [4x4]; [3x3]; [3x3]; [3x3]; and obtaining the corresponding priority vectors. These vectors are then multiplied by the weight of the corresponding objective, resulting in vector of dimension [20x1].

In Fig. 3.8, and unlike other models (McIvor et al., 1997; Cáñez et al., 2000, Water and Peet, 2006), that consider an additional level with areas such as Engineering, R&D, Technology and Manufacturing, Supply Chain Management and Logistics, this model presents in Level 4 three options – Make, Make and Buy, and Buy.

The reason for not considering the above mentioned areas has to do with the intention of creating a simpler model. Saaty (1990b) states that in order to avoid the complexity with which a model can easily expand to, thus becoming tedious to deal with, the hierarchy should be carefully constructed, choosing between faithfulness to reality and our understanding of the situation from which answers can be obtained. Thus, the strategy adopted was to assign the indicators of each area to the equivalent objectives.

As in the procedure above, a pair-wise comparison of these three options has to be made with the objectives. This comparison intends to assess the contribution of the objectives and their indicators when choosing one of the three options, thus this will result in 20 matrices, each with a dimension of [3x3], resulting in 20 eigenvectors of dimension [3x1]. These priority vectors will then be combined in a matrix with a dimension of [3x20] that, after multiplying by the ranking vector of all objectives' indicators, will result in the weighed ranking of the three options in terms of their importance with respect to the market.

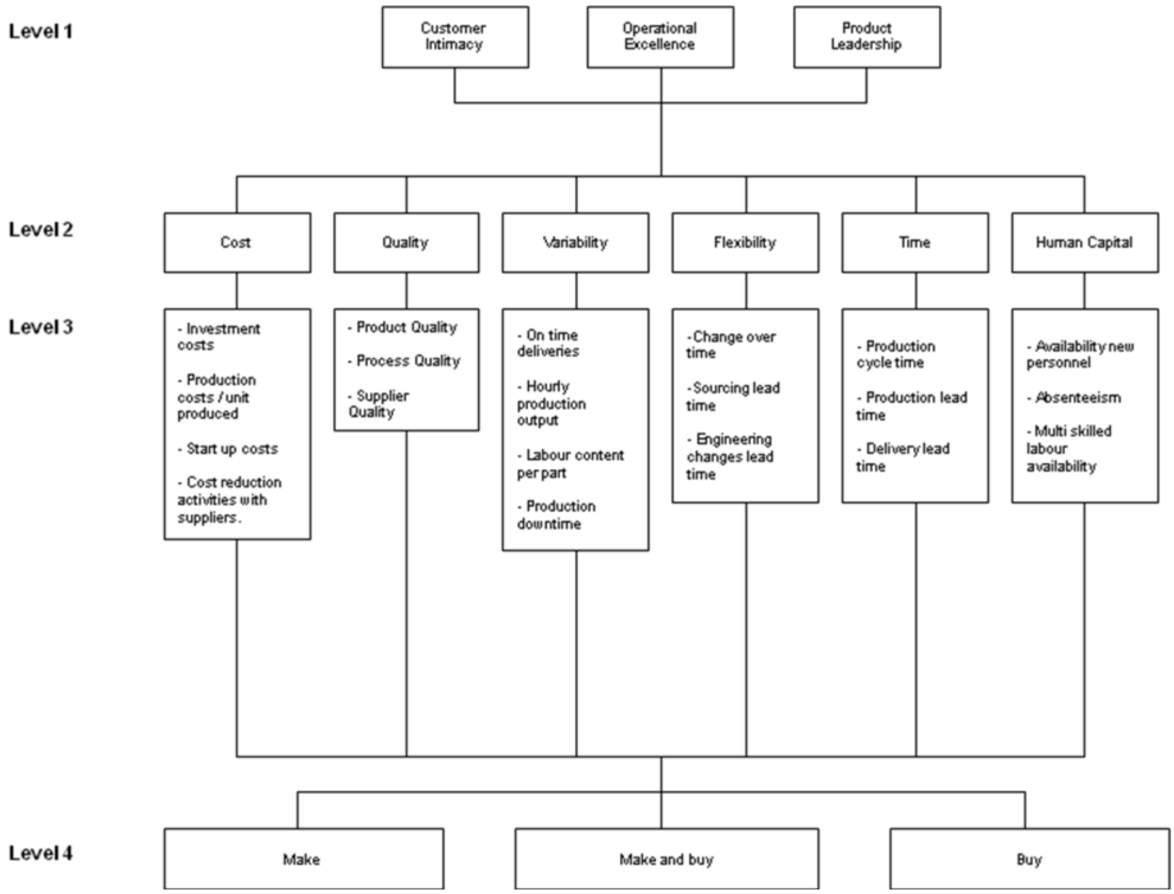

Figure 3.8. Hierarchic structure with the three options: Make, Make and Buy, and Buy.

If the resulting ranking vector in Level 4 indicates that the best option is either “Make and Buy”, or just “Buy”, i.e., if the company should decide to produce in-house an amount of a given product and to outsource the remainder amount, or just to outsource the product/process or parts of it, it has to conduct the fifth and final level of the model.

As shown in Fig. 3.9, Level 5 consists of determining the type of relationship with the supplier. In this model, the option “supplier” is considered for simple short-term contracts, while the option “partnership” for a long-term relationship. Wilson (1995) identified a series of relationship variables that should be considered when choosing the supplier and the type of relationship to be established, as not all suppliers are eligible for a cooperative relationship. Wilson states that, one of the variables - the mutual goals, encourages a mutual dyadic interaction that will lead to the achievement of the mutual goals, as they are as defined as the “*degree to which partners share goals that can only be accomplished through joint action and the maintenance of the relationship*” (Wilson, 1995).

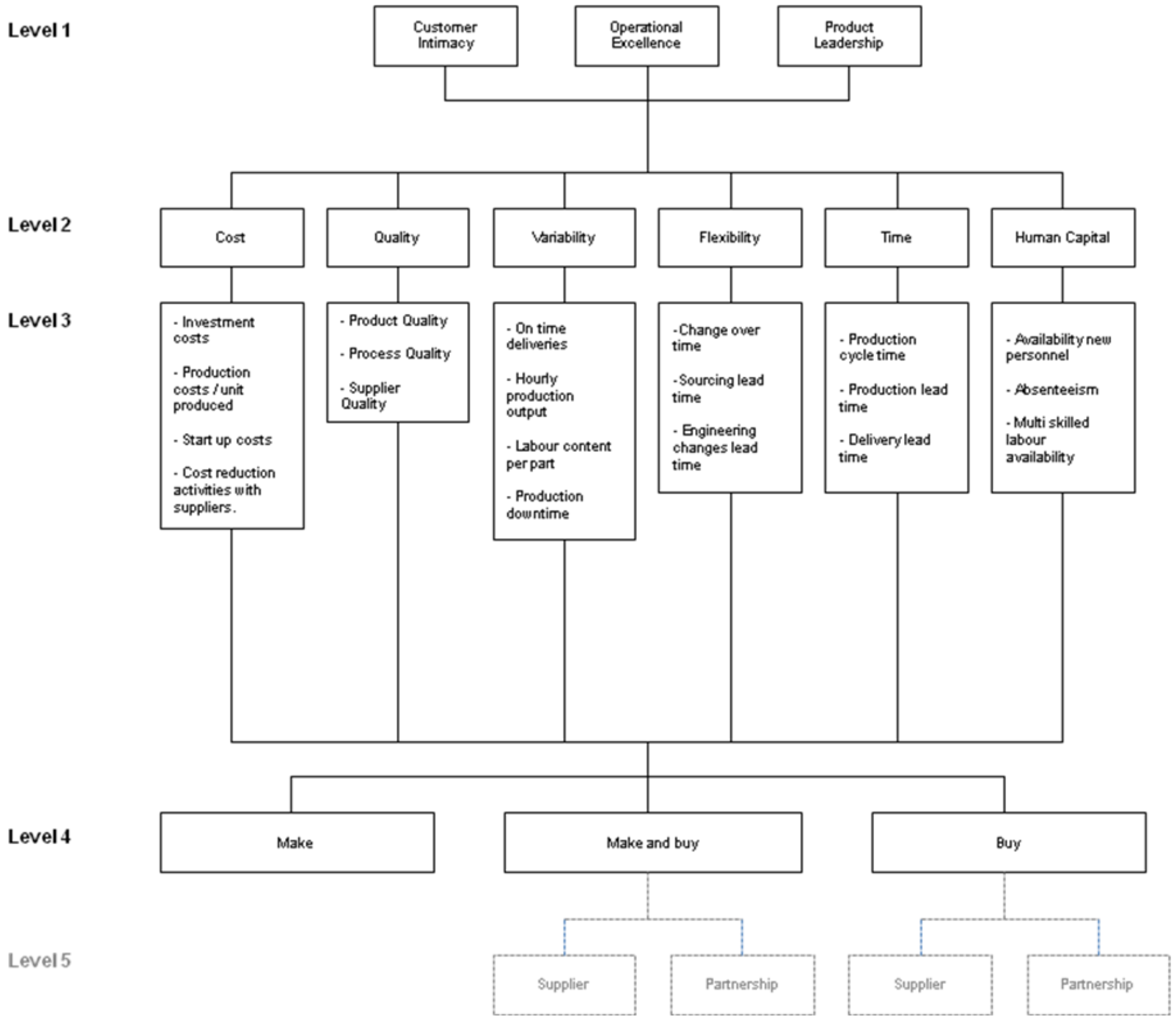

Figure 3.9. The final AHP hierarchy

Prajogo and Olhager (2012), report that companies are using fewer suppliers over a longer period of time and that the current trend in outsourcing is building long-term relationships, which are enhanced to a strategic level, i.e., a supplier is considered to be an integral part of operations.

Given the abovementioned, supplier selection as well as the type of relationship that should be established can be addressed as a MCDM problem. Chai et al. (2013) carried out a literature review of the application of decision-making techniques in supplier selection, in which the AHP technique was the one which was the most popular among researchers. Thus, the approach, proposed by Kar (2013), to support the supplier selection problem by integrating fuzzy Analytic Hierarchy Process (AHP) and fuzzy goal programming for Discriminant Analysis (DA), which is a method used to find a combination of attributes which characterizes or separates two or more groups or classes of objects or events, can be a good option to integrate with the proposed framework.

In this chapter the proposed framework was presented. Each of the areas/objectives addressed by the framework was detailed and the corresponding indicators presented. The integration of the

AHP methodology with the framework is explained together with each of the two phases that make up the decision making process, but this framework must be implemented in order to resolve the make-or-buy issues that come up. Therefore an implementation procedure for this framework is presented in the next subchapter.

3.3. Implementation of the proposed framework

The final step of this study is to propose an implementation procedure of the developed framework, based on the work developed by Platts et al. (2002). Thus, based on the framework presented above, a three phase process was developed. The process consists of three phases: a preparation phase; a data collection phase; and an analysis and results phase. Each phase is described and detailed.

The design of the process followed the one described by Platts et al. (2002). It requires the specification of the procedure and the definition of the participants, including the person who will have the advisory role and the decision makers.

Phase 1: Preparation phase

In this phase the preparatory work for the project occurs. The project team is selected, briefed and the component or process to be considered is identified and specified.

In addition to the multi-functional team or committee, that is responsible for assessing the make-or-buy issues, in which all the departments that contribute to the decision, or that are affected by it, should take part, Moschuris (2008) identifies two main roles in the make-or-buy process, and the degree of involvement for each functional area, namely:

1. The advisory role, which is responsible for starting the make-or-buy issue, by recognizing the need, and for gathering all the data required (Phase 2) for the evaluation of each alternative that precedes the Analysis stage (Phase 3). The technical and production functions were identified by having the highest degree of involvement, followed by the financial, purchasing, and engineering functions.
2. The decision maker has the authority to take the final decision. Regarding the participation of each functional area, the production and technical functions show the highest degree of involvement, while the financial, purchasing, marketing, and sales functions' involvement varies according to the contextual variables:
    a. In companies that employ mainly mass production technologies, the financial and the marketing functions have a great degree of involvement in this stage.
    b. In large companies, the purchasing function is one of the main participants in relation to the decision-making role.

c. When the make-or-buy issue refers to items with a potentially large impact on the companies' profits, the marketing and sales functions are very involved in this stage.

Phase 2: Data collection

In this phase the data within the framework shown in Fig. 3.1. is specified and gathered. The process consists in the weighting of the relative importance of the various factors in the framework.

The data specification, and the weighting and rating are carried out in two multi-functional workshops, as the team is composed of elements from different functional areas. In the first workshop the weighting and rating of the strategic goals in Level 1 is carried out. For this stage the multi-functional team should be comprised of executive managers, as they are the ones responsible for the strategic decisions.

In the second workshop, the rating of the objectives, in Level 2, in relation to each of the three value disciplines at the level above is carried out. The next step, Level 3, consists of rating the indicators of each of the six objectives and obtaining their importance in relation to the corresponding objective.

The rating, along this process, is based on a scale between 1 (equally good) and 9 (absolutely better), as the other option in the pairing is assigned a rating equal to the inverse of this value. Afterwards, the ranking vector is determined and normalized.

In the final step, the criteria weights are combined to produce an overall score for each option (for each element in the level below add its weighed values and obtain its overall or global priority). The process of weighing and adding is executed when the final priorities of the three options – make, make and buy, or buy, in Level 4 are obtained.

Regarding the team members, in the second workshop the participants should belong to the following hierarchical levels: strategic, tactical and operational.

Phase 3: Analysis and supplier relation selection

In this phase, having obtained the indication of the priority for making, buying, or making and buying, and if the priority vector indicates that the best ranked option is buying or making and buying, then the decision has to be made regarding the relation with the supplier. As Water and Peet (2006) mention, the choice of the proper relationship with one or more suppliers can be as important as the consideration of the make-or-buy question itself, due to the fact that the competitive position of the company may be compromised once the organisation no longer has total control over the production of the outsourced products. For this matter, a third and final workshop should be conducted, in order to decide what type of relationship with the supplier(s) should be chosen. Ideally, the team members would be the same as in the second workshop.

In Fig. 3.10, a representation of the procedure above described can be found.

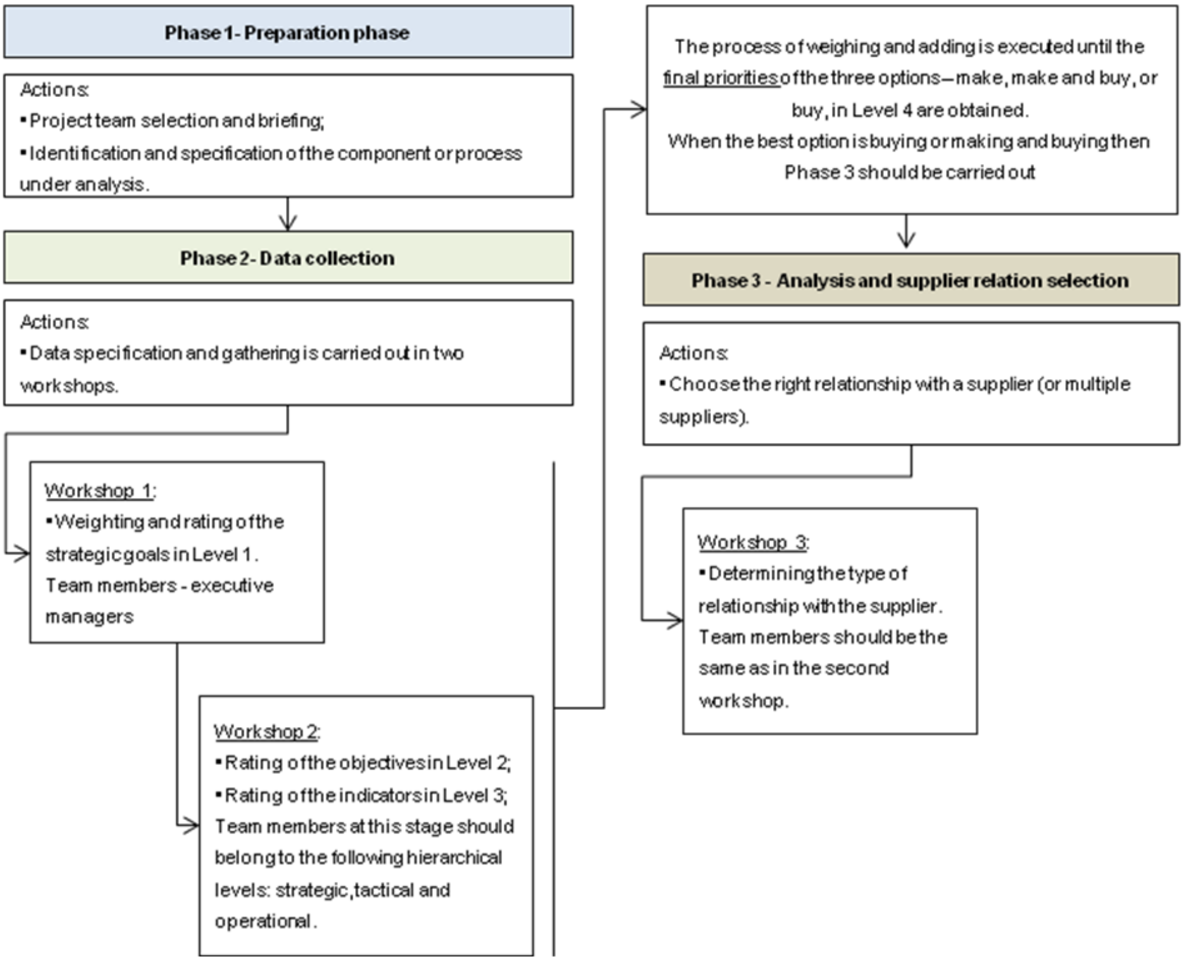

Figure 3.10. Implementaion procedure

This implementation proposal represents an attempt to determine the participants and the organizational roles in the make-or-buy process. The centre of the decision-making lies in a committee, which varies among companies along two basic dimensions of authority and dispersion Moschuris (2008). These committees include personnel from a number of functions, such as production, technical, and financial, and also of board members (directors). Although the Managing Director may retain the final decision-making authority, the other members of the board, who are usually heads of the various functional departments, may have a considerable amount of advisory influence in the committee. With respect to the involvement in the committees mentioned above, Moschuris (2008) identified the production and technical functions as the functions that show the highest degree of involvement, followed by financial, purchasing, and engineering in opposition to the sales, marketing, and information technology functions that show the lowest degree of involvement. While production and technical functions generally show the highest degree of involvement as decision makers, the degree of involvement of the financial, purchasing, marketing, and sales functions varies with the contextual variables. The financial and the marketing functions are greatly involved in the decision making stage in companies that employ primarily mass production technologies. The purchasing function is one of the main participants in the decision-

-making role in large companies. Finally, the marketing and sales functions exert much involvement in the decision-making stage when the make-or-buy issue refers to items with a potentially large impact on profitability.

The main conclusion is that traditionally in-house production vs. outsourcing decisions have often been made on an ad hoc basis. This means that many companies take the operational/cost-based approach to make-or-buy, with decisions taken individually to achieve short-term cost savings or operational advantage. Due to this fact, companies fail to consider significant strategic issues that exist behind many make-or-buy issues. For example, it is important to consider the present and potential technological capabilities of the firm as well as the effects on the finished product if the company outsources some of its items/services. Therefore, in order to improve the effectiveness and efficiency of make-or-buy decisions, enterprises should adopt a policy approach, which rests on an overview of their strategic direction and the activities that are, or should be, core to their success. Moschuris (2008) mentions an interesting finding which is the relative low involvement of the purchasing function in the make-or-buy process. This makes the gathering of accurate information regarding external suppliers difficult, because the implementation of such a process requires that the purchasing function should move away from that of an operational and tactical function to a more strategic one.

Chapter 4

Case Study

In this chapter the implementation of the framework developed in this study will be presented and described.

4.1. Case presentation

The company in this case study operates in the automobile sector and is part of a large corporation that operates worldwide. It serves namely the mature markets of Europe and North America as well as South America, and participates in the growth of emerging Asian markets. Its core competences allow the company to provide acoustic and thermal management solutions for vehicles. The manufacturing facilities are located in the close vicinity of the customer production site to guarantee a successful partnership.

The make-or-buy issue emerged after the company acquired a contract to deliver, as part of a bigger package, a part produced by injection of Polyurethane (PU) Foam in a closed tool. The part is an insulator in PU foam, 50 Kg/m^3 density, weighing 195 grams and meeting a long list of other customer requirements. Due to its characteristics this insulator is labour intensive which makes a manual production process too expensive, driving the cost to non-competitive values.

The alternative considered was to design an automated production process requiring a very high investment in relation to the life time sales of this product. Thus, this became a good opportunity to test the framework presented in the previous chapters.

4.2. Phase 1: Preparation phase

As mentioned earlier, in this phase the team members are selected, briefed and the component identified and specified. However, due to the fact that the time constraints were too high to involve each team member at the same time, the work was focused on the manager who accepted the invitation to test and validate the make-or-buy framework in a case currently under analysis by his company. The manager is responsible for the development and manufacturing strategies of the company and started off his career as a maintenance engineer. As he is also the former quality and reliability manager his experience was considered wide enough to be able to provide a good approach in this phase of the framework development. The base of operations is located in Switzerland where the core products are developed.

Based on the manager’s considerable experience this phase is very important as the involvement of the various company contributors is underestimated. In addition, the fact that unstructured approaches are frequently used drives the make-or-buy studies in different directions according to the experience of the project manager/decision maker.

These two statements led the manager to consider this work as a great contribution to professionalize any future make-or-buy decision making frameworks.

4.3. Phase 2: Data Collection

In this phase the weighting and rating of the factors of level 1 to level 4 was supposed to be carried out in two workshops. The first workshop concerning Level 1 and the second one concerning levels 2 to 3. However, as the team was only formed by one person it was decided to perform the weighting and rating of all the factors in a single workshop. The rating, based on the scale developed by Saaty (1990b) consists of performing a pair-wise comparison between two objectives at a time. For Level 1, the comparison made of the three value disciplines in respect to the market, resulted in the following matrix:

	Customer Intimacy	Operational Excellence	Product Leadership
Customer Intimacy	1,00	0,13	3,00
Operational Excellence	8,00	1,00	9,00
Product Leadership	0,33	0,11	1,00

Figure 4.1. Comparison matrix, M1, for Level 1

After the comparison matrix was computed, the next step, as mentioned in chapter 3, was to normalize the matrix and determine the priority vector. After the priority vector – Pv.L1 (Fig. 4.2) had been found the final step was to check the consistency of judgements. This led to a Consistency Ratio of 0,096 which verified the condition of CR < 0,1. Any higher value and the judgements would need to be re-examined. On page A.4 of the Annex 1 the details of these calculations are presented.

$$\begin{vmatrix} 0{,}146 \\ 0{,}786 \\ 0{,}068 \end{vmatrix}$$

Figure 4.2. Priority vector, Pv.L1, of Level 1

Regarding Level 2, the rating of six the performance objectives was done by taking into consideration each one of the three value disciplines. This resulted in the three matrices of dimension [6x6] below:

	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	1,00	3,00	2,00	3,00	1,00
Quality	1,00	1,00	1,00	0,50	3,00	1,00
Variability	0,33	1,00	1,00	0,33	3,00	1,00
Flexibility	0,50	2,00	3,00	1,00	1,00	1,00
Time	0,33	0,33	0,33	1,00	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Figure 4.3. Comparison matrix, M1, for Level 2 regarding the value discipline of "Customer Intimacy"

	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	1,00	3,00	1,00	3,00	1,00
Quality	1,00	1,00	1,00	1,00	3,00	1,00
Variability	0,33	1,00	1,00	1,00	0,33	1,00
Flexibility	1,00	1,00	1,00	1,00	3,00	1,00
Time	0,33	0,33	3,00	0,33	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Figure 4.4. Comparison matrix, M2, for Level 2 regarding the value discipline of "Operational Excelence"

	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	4,00	2,00	2,00	2,00	1,00
Quality	0,25	1,00	2,00	0,33	0,50	1,00
Variability	0,50	0,50	1,00	0,33	2,00	1,00
Flexibility	0,50	3,00	3,00	1,00	2,00	1,00
Time	0,50	2,00	0,50	0,50	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Figure 4.5. Comparison matrix, M3, for Level 2 regarding the value discipline of "Product Leadership"

From each one of these matrices, the corresponding priority vector or eigenvector was computed:

- Pv.1.L2 is the priority vector of matrix M1 (In Fig. 4.6., the first column corresponds to Pv.1.L2);
- Pv.2.L2 is the priority vector of matrix M2 (In Fig. 4.6., the second column corresponds to

Pv.2.L2);

- Pv.3.L2 is the priority vector of matrix M3 (In Fig. 4.6., the third column corresponds to Pv.3.L2).

The consistency check was performed and, after some corrections were made, the following Consistency Ratios were obtained:

- $CR_{Matrix\ M1} = 0{,}095$;
- $CR_{Matrix\ M2} = 0{,}096$;
- $CR_{Matrix\ M3} = 0{,}085$.

As these values are all < 0,1 the judgements were found to be consistent, the priority matrix of Level 2 – matrix M4, made up of the resulting priority vectors of each one of the three matrices, was formed:

	Pv.1.L2	Pv.2.L2	Pv.3.L2
Cost	0,246	0,220	0,269
Quality	0,168	0,187	0,109
Variability	0,136	0,124	0,125
Flexibility	0,196	0,187	0,218
Time	0,098	0,125	0,123
Human Capital	0,154	0,157	0,156

Figure 4.6. Priority matrix, M4, for Level 2

Refer to pages A.6 to A.10 for details.

By multiplying the priority matrix of Level 2, M4, by the priority vector of the M1 matrix in Level 1, the global priority vector for Level 2 – Pv.L2, was found:

	Pv.1.L2	Pv.2.L2	Pv.3.L2		Pv.L1		Pv.L2
Cost	0,246	0,220	0,269		0,146	=	0,227
Quality	0,168	0,187	0,109				0,179
Variability	0,136	0,124	0,125	x	0,786		0,126
Flexibility	0,196	0,187	0,218				0,190
Time	0,098	0,125	0,123		0,068		0,121
Human Resources	0,154	0,157	0,156				0,157

Figure 4.7. Global priority vector for Level 2

In Level 3, the importance of the performance indicators is assessed with regards to the corresponding objective. This is done by performing pair-wise comparisons between each set of indicators, which results in the following six matrices:

	Investment costs	Production costs / unit produced	Start up costs	Cost reduction activities with suppliers
Investment costs	1,00	0,33	0,11	0,20
Production costs / unit produced	3,00	1,00	1,00	1,00
Start up costs	9,00	1,00	1,00	3,00
Cost reduction activities with suppliers	5,00	1,00	0,33	1,00

Figure 4.8. Comparison matrix, M1, for Level 3 regarding the objective "Cost"

	Product Quality	Process Quality	Supplier Quality
Product Quality	1,00	1,00	3,00
Process Quality	1,00	1,00	3,00
Supplier Quality	0,33	0,33	1,00

Figure 4.9. Comparison matrix, M2, for Level 3 regarding the objective "Quality"

	On time deliveries	Hourly production output	Labour content per part	Production downtime
On time deliveries	1,00	8,00	6,00	8,00
Hourly production output	0,11	1,00	2,00	1,00
Labour content per part	0,14	0,33	1,00	0,20
Production downtime	0,11	1,00	5,00	1,00

Figure 4.10. Comparison matrix, M3, for Level 3 regarding the objective "Variability"

	Change over time	Sourcing lead time	Engineering changes lead time
Change over time	1,00	3,00	3,00
Sourcing lead time	0,33	1,00	2,00
Engineering changes lead time	0,33	0,50	1,00

Figure 4.11. Comparison matrix, M4, for Level 3 regarding the objective "Flexibility"

	Production cycle time	Production lead time	Delivery lead time
Production cycle time	1,00	3,00	3,00
Production lead time	0,33	1,00	2,00
Delivery lead time	0,33	0,50	1,00

Figure 4.12. Comparison matrix, M5, for Level 3 regarding the objective "Time"

	Availability new personnel	Absenteeism	Multi skilled labour availability
Availability new personnel	1,00	0,20	1,00
Absenteeism	5,00	1,00	5,00
Multi skilled labour availability	1,00	0,20	1,00

Figure 4.13. Comparison matrix, M6, for Level 3 regarding the objective "Human Capital"

Similarly to the procedure in Level 2, for each one of the matrices above, the corresponding priority vector was computed and the consistency analysis conducted. When the consistency analysis was performed, it was found that some of the judgments needed to be corrected as they showed to be inconsistent. Refer to pages A.11 to A.18 for details.

Each of the priority vectors obtained was then multiplied by the weight of the corresponding performance objective and the combination of the 6 vectors resulted in the global priority vector for Level 3 – Pv.L3, of dimension [20x1]:

		Pv.L3
Pv.2.L3	3.1.1	0,014
	3.1.2	0,061
	3.1.3	0,101
	3.1.4	0,052
Pv.4.L3	3.2.1	0,077
	3.2.2	0,077
	3.2.3	0,026
Pv.6.L3	3.3.1	0,085
	3.3.2	0,020
	3.3.3	0,007
	3.3.4	0,025
Pv.8.L3	3.4.1	0,105
	3.4.2	0,045
	3.4.3	0,028
Pv.10.L3	3.5.1	0,071
	3.5.2	0,031
	3.5.3	0,019
Pv.12.L3	3.6.1	0,022
	3.6.2	0,122
	3.6.3	0,022

Figure 4.14. Global priority vector for Level 3

In Level 4, each of the three available options – “Make”; “Make and Buy”; “Buy”, are pair-wise compared considering each of the indicators in the level above. This comparison results in 20 matrices of dimension [3x3].

	M	MaB	B
M	1,00	0,33	0,13
MaB	3,00	1,00	1,00
B	8,00	1,00	1,00

Figure 4.15. Comparison matrix, M1, for Level 4 regarding the Cost indicator “Investment Costs”.

	M	MaB	B
M	1,00	2,00	3,00
MaB	0,50	1,00	0,20
B	0,50	2,00	1,00

Figure 4.16. Comparison matrix, M2, for Level 4 regarding the Cost indicator “Production costs / unit produced”.

	M	MaB	B
M	1,00	0,25	0,33
MaB	3,00	1,00	0,33
B	3,00	3,00	1,00

Figure 4.17. Comparison matrix, M3, for Level 4 regarding the Cost indicator “Start up costs”.

	M	MaB	B
M	1,00	1,00	0,20
MaB	1,00	1,00	1,00
B	4,00	0,25	1,00

Figure 4.18. Comparison matrix, M4, for Level 4 regarding the Cost indicator “Cost reduction activities with suppliers”.

	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00

Figure 4.19. Comparison matrix, M5, for Level 4 regarding the Quality indicator “Product Quality”.

	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00

Figure 4.20. Comparison matrix, M6, for Level 4 regarding the Quality indicator “Process Quality”.

	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Figure 4.21. Comparison matrix, M7, for Level 4 regarding the Quality indicator “Supplier Quality”.

	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Figure 4.22. Comparison matrix, M8, for Level 4 regarding the Variability indicator “On time deliveries”.

	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Figure 4.23. Comparison matrix, M9, for Level 4 regarding the Variability indicator “Hourly production output”.

	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Figure 4.24. Comparison matrix, M10, for Level 4 regarding the Variability indicator “Labour content per part”.

	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Figure 4.25. Comparison matrix, M11, for Level 4 regarding the Variability indicator “Production downtime”.

	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Figure 4.26. Comparison matrix, M12, for Level 4 regarding the Flexibility indicator “Change over time”.

	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00

Figure 4.27. Comparison matrix, M13, for Level 4 regarding the Flexibility indicator “Sourcing leadtime”.

	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00

Figure 4.28. Comparison matrix, M14, for Level 4 regarding the Flexibility indicator “Engineering changes leadtime”.

	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Figure 4.29. Comparison matrix, M15, for Level 4 regarding the Time indicator “Production cycle time”.

	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Figure 4.30. Comparison matrix, M16, for Level 4 regarding the Time indicator “Production lead time”.

	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Figure 4.31. Comparison matrix, M17, for Level 4 regarding the Time indicator “Delivery lead time”.

	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Figure 4.32. Comparison matrix, M18, for Level 4 regarding the Human Capital indicator “Availability new personnel”.

	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Figure 4.33. Comparison matrix, M19, for Level 4 regarding the Human Capital indicator “Absenteeism”.

	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Figure 4.34. Comparison matrix, M20, for Level 4 regarding the Human Capital indicator “Multi skilled labour availability”.

Similarly to levels 1, 2 and 3, for each of the above matrices, the corresponding priority vector was calculated and the consistency analysis made (refer to page A.18 for details). Some of the judgements initially made required some adjustments as they were found to be inconsistent.

The final step was to combine the 20 priority vectors into a single matrix of dimension [3x20] – M21, and multiply it by the global priority vector for Level 3 – Pv.L3. The result was the overall priority vector – Pv.L4.

Pv.L4	=	0,38	In percentage:	M	38.25%
		0,29		MaB	28.85%
		0,32		B	32.90%

Figure 4.35. Overall priority vector – Pv.L4

In Figure 4.36 the final hierarchic structure with the rating for each objective in all levels is detailed.

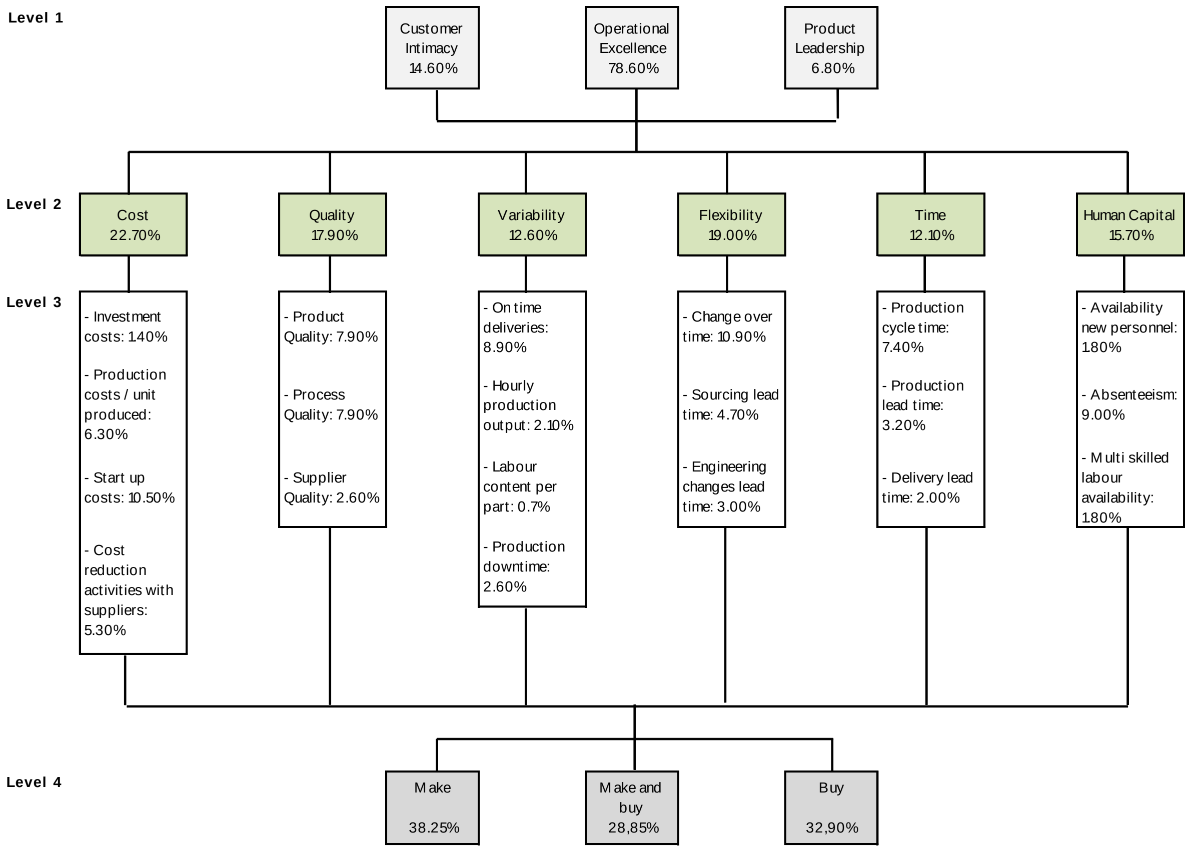

Figure 4.36. Final hierarchic structure

4.4. Phase 3: Analysis and supplier relation selection

Regarding the present case, it can be concluded that the highest ranking option is to "Make", with 38.25% against the 28.85% for the option "Make and Buy", and the 32.90% for the "Buy" option. These values clearly indicate that the best option is to produce the component in-house rather than outsourcing its production to an external supplier.

From the previous phase, the value discipline that was found to be more important was the "Operational Excellence", with a rate of 78.60%. From this value it can be concluded that the goal, is to offer a reliable product at a low price. This conclusion is supported by the values obtained in Level 2 for each objective.

In Level 2, the "Cost" objective presents the highest percentage – 22.70%, which is coherent with the results obtained in Level 1, where the value discipline which received the highest rank was the "Operational Excellence".

The second highest ranking object is "Flexibility" with 19.00%. This result is also coherent with the preferred value discipline, as "Flexibility" is an important tool that allows a production system to change or adapt quickly and economically, thus, creating products that meet the demands of a diversified customer base.

The objective "Quality" was the third highest ranked, with a value of 17.90%, to which Product and

Process Quality contribute equally with 7,90% (against the 2,60% for “Supplier Quality”) which is in line with the value discipline “Operational Excellence”.

Regarding “Human Capital”, with the indicator “Absenteeism” contributing with 9.00% of the total score of 15.70%. This helps to demonstrate the importance of the employees’ skills to a company’s competitive advantage.

The remainder two objectives – “Variability” and “Time”, were ranked with an identical percentage – 12.60% and 12.10%, respectively. The indicator “On time deliveries” was ranked with the highest score of the indicators regarding Variability – 8.90% which is in line with the indicator “Production cycle time”, which was the highest ranking indicator for the objective “Time” with 7.40%.

Unfortunately, the order was cancelled after the decision process took place making it impossible to know if the company’s top management was convinced enough to trust in what the model was indicating and adjust their strategy accordingly. However, in terms of usefulness the framework was found to be valuable when well applied, adding credibility to the make-or-buy study/decision. This is due to the fact that when the make-or-buy issue arises, the decisions made were based on results that derive from unstructured methodologies that normally have the criteria “Cost” as the fundamental objective. These results can have a positive financial impact in the short term, but in the long term can affect the company’s future, as, e.g., it can provide an opportunity for a supplier to turn into a direct competitor.

Chapter 5

Conclusions and future work

In this chapter the conclusions of this study as well as a proposal for future studies are presented.

5.1. Conclusions

In this study a decision making framework that can be applied when the make-or-buy issue arises, has been developed and tested in a real make-or-buy decision making situation. It's a two-phase model which has in the external environment the trigger for the make-or-buy process. It starts with three different value disciplines – Customer Intimacy; Product Leadership; and Operational Excellence, which form the value discipline of the customer (Treacy and Wiedersema, 1997). To the value disciplines six objectives are associated: Cost; Quality; Variability; Flexibility; Time; and Human Capital. The objective of variability has been added and is new compared with other models presented in the literature. According to ElMaraghy (2005), one of the most important priorities of manufacturing is to have a good level of responsiveness and adaptability to the variety demanded by the market, remaining profitable and maintaining the levels of quality.

In the second and last phase, three options are available: Make; Make and Buy; and Buy. The Make and Buy option, in comparison to other models, is new. According to Puranaman et al. (2013) companies, in practice, engage in plural sourcing, i.e., they make and buy the same product, thus this option was added.

After choosing which of the sourcing options is the most appropriate to pursue, the right type of relationship with a supplier should be found. This step is equally important because, although a strategic alliance is an opportunity to learn new skills from their partners in order to achieve common goals, linked to the strategic objectives, a company should protect its own distinctive skills from being internalized by their partners.

The structure of the model was designed so that the AHP methodology could be applied in ranking the capability factors of an organization (Water and Peet, 2006). The results obtained with the application of the case study demonstrated coherency between the results obtained in each level. This was to be expected as the judgments made are subjected to a consistency check along the process. It also should be said that the model is well defined and the integration with the AHP methodology was properly performed. This is important as unstructured approaches drive a make-or--buy study in different directions varying the conclusions on the experience of the project manager/decision maker.

In what concerns the implementation procedure, although it was not possible, due to time constraints, to follow the procedure as planned, it received a positive feedback from the manager who participated in the process. The contribution of each of the designated team members is very important due to their individual experience. The structure of the procedure allows the mobilisation of the different departments/functions, according to the need for information/knowledge that each one of the three phases requires.

The question remains, if the team had been assembled according to the implementation procedure, would the results have been any different? In the next subchapter, a proposal to answer this question is made.

5.2. Proposals for future studies

Regarding future developments a larger empirical research is suggested to assess the model's utility and applicability in real-world make-or-buy decision making situations. This would also allow the results obtained in the case study to be confirmed, as it was not possible to implement the procedure as planned.

This study would be accompanied by workshops in the companies where the framework would be implemented to assess who the members of the multi-functional team would be as there may be variations according to the size of the company, operations technology, as well as in the characteristics of the item/service under analyses. This would allow the teams' composition to be adapted to the companies' characteristics. Thus, each of the three implementation phases can be shaped according to a specific procedure defined.

Although a spreadsheet has been developed, some work in preparing the matrices is still required. Thus a mechanism to allow companies to create and collect data to be used in a software tool to facilitate the application of AHP methodology and its implementation in industrial companies also needs to be developed so that the procedure can be made quicker.

The integration of the work developed by Puranan et al. (2013) with this framework would also be facilitated by the development of the software tool, as, when the final decision is to Make and Buy, the percentage to make and to buy could be calculated.

As different industries have common but at the same time specific objectives and the respective indicators, a more comprehensive study should be conducted in order to assess which ones this framework should consider for each industrial sector.

Regarding the supplier selection problem, the approach proposed by Kar (2013), to support the supplier selection problem by integrating fuzzy Analytic Hierarchy Process (AHP) and fuzzy goal programming for discriminant analysis could be a good option to integrate with the proposed framework.

Bibliography

Abele, E., Liebeck, T., Wörn, A., "Measuring Flexibility in Investment Decisions for Manufacturing Systems", Annals of the CIRP Vol. 55 (1), 2006.

Balakrishnan, S., "The dynamics of make or buy decisions", European Journal of Operational Research, Volume 74, Issue 3, 5, pp. 552–571, 1994.

Cáñez, L.E., Platts, K.W., Probert, D.R., "Developing a framework for make-or-buy decisions", International Journal of Operations and Production Management, 20(11), pp. 1313−1330, 2000.

Chryssolouris, G., "Flexibility and Its Measurement", Annals of the CIRP 45 (2), pp. 581–587, 1996.

Chai, J., Liu, J.N.K., Ngai, E.W.T., "Application of decision-making techniques in supplier selection: A systematic review of literature", Expert Systems with Applications 40, pp. 3872-3885, 2013.

Chryssolouris, G., "Manufacturing Systems: Theory and Practice", Springer-Verlag, 1992.

Correa, H. L., Gianesi, I. G. N., "Service Operations Flexibility." In Proceedings of the 1st Euroma Conference, pp. 385-390, London: Cambridge University Press, 1994.

ElMaraghy, H., " Flexible and Reconfigurable Manufacturing Systems Paradigms", International Journal of Flexible Manufacturing Systems Special Issue on Reconfigurable Manufacturing Systems 17(4), pp. 261-276, 2005.

Hwang, C., Yoon, K., "Multiple Attribute Decision Making: Methods and Applications: A State-of-the-Art Survey", Springer-Verlag, 1981.

Holcomb, T.R., Hitt, M.A., "Toward a model of strategic outsourcing", Journal of Operations Management 25, pp. 464-481, 2007.

Jain, A., Jain, P.K., Chan, Felix T.S., Singh, S. "A review on manufacturing flexibility", International Journal of Production Research, Vol. 51, No. 19, pp. 5946–5970, 2013.

Juran, J., Gryna, F., "Juran's Quality Control Handbook – 4th Edition, MacGraw-Hill, Inc., 1988.

Kar, A.K., "Revisiting the supplier selection problem: An integrated approach for group decision support", Expert Systems with Applications 41, pp. 2762-2771, 2014.

Ketelhöhn , W., "International Business Strategy", Butterworth-Heinemann, Oxford, UK, 1993.

Kraljic, P., "Purchasing must become supply management", Harvard Business Review 61 (5), pp. 109-117, 1983.

Lepak, David P., Snell, Scott A., "The Human Resource Architecture: Toward a Theory of Human Capital Allocation and Development", The Academy of Management Review, Vol. 24, No. 1, pp. 31-48, 1999.

McIvor, R.T., “A practical framework for understanding the outsourcing process”, Supply Chain Management: An International Journal, Volume 5 . Number 1, pp. 22-36, 2000.

McIvor, R.T., & Humphreys, P.K., “A case-based reasoning approach to the make-or-buy decision”, Integrated Manufacturing Systems, 11(5), pp. 295-310, 2000.

McIvor, R.T., & Humphreys, P.K., McAleer, W.E., “A strategic model for the formulation of an effective make or buy decision”, Management Decision, Vol. 35 No. 2, pp. 169-178, 1997.

Miles, M., Huberman, M., Saldaña, J., “Qualitative data analysis: A methods sourcebook - Third edition”, Sage Publications, Inc., California, 2014.

Moschuris, S.J., “Organizational participants in the make-or-buy process”, Industrial Marketing Management 37, pp. 143-153, 2008.

Olsen, R.F., Ellram, I.M., “A portfolio approach to supplier relationships”, Industrial Marketing Management 26 (2), pp. 101-113, 1997.

Padillo, J.M., Diaby, M., “A multiple-criteria decision methodology for the make-or-buy problem”, International Journal of Production research, vol. 37, No. 14, pp. 3203-3229, 1999.

Parka, Jin-Kyu, Ro, Young K., “The impact of a firm’s make, pseudo-make, or buy strategy on product performance”, Journal of Operations Management 29, pp. 289-304, 2011.

Platts, K.W., Probert, D.R., Cáñez, L., “Make vs. buy decisions: A process incorporating multi-attribute decision-making”, International Journal of Production Economics 77, pp. 247-257, 2002.

Prahalad, C.K., Hamel, G., “The Core Competences of the Corporation”, Harvard Business Review, May-June, 1990.

Prajogo, D., Olhager, J., “Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration”, Int. J. Production Economics 135, pp. 514-522, 2012.

Probert, D.R., “The practical development of a make or buy strategy: the issue of process positioning”, Academy of Management Executive, Vol. 6 No. 1, pp. 23-30, 1996.

Puranam, P., Gulati, R., Bhattacharya, S., “How much to make and how much to buy? An analysis of optimal plural sourcing strategies”, Strategic Management Journal, 34: pp. 1145-1161, 2013.

Quélin, B., Duhamel, F., “Bringing Together Strategic Outsourcing and Corporate Strategy: Outsourcing Motives and Risks”, European Management Journal Vol. 21, No. 5, pp. 647–661, October 2003.

Rao, R. Venkata, “Decision Making in the Manufacturing Environment: Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods”, Springer-Verlag, London ,2007.

Saaty, T.L., “Decision making with the analytic hierarchy process”, Int. J. Services Sciences, Vol. 1, No. 1, pp. 83-98, 2008.

Saaty, T.L., “How to make a decision: The Analytic Hierarchy Process”, European Journal of

Operational Research 48, pp. 9-26, 1990a.

Saaty, T.L., “The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation”, RWS Publications, Pittsburgh, 1990b.

Treacy, M., Wiedersema, F.D., “The Discipline of Market Leaders: Choose Your Customers, Narrow Your Focus, Dominate Your Market”, Basic Books, 1997.

Ulrich, D., “Measuring Human Resources: An overview of practice and a prescription for results”, Human Resource Management, Vol. 36, No. 3, pp. 303-320, 1997.

Welch J., Nayak, P., “Strategic sourcing: a progressive approach to the make-or-buy decision”, Harvard Business review, November-December, pp. 98-107, 1992.

Water, H., Heelen P., “A decision support model based on the Analytic Hierarchic Process for the Make or Buy decision in Manufacturing”, Journal of Purchasing & Supply Management 12, pp. 258-271, 2007.

Williamson, O.E., “Markets and Hierarchies”, Free Press, New York, 1975.

Wilson, David T., “An Integrated Model of Buyer-Seller Relationships”, An Journal of the Academy of Marketing Science, Vol. 23, No. 4, pp. 335-345, 1995.

Winston, W.L., “Operations Research: Applications and Algorithms – Third Edition”, Duxbury Press – Wadsworth Publishing Company, Belmont, California, 1994.

Zanakis, S. H., Solomon, A., Wishart, N., Dublish, S., “Multi-attribute decision making: A simulation comparison of select methods”, European Journal of Operational Research IO7, pp. 507-529, 1998.

Annex I

Numerical references

In this annex, the codes for each of the objectives and their indicators are presented.

Codes for the indicators

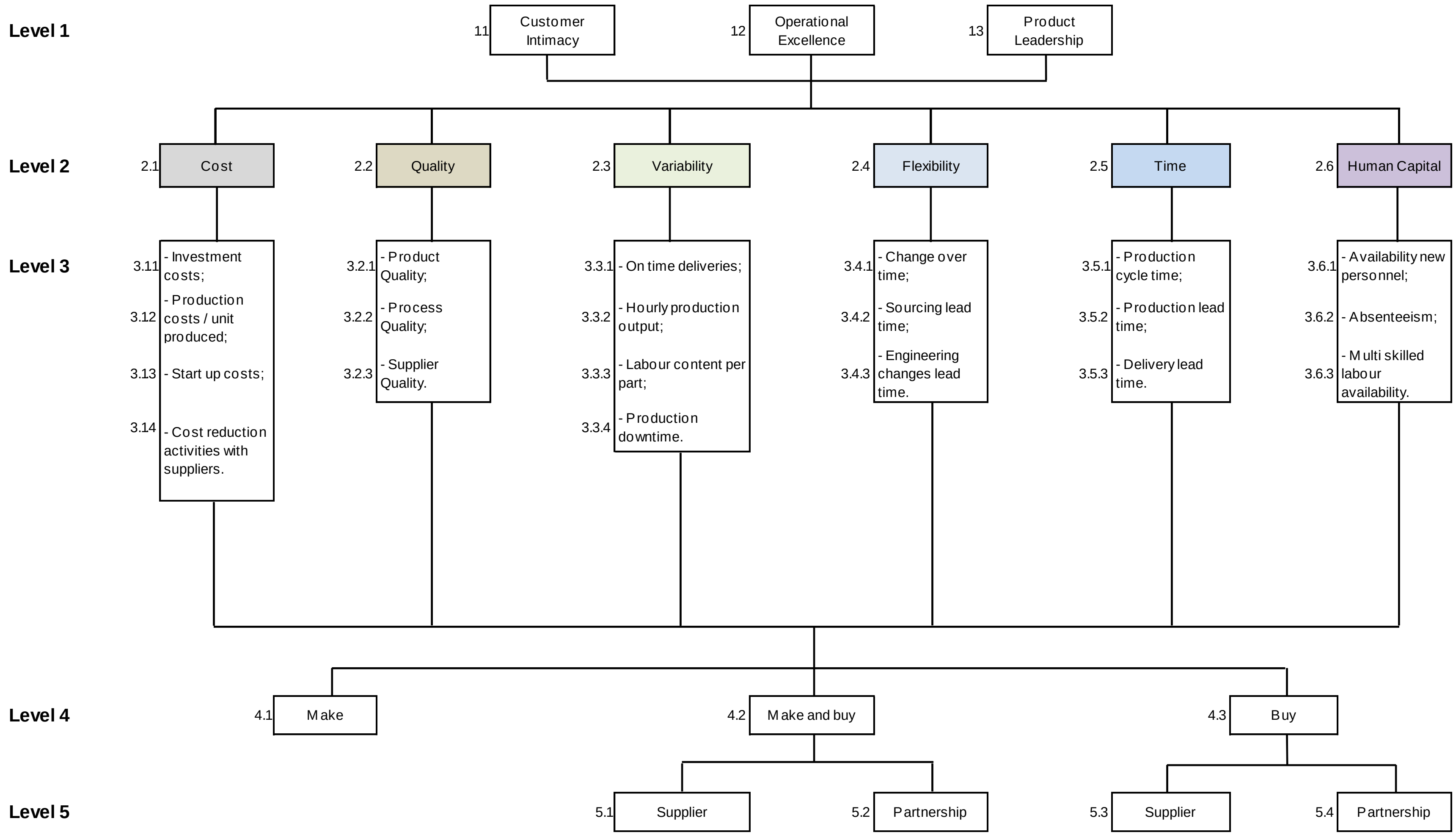

Figure A.1. Numerical references used in the framework

Annex II

Calculations

In this annex, the calculations that result in ranking of each option are presented.

Level 1 calculations

Calculate the Level 1 comparison matrix [3x3]:

Step 1. **Value disciplines' matrix**

	Customer Intimacy	Operational Excellence	Product Leadership
Customer Intimacy	1,00	0,13	3,00
Operational Excellence	8,00	1,00	9,00
Product Leadership	0,33	0,11	1,00

Step 2. **Determine the normalized matrix**

	Customer Intimacy	Operational Excellence	Product Leadership
Customer Intimacy	1,00	0,13	3,00
Operational Excellence	8,00	1,00	9,00
Product Leadership	0,33	0,11	1,00
	9,33	1,24	13,00

$\xrightarrow{\text{Normalize}}$

	Customer Intimacy	Operational Excellence	Product Leadership	Average (relative priority) **Pv.L1**
Customer Intimacy	0,107	0,101	0,231	0,146
Operational Excellence	0,857	0,809	0,692	0,786
Product Leadership	0,036	0,090	0,077	0,068

Step 3. **Check for consistency**

Step 3.1. Consistency measure: Multiply pairwise comparison matrix by relative priorities

$$0{,}146 \begin{Bmatrix} 1{,}00 \\ 8{,}00 \\ 0{,}33 \end{Bmatrix} + 0{,}786 \begin{Bmatrix} 0{,}13 \\ 1{,}00 \\ 0{,}11 \end{Bmatrix} + 0{,}068 \begin{Bmatrix} 3{,}00 \\ 9{,}00 \\ 1{,}00 \end{Bmatrix} = \begin{Bmatrix} 0{,}447 \\ 2{,}564 \\ 0{,}204 \end{Bmatrix}$$

Step 3.1.1. Divide weighted sum vector elements by associated priority value (results in the the matrix's eigenvector - Ev.L1)

$$\begin{Bmatrix} 0{,}447 \\ 2{,}564 \\ 0{,}204 \end{Bmatrix} \begin{matrix} / \\ / \\ / \end{matrix} \begin{matrix} 0{,}146 \\ 0{,}786 \\ 0{,}068 \end{matrix} = \overset{\textbf{Ev.L1}}{\begin{Bmatrix} 3{,}055 \\ 3{,}262 \\ 3{,}017 \end{Bmatrix}}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.1.

$$\lambda max = \begin{Bmatrix} 3{,}055 \\ 3{,}262 \\ 3{,}017 \end{Bmatrix} / 3 = 3{,}111$$

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,056
RI = 0,58
CR = 0,096 < 0,1 **Consistency acceptable**

Level 2 calculations

Calculate the 3 Level 2 comparison matrices [6x6] in relation to the Level 1 disciplines:

Step 1. **Customer Intimacy (CI)**

M1:	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	1,00	3,00	2,00	3,00	1,00
Quality	1,00	1,00	1,00	0,50	3,00	1,00
Variability	0,33	1,00	1,00	0,33	3,00	1,00
Flexibility	0,50	2,00	3,00	1,00	1,00	1,00
Time	0,33	0,33	0,33	1,00	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Step 2. **Determine the normalized matrix**

CI	Cost	Quality	Variability	Flexibility	Time	Human Capital	Normalize
Cost	1,00	1,00	3,00	2,00	3,00	1,00	$\longrightarrow$
Quality	1,00	1,00	1,00	0,50	3,00	1,00	
Variability	0,33	1,00	1,00	0,33	3,00	1,00	
Flexibility	0,50	2,00	3,00	1,00	1,00	1,00	
Time	0,33	0,33	0,33	1,00	1,00	1,00	
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00	
	4,17	6,33	9,33	5,83	12,00	6,00	

Normalize		Cost	Quality	Variability	Flexibility	Time	Human Capital	Average (relative prirority) **Pv.1.L2**
$\longrightarrow$	Cost	0,240	0,158	0,321	0,343	0,250	0,167	0,246
	Quality	0,240	0,158	0,107	0,086	0,250	0,167	0,168
	Variability	0,080	0,158	0,107	0,057	0,250	0,167	0,136
	Flexibility	0,120	0,316	0,321	0,171	0,083	0,167	0,196
	Time	0,080	0,053	0,036	0,171	0,083	0,167	0,098
	Human Capital	0,240	0,158	0,107	0,171	0,083	0,167	0,154

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.1.L2

$$\begin{Bmatrix} 6,759 \\ 6,542 \\ 6,604 \\ 6,707 \\ 6,437 \\ 6,476 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 6,588

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,118
RI = 1,24
CR = 0,095 < 0,1 **Consistency acceptable**

Calculate the 3 Level 2 comparison matrices [6x6] in relation to the Level 1 disciplines:

Step 1. **Operational Excellence (OE)**

M2:	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	1,00	3,00	1,00	3,00	1,00
Quality	1,00	1,00	1,00	1,00	3,00	1,00
Variability	0,33	1,00	1,00	1,00	0,33	1,00
Flexibility	1,00	1,00	1,00	1,00	3,00	1,00
Time	0,33	0,33	3,00	0,33	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Step 2. **Determine the normalized matrix**

OE	Cost	Quality	Variability	Flexibility	Time	Human Capital	Normalize
Cost	1,00	1,00	3,00	1,00	3,00	1,00	→
Quality	1,00	1,00	1,00	1,00	3,00	1,00	
Variability	0,33	1,00	1,00	1,00	0,33	1,00	
Flexibility	1,00	1,00	1,00	1,00	3,00	1,00	
Time	0,33	0,33	3,00	0,33	1,00	1,00	
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00	
	4,67	5,33	10,00	5,33	11,33	6,00	

Normalize →	Cost	Quality	Variability	Flexibility	Time	Human Capital	Average (relative prirority) **Pv.2.L2**
Cost	0,214	0,188	0,300	0,188	0,265	0,167	0,220
Quality	0,214	0,188	0,100	0,188	0,265	0,167	0,187
Variability	0,071	0,188	0,100	0,188	0,029	0,167	0,124
Flexibility	0,214	0,188	0,100	0,188	0,265	0,167	0,187
Time	0,071	0,063	0,300	0,063	0,088	0,167	0,125
Human Capital	0,214	0,188	0,100	0,188	0,088	0,167	0,157

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.2.L2

$$\left\{\begin{matrix} 6,805 \\ 6,695 \\ 6,220 \\ 6,695 \\ 6,802 \\ 6,355 \end{matrix}\right\}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 6,595

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,119
RI = 1,24
CR = 0,096 < 0,1 **Consistency acceptable**

Calculate the 3 Level 2 comparison matrices [6x6] in relation to the Level 1 disciplines:

Step 1. **Product Leadership (PL)**

M3:	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	4,00	2,00	2,00	2,00	1,00
Quality	0,25	1,00	2,00	0,33	0,50	1,00
Variability	0,50	0,50	1,00	0,33	2,00	1,00
Flexibility	0,50	3,00	3,00	1,00	2,00	1,00
Time	0,50	2,00	0,50	0,50	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00

Step 2. **Determine the normalized matrix**

PL	Cost	Quality	Variability	Flexibility	Time	Human Capital
Cost	1,00	4,00	2,00	2,00	2,00	1,00
Quality	0,25	1,00	2,00	0,33	0,50	1,00
Variability	0,50	0,50	1,00	0,33	2,00	1,00
Flexibility	0,50	3,00	3,00	1,00	2,00	1,00
Time	0,50	2,00	0,50	0,50	1,00	1,00
Human Capital	1,00	1,00	1,00	1,00	1,00	1,00
	3,75	11,50	9,50	5,17	8,50	6,00

Normalize →

Normalize →

	Cost	Quality	Variability	Flexibility	Time	Human Capital	Average (relative prirority) **Pv.3.L2**
Cost	0,267	0,348	0,211	0,387	0,235	0,167	0,269
Quality	0,067	0,087	0,211	0,065	0,059	0,167	0,109
Variability	0,133	0,043	0,105	0,065	0,235	0,167	0,125
Flexibility	0,133	0,261	0,316	0,194	0,235	0,167	0,218
Time	0,133	0,174	0,053	0,097	0,118	0,167	0,123
Human Capital	0,267	0,087	0,105	0,194	0,118	0,167	0,156

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.3.L2

$$\begin{Bmatrix} 6,665 \\ 6,569 \\ 6,328 \\ 6,694 \\ 6,505 \\ 6,405 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 6,53

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,106
RI = 1,24
CR = 0,085 < 0,1 **Consistency acceptable**

Build the L2 eigenvector matrix [6x3] and multiply by the Ev.L1 [6x1]

M4:	Ev.1. L2	Ev.2. L2	Ev.3. L2		**Ev.L1**		**Ev.L2**
Cost	0,246	0,220	0,269			=	0,227
Quality	0,168	0,187	0,109	x	0,146		0,179
Variability	0,136	0,124	0,125				0,126
Flexibility	0,196	0,187	0,218		0,786		0,190
Time	0,098	0,125	0,123				0,121
Human Capital	0,154	0,157	0,156		0,068		0,157

Level 3 calculations

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Cost**

M1:	3.1.1	3.1.2	3.1.3	3.1.4
3.1.1	1,00	0,33	0,11	0,20
3.1.2	3,00	1,00	1,00	1,00
3.1.3	9,00	1,00	1,00	3,00
3.1.4	5,00	1,00	0,33	1,00

Step 2. **Determine the normalized matrix**

Cost	3.1.1	3.1.2	3.1.3	3.1.4
3.1.1	1,00	0,33	0,11	0,20
3.1.2	3,00	1,00	1,00	1,00
3.1.3	9,00	1,00	1,00	3,00
3.1.4	5,00	1,00	0,33	1,00
	18,00	3,33	2,44	5,20

Normalize $\longrightarrow$

Normalize $\longrightarrow$

Cost	3.1.1	3.1.2	3.1.3	3.1.4	Average (relative prirority) **Pv.1.L3**
3.1.1	0,06	0,10	0,05	0,04	0,060
3.1.2	0,17	0,30	0,41	0,19	0,267
3.1.3	0,50	0,30	0,41	0,58	0,447
3.1.4	0,28	0,30	0,14	0,19	0,227

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev1.L3

$$\begin{Bmatrix} 4,072 \\ 4,194 \\ 4,327 \\ 4,156 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 4,19

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,062
RI = 0,9
CR = 0,069 < 0,1

Consistency acceptable

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

Pv.2.L3

$$\begin{Bmatrix} 0,060 \\ 0,267 \\ 0,447 \\ 0,227 \end{Bmatrix} \times \mathbf{Ev.L2}_{Cost} = \begin{Bmatrix} 0,014 \\ 0,061 \\ 0,101 \\ 0,052 \end{Bmatrix}$$

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Quality**

M2:	3.2.1	3.2.2	3.2.3
3.2.1	1,00	1,00	3,00
3.2.2	1,00	1,00	3,00
3.2.3	0,33	0,33	1,00

Step 2. **Determine the normalized matrix**

Quality	3.2.1	3.2.2	3.2.3
3.2.1	1,00	1,00	3,00
3.2.2	1,00	1,00	3,00
3.2.3	0,33	0,33	1,00
	2,33	2,33	7,00

Normalize $\longrightarrow$

Normalize $\longrightarrow$

Quality	3.2.1	3.2.2	3.2.3	Average (relative priority) **Pv.3.L3**
3.2.1	0,43	0,43	0,43	0,429
3.2.2	0,43	0,43	0,43	0,429
3.2.3	0,14	0,14	0,14	0,143

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.2.L3

$$\begin{Bmatrix} 3{,}000 \\ 3{,}000 \\ 3{,}000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step

$\lambda_{max} =$ 3,00

Step 3.3. Compute the Consistancy Index (CI) and the

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1

Consistency acceptable

Note: In this case we consider that the consistency is perfect

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

Pv.4.L3

$$\begin{Bmatrix} 0{,}429 \\ 0{,}429 \\ 0{,}143 \end{Bmatrix} \times \mathbf{Ev.L2}_{\mathbf{Quality}} = \begin{Bmatrix} 0{,}077 \\ 0{,}077 \\ 0{,}026 \end{Bmatrix}$$

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Variability**

M3:	3.3.1	3.3.2	3.3.3	3.3.4
3.3.1	1,00	9,00	7,00	9,00
3.3.2	0,11	1,00	3,00	1,00
3.3.3	0,14	0,33	1,00	0,20
3.3.4	0,11	1,00	5,00	1,00

Step 2. **Determine the normalized matrix**

Variability	3.1.1	3.1.2	3.1.3	3.1.4
3.3.1	1,00	8,00	6,00	8,00
3.3.2	0,11	1,00	2,00	1,00
3.3.3	0,14	0,33	1,00	0,20
3.3.4	0,11	1,00	5,00	1,00
	1,37	10,33	14,00	10,20

Normalize $\longrightarrow$

Normalize $\longrightarrow$

Variability	3.1.1	3.1.2	3.1.3	3.1.4	Average (relative prirority) **Pv.5.L3**
3.3.1	0,73	0,77	0,43	0,78	0,680
3.3.2	0,08	0,10	0,14	0,10	0,105
3.3.3	0,10	0,03	0,07	0,02	0,057
3.3.4	0,08	0,10	0,36	0,10	0,158

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.3.L3

$$\begin{Bmatrix} 4,599 \\ 4,320 \\ 3,873 \\ 3,938 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 4,18

Step 3.3. Compute the Consistancy Index (CI) and the

CI = 0,061

RI = 0,9

CR = 0,068 < 0,1

Consistency acceptable

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

Pv.6.L3

$$\begin{Bmatrix} 0,680 \\ 0,105 \\ 0,057 \\ 0,158 \end{Bmatrix} \times \mathbf{Ev.L2}_{\mathbf{Variability}} = \begin{Bmatrix} 0,085 \\ 0,020 \\ 0,007 \\ 0,025 \end{Bmatrix}$$

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Flexibility**

M4:	3.4.1	3.4.2	3.4.3
3.4.1	1,00	3,00	3,00
3.4.2	0,33	1,00	2,00
3.4.3	0,33	0,50	1,00

Step 2. **Determine the normalized matrix**

Flexibility	3.4.1	3.4.2	3.4.3
3.4.1	1,00	3,00	3,00
3.4.2	0,33	1,00	2,00
3.4.3	0,33	0,50	1,00
	1,67	4,50	6,00

Normalize $\rightarrow$

Normalize $\rightarrow$

Flexibility	3.4.1	3.4.2	3.4.3	Average (relative prirority) **Pv.7.L3**
3.4.1	0,60	0,67	0,50	0,589
3.4.2	0,20	0,22	0,33	0,252
3.4.3	0,20	0,11	0,17	0,159

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.4.L3

$$\begin{Bmatrix} 3{,}094 \\ 3{,}044 \\ 3{,}023 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1

Consistency acceptable

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

Pv.8.L3

$$\begin{Bmatrix} 0{,}589 \\ 0{,}252 \\ 0{,}159 \end{Bmatrix} \times \mathbf{Ev.L2}_{\mathbf{Variability}} = \begin{Bmatrix} 0{,}105 \\ 0{,}045 \\ 0{,}028 \end{Bmatrix}$$

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Time**

M5:	3.5.1	3.5.2	3.5.3
3.5.1	1,00	3,00	3,00
3.5.2	0,33	1,00	2,00
3.5.3	0,33	0,50	1,00

Step 2. **Determine the normalized matrix**

Time	3.5.1	3.5.2	3.5.3
3.5.1	1,00	3,00	3,00
3.5.2	0,33	1,00	2,00
3.5.3	0,33	0,50	1,00
	1,67	4,50	6,00

Normalize $\longrightarrow$

Time	3.5.1	3.5.2	3.5.3	Average (relative prirority) **Pv.9.L3**
3.5.1	0,60	0,67	0,50	0,589
3.5.2	0,20	0,22	0,33	0,252
3.5.3	0,20	0,11	0,17	0,159

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.5.L3

$$\begin{Bmatrix} 3,094 \\ 3,044 \\ 3,023 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1

Consistency acceptable

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

$$\begin{Bmatrix} 0,589 \\ 0,252 \\ 0,159 \end{Bmatrix} \times \mathbf{Ev.L2}_{Time} = \begin{Bmatrix} 0,071 \\ 0,031 \\ 0,019 \end{Bmatrix}$$

Pv.10.L3

Assess the importance of the performance indicators in L3 regarding the objectives in L2

Step 1. **Indicator:** **Human Capital**

M6:	3.6.1	3.6.2	3.6.3
3.6.1	1,00	0,20	1,00
3.6.2	5,00	1,00	5,00
3.6.3	1,00	0,20	1,00

Step 2. **Determine the normalized matrix**

Human Capital	3.6.1	3.6.2	3.6.3
3.6.1	1,00	0,20	1,00
3.6.2	5,00	1,00	5,00
3.6.3	1,00	0,20	1,00
	7,00	1,40	7,00

Normalize →

Human Capital	3.2.1	3.2.2	3.2.3	Average (relative prirority) **Pv.11.L3**
3.2.1	0,14	0,14	0,14	0,143
3.2.2	0,71	0,71	0,71	0,714
3.2.3	0,14	0,14	0,14	0,143

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.6.L3

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,00

Step 3.3. Compute the Consistancy Index (CI) and the

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1

Consistency acceptable

Note: In this case we consider that the consistency is perfect

Step 4. **Determine the relative importance of each performance indicator regarding the conrresponding factor**

Pv.12.L3

$$\begin{Bmatrix} 0,143 \\ 0,714 \\ 0,143 \end{Bmatrix} \times Ev.L2_{Human\ Capital} = \begin{Bmatrix} 0,017 \\ 0,087 \\ 0,017 \end{Bmatrix}$$

Build a [20x1] matrix with the 6 priority vectors of L3 ([4x1];[3x1];[4x1];[3x1];[3x1];[3x1])

M7:

		Pv.L3
Pv.1.L3	3.1.1	0,014
	3.1.2	0,061
	3.1.3	0,101
	3.1.4	0,052
Pv.4.L3	3.2.1	0,077
	3.2.2	0,077
	3.2.3	0,026
Pv.6.L3	3.3.1	0,085
	3.3.2	0,020
	3.3.3	0,007
	3.3.4	0,025
Pv.8.L3	3.4.1	0,105
	3.4.2	0,045
	3.4.3	0,028
Pv.10.L3	3.5.1	0,071
	3.5.2	0,031
	3.5.3	0,019
Pv.12.L3	3.6.1	0,022
	3.6.2	0,112
	3.6.3	0,022

Level 4 calculations

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M1:

Ev. L3 - 3.1.1	M	MaB	B
M	1,00	0,33	0,13
MaB	3,00	1,00	1,00
B	8,00	1,00	1,00

Step 2. **Determine the normalized matrix**

Ev. L3 - 3.1.1	M	MaB	B
M	1,00	0,33	0,13
MaB	3,00	1,00	1,00
B	8,00	1,00	1,00
	12,00	2,33	2,13

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.1.L4**
M	0,08	0,14	0,06	0,095
MaB	0,25	0,43	0,47	0,383
B	0,67	0,43	0,47	0,522

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.1.L4

$$\begin{Bmatrix} 3,031 \\ 3,107 \\ 3,190 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,11

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,055

RI = 0,58

CR = 0,094 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M2:

E.V. L3 - 3.1.2	M	MaB	B
M	1,00	2,00	2,00
MaB	0,50	1,00	0,50
B	0,50	2,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.1.2	M	MaB	B
M	1,00	2,00	3,00
MaB	0,50	1,00	0,20
B	0,50	2,00	1,00
	2,00	5,00	4,20

Normalize →

	M	MaB	B	Average (relative priority) **Pv.2.L4**
M	0,50	0,40	0,71	0,538
MaB	0,25	0,20	0,05	0,166
B	0,25	0,40	0,24	0,296

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.2.L4

$$\begin{Bmatrix} 3,267 \\ 2,979 \\ 3,029 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,09

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,046

RI = 0,58

CR = 0,079 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M3:

E.V. L3 - 3.1.3	M	MaB	B
M	1,00	0,33	0,33
MaB	3,00	1,00	0,33
B	3,00	3,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.1.3	M	MaB	B
M	1,00	0,25	0,33
MaB	3,00	1,00	0,33
B	3,00	3,00	1,00
	7,00	4,25	1,67

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.3. L4**
M	0,14	0,06	0,20	0,134
MaB	0,43	0,24	0,20	0,288
B	0,43	0,71	0,60	0,578

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.3.L4

$$\begin{Bmatrix} 2,977 \\ 3,064 \\ 3,189 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,08

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,038

RI = 0,58

CR = 0,066 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M4:

E.V. L3 - 3.1.4	M	MaB	B
M	1,00	1,00	0,25
MaB	1,00	1,00	4,00
B	4,00	0,25	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.1.4	M	MaB	B
M	1,00	1,00	0,20
MaB	1,00	1,00	1,00
B	4,00	0,25	1,00
	6,00	2,25	2,20

Normalize →

	M	MaB	B	Average (relative priority) **Pv.4. L4**
M	0,17	0,44	0,09	0,234
MaB	0,17	0,44	0,45	0,355
B	0,67	0,11	0,45	0,411

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.4.L4

$$\begin{Bmatrix} 2,869 \\ 2,815 \\ 3,495 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,06

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,030

RI = 0,58

CR = 0,051 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M5:

E.V. L3 - 3.2.1	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.2.1	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00
	3,00	3,00	3,00

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.5.L4**
M	0,33	0,33	0,33	0,333
MaB	0,33	0,33	0,33	0,333
B	0,33	0,33	0,33	0,333

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.5.L4

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,00

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M6:

E.V. L3 - 3.2.2	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.2.2	M	MaB	B
M	1,00	1,00	1,00
MaB	1,00	1,00	1,00
B	1,00	1,00	1,00
	3,00	3,00	3,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.6.L4**
M	0,33	0,33	0,33	0,333
MaB	0,33	0,33	0,33	0,333
B	0,33	0,33	0,33	0,333

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.6.L4

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,00

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M7:

E.V. L3 - 3.2.3	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.2.3	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00
	1,67	5,00	5,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.7.L4**
M	0,60	0,60	0,60	0,600
MaB	0,20	0,20	0,20	0,200
B	0,20	0,20	0,20	0,200

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev7.L4

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,00

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M8: E.V. L3 - 3.3.1	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.3.1	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00
	1,67	5,00	5,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.8.L4**
M	0,60	0,60	0,60	0,600
MaB	0,20	0,20	0,20	0,200
B	0,20	0,20	0,20	0,200

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev8.L4

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,00

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M9:

E.V. L3 - 3.3.2	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.3.2	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00
	4,00	3,00	2,50

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.9.L4**
M	0,25	0,33	0,20	0,261
MaB	0,25	0,33	0,40	0,328
B	0,50	0,33	0,40	0,411

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.9.L4

$$\begin{Bmatrix} 3,043 \\ 3,051 \\ 3,068 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M10:

E.V. L3 - 3.3.3	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.3.3	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00
	4,00	3,00	2,50

Normalize →

	M	MaB	B	Average (relative priority) **Pv.10.L4**
M	0,25	0,33	0,20	0,261
MaB	0,25	0,33	0,40	0,328
B	0,50	0,33	0,40	0,411

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.10.L4

$$\begin{Bmatrix} 3,043 \\ 3,051 \\ 3,068 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M11:

E.V. L3 - 3.3.4	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.3.4	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00
	2,50	3,00	4,00

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.11.L4**
M	0,40	0,33	0,50	0,411
MaB	0,40	0,33	0,25	0,328
B	0,20	0,33	0,25	0,261

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.11.L4

$$\begin{Bmatrix} 3,068 \\ 3,051 \\ 3,043 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M12:

E.V. L3 - 3.4.1	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.4.1	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00
	2,50	3,00	4,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.12.L4**
M	0,40	0,33	0,50	0,411
MaB	0,40	0,33	0,25	0,328
B	0,20	0,33	0,25	0,261

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.12.L4

$$\left\{\begin{matrix} 3{,}068 \\ 3{,}051 \\ 3{,}043 \end{matrix}\right\}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M13:

E.V. L3 - 3.4.2	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.4.2	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00
	1,53	5,00	7,00

Normalize →

	M	MaB	B	Average (relative priority) **Pv.13.L4**
M	0,65	0,60	0,71	0,655
MaB	0,22	0,20	0,14	0,187
B	0,13	0,20	0,14	0,158

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.13.L4

$$\left\{\begin{matrix} 3,058 \\ 3,015 \\ 3,015 \end{matrix}\right\}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,03

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,015

RI = 0,58

CR = 0,025 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M14:

E.V. L3 - 3.4.3	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.4.3	M	MaB	B
M	1,00	3,00	5,00
MaB	0,33	1,00	1,00
B	0,20	1,00	1,00
	1,53	5,00	7,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.14.L4**
M	0,65	0,60	0,71	0,655
MaB	0,22	0,20	0,14	0,187
B	0,13	0,20	0,14	0,158

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.14.L4

$$\begin{Bmatrix} 3,058 \\ 3,015 \\ 3,015 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,03

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,015

RI = 0,58

CR = 0,025 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M15:

E.V. L3 - 3.5.1	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.5.1	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00
	2,50	3,00	4,00

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.15.L4**
M	0,40	0,33	0,50	0,411
MaB	0,40	0,33	0,25	0,328
B	0,20	0,33	0,25	0,261

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.15.L4

$$\begin{Bmatrix} 3,068 \\ 3,051 \\ 3,043 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M16:

E.V. L3 - 3.5.2	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.5.2	M	MaB	B
M	1,00	3,00	3,00
MaB	0,33	1,00	1,00
B	0,33	1,00	1,00
	1,67	5,00	5,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.16.L4**
M	0,60	0,60	0,60	0,600
MaB	0,20	0,20	0,20	0,200
B	0,20	0,20	0,20	0,200

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.16.L4

$$\begin{Bmatrix} 3,000 \\ 3,000 \\ 3,000 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,00

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,000

RI = 0,58

CR = 0,000 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M17:

E.V. L3 - 3.5.3	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.5.3	M	MaB	B
M	1,00	1,00	2,00
MaB	1,00	1,00	1,00
B	0,50	1,00	1,00
	2,50	3,00	4,00

Normalize $\longrightarrow$

	M	MaB	B	Average (relative prirority) **Pv.17.L4**
M	0,40	0,33	0,50	0,411
MaB	0,40	0,33	0,25	0,328
B	0,20	0,33	0,25	0,261

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.17.L4

$$\begin{Bmatrix} 3{,}068 \\ 3{,}051 \\ 3{,}043 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

λ_{max} = 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M18:

E.V. L3 - 3.6.1	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.6.1	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00
	4,00	3,00	2,50

Normalize $\longrightarrow$

	M	MaB	B	Average (relative pirority) **Pv.18.L4**
M	0,25	0,33	0,20	0,261
MaB	0,25	0,33	0,40	0,328
B	0,50	0,33	0,40	0,411

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.18.L4

$$\begin{Bmatrix} 3,043 \\ 3,051 \\ 3,068 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M19:

E.V. L3 - 3.6.2	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.6.2	M	MaB	B	Normalize		M	MaB	B	Average (relative prirority) **Pv.19.L4**
M	1,00	1,00	0,50	→	M	0,25	0,33	0,20	0,261
MaB	1,00	1,00	1,00		MaB	0,25	0,33	0,40	0,328
B	2,00	1,00	1,00		B	0,50	0,33	0,40	0,411
	4,00	3,00	2,50						

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.19.L4

$$\begin{Bmatrix} 3{,}043 \\ 3{,}051 \\ 3{,}068 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

Calculate the weight of each option by multiplying the matrix of eigenvectors of the options by the vector of the performance indicators

Step 1.

M20:

E.V. L3 - 3.6.3	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00

Step 2. **Determine the normalized matrix**

E.V. L3 - 3.6.3	M	MaB	B
M	1,00	1,00	0,50
MaB	1,00	1,00	1,00
B	2,00	1,00	1,00
	4,00	3,00	2,50

Normalize →

	M	MaB	B	Average (relative prirority) **Pv.20.L4**
M	0,25	0,33	0,20	0,261
MaB	0,25	0,33	0,40	0,328
B	0,50	0,33	0,40	0,411

Step 3. **Check for consistency**

Step 3.1. Consistency measure

Ev.20.L4

$$\begin{Bmatrix} 3,043 \\ 3,051 \\ 3,068 \end{Bmatrix}$$

Step 3.2. Compute average (denoted λmax) of the values from Step 3.1.

$\lambda_{max} =$ 3,05

Step 3.3. Compute the Consistancy Index (CI) and the Consistancy Ratio (CR)

CI = 0,027

RI = 0,58

CR = 0,046 < 0,1 **Consistency acceptable**

The combination of the priority vectors results in a [3x20] matrix that is multiplied by the weights of indicators in Level 3, thus resulting in the final rank of the 3 available options: Make; Make and Buy; Buy.

M21: [3x20]

	Pv.1.L4	Pv.2.L4	Pv.3.L4	Pv.4.L4	Pv.5.L4	Pv.6.L4	Pv.7.L4	Pv.8.L4	Pv.9.L4	Pv.10.L4	Pv.11L4	Pv.12.L4	Pv.13.L4	Pv.14.L4	Pv.15.L4	Pv.16.L4	Pv.17.L4	Pv.18.L4	Pv.19.L4	Pv.20.L4
M	0,095	0,538	0,134	0,234	0,333	0,333	0,600	0,600	0,261	0,261	0,411	0,411	0,655	0,655	0,411	0,600	0,411	0,261	0,261	0,261
MaB	0,383	0,166	0,288	0,355	0,333	0,333	0,200	0,200	0,328	0,328	0,328	0,328	0,187	0,187	0,328	0,200	0,328	0,328	0,328	0,328
B	0,522	0,296	0,578	0,411	0,333	0,333	0,200	0,200	0,411	0,411	0,261	0,261	0,158	0,158	0,261	0,200	0,261	0,411	0,411	0,411

x

Pv.L3 [20x1]

0,014
0,061
0,101
0,052
0,077
0,077
0,026
0,085
0,020
0,007
0,025
0,105
0,045
0,028
0,071
0,031
0,019
0,022
0,112
0,022

=

Pv.L4
Final priorities

= 0,38	In percentage:	M	38,25
0,29		MaB	28,85
0,33		B	32,90