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Multicriteria methodology for decoupling point placement under production postponement strategy

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Lemma

Tu sola existencia te dota de la responsabilidad y el deber de pensar, no por ti si no por los demás.

El día en que entendamos nuestra gran responsabilidad sabremos qué hacer con todo lo que se nos ha dado.

Your existence gives you the responsibility and the duty to think, not for you but for others.

The day when we understand our great responsibility, we will know what to do with everything that has been given to us.

Iván D. Gómez J.

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Abstract

The accelerated growth of global markets and the increased bargaining power of customers, has generated a highly competitive environment with a lot of risks for manufacturing companies. In response, the literature has shown mass customization and, in particular way, the postponement strategy as new paradigms of production that allows offering simultaneously high levels of flexibility and efficiency to consumers.

Regarding this issue, the decoupling point location is positioned as the most important decision in the implementation of postponement. Starting from the importance of this topic and from a review of the state of the art, it was detected the need to develop a methodology to locate the decoupling point, by integrating qualitative and quantitative criteria and that additionally allows the participation of panel of experts.

Thereby, this thesis shows the development of a new multi-criteria methodology; which consists of 7 steps that allow locating the decoupling point, in a production system, according to the needs of the system and relying on the experience and knowledge of experts. Additionally, in order to validate the performance of the methodology in real cases, two study cases developed in the companies Herragro S.A. and Muebles Marco Gomez, are presented.

Key words: Production postponement, multicriteria methodology, mass customization, decoupling point, production system.

Resumen

Metodología multicriterio para la ubicación del punto de desacople bajo la estrategia de aplazamiento en la producción

El crecimiento acelerado de los mercados globalizados y el aumento del poder de negociación de los clientes, ha generado un ambiente fuertemente competitivo y con gran cantidad de riesgos para las empresas manufactureras. Como respuesta, la literatura ha mostrado a la personalización masiva y, de forma particular a la estrategia de aplazamiento como nuevos paradigmas de la producción que permiten ofrecer a los clientes de forma simultánea altos niveles de flexibilidad y eficiencia.

Frente a este tema la ubicación del punto de desacople se posiciona como la decisión más importante en la implementación del aplazamiento. Partiendo de la importancia de este tópico y de una revisión del estado del arte, se detecta la necesidad de desarrollar una metodología que permita ubicar el punto de desacople integrando criterios cualitativos y cuantitativos y que adicionalmente permita la participación de grupos de expertos.

De esta forma, la presente tesis muestra el desarrollo de una nueva metodología multicriterio; la cual está conformada por 7 pasos que permiten ubicar el punto de desacople, en un sistema de producción, acorde con las necesidades del sistema y apoyándose de la experiencia y conocimiento de los expertos. Adicionalmente, y con el objetivo de validar el funcionamiento de la metodología en casos reales, se presentan dos casos de estudio desarrollados en las empresas Herragro S.A y Muebles Marco Gómez.

Palabras clave: Aplazamiento en la producción, metodología multicriterio, personalización masiva, punto de desacople, sistema de producción.

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List of symbols and abbreviations

The symbols and abbreviations which you will find in this thesis is presented following. The identification of this information will make easier to understand all the information which will be shown.

Symbols with latin letters

Symbols	Concept	Location
a_m	Alternative m	Table 2-3
c_n	Criterion m	Table 2-3
w_j	Criterion weight j	Eq. 1
X_{ij}	Value of alternative i respect the criterion j	Table 2-3
W_i	Weight vector associated to the alternative i	Eq. 1
γ	Relative weight to the opinion of the expert k	Eq. 3,4 and 5
C_{jk}	Relative importance of criterion j given by the expert k.	Eq. 6
W_{jA}	Subjective weighting I of criterion j	Eq. 6
T	Mean value of ranges	Eq. 7 and 8
n	Number of criteria	Eq. 7 and 9
M	Number of experts	Eq. 7 and 9
D^2	Deviation for each criterion	Eq. 8 and 9
W	Kendall's index	Eq. 9
P_{jik}	Preference of criterion j respect to criterion i, according to expert k.	Table 3-1 y Eq. 10
P'_{jik}	Binary logical complement of P_{jik}.	Table 3-1
W_{jBk}	Subjetive weighting II of criterion j, given by expert k	Eq. 10

Symbols	Concept	Location
W_{jB}	Subjetive weighting II of criterion j	Eq. 11
W_{jD}	Final weighting of criter j	Eq. 12
a_{pf}	Value of the paired comparison between ADP_p and ADP_f made by expert *k*	Eq. 13
n_{pfk}	Normalized value of comparison between ADP_p respect to ADP_f made by expert k	Eq. 14
S_{fk}	Eigenvector or priority vector for the expert k *k*	Eq. 15
S_f	Final eigenvector or priority vector respect to ADP_f	Eq. 16
R	Resulting vector	Eq. 17
A	Comparison matrix	Eq. 17
d_{Max}	Largest or principal eingenvalue	Eq. 18
CI	Consistency index calculation	Eq. 19
CR	Consistency ratio calculation	Eq. 20
RI	Índice de consistencia aleatoria	Ec. 19
AC_{jp}	Assessment of criterion j at ADP *p*	Table 3-5
AC'_{jp}	Homogenized value AC_{jp} of the vector AC_j	Eq. 21
AC^N_{jp}	Normalized value of AC_{jp}	Eq. 22
Q_p	Final grade for the ADP_p.	Eq. 23

Subscripts

Symbols	Concept
j	Criterion
i	Criterion
n	Criterion. It was used just in the tables.
k	Expert
p	Alternative decoupling point
f	Alternative decoupling point
m	Alternative decoupling point. It was just used in the tables.

Superscrip

Symbols	Concept
N	Normalized data
‘	Mathematical complement

Abbreviations

Abbreviations	Concept
DP	Decoupling point
ADP	Alternative decoupling point
SO	Single objective optimization
MO	Multi-objetive model
QT	Model with queuing theory
MS	Simulation model
DM	Dynamic model

Abbreviations	**Concept**
GM	Graphic model
ES	Method experts
ME	Multicriteria model based on entropy technology
PST	Polychromatic sets theory
AHP	Analytical hierarchy process
FANP	Fuzzy analytic network process

1. Introduction

Competition among factories has maintained a progressive growth, driven by the fastest technological developments, the globalization boom, heterogeneous markets and the rapid changes in customer needs. These customers are looking for a variety of individualized products (Ferguson, Olewnik, & Cormier, 2014; Modrak, Marton, & Bednar, 2015; Mourtzis, Doukas, Psarommatis, Giannoulis, & Michalos, 2014). This situation has caused high levels of uncertainty in sales forecasts and market analyses. Therefore, planning and control difficulties have arisen (Harrison & Skipworth, 2008; Yang & Burns, 2003).

As noted by the European Commission, (2010) and Ferreira et al. (2015), because of the globalization and the growing need to produce tailored markets in each place of the world, factories in their quest to seek continuous improvement, have had to face much more complex and dynamic markets with high levels of uncertainty in their sales forecast. These are factors that cause difficulties and losses in the industry (Yang, Burns, & Backhouse, 2004) that are evidenced by low competitiveness and disadvantageous price relationships, which limit the management of the company (Jiang, 2012).

The aforementioned has forced companies to develop more aggressive strategies in order to increase their market share. Thus, it is necessary to reduce costs and increase production capacity while improving service levels and customer experience (Kumar & Wilson, 2009; Skipworth & Harrison, 2004). Although for many years one of primary objectives of companies has been to produce large batches of products with the goal of decreasing costs, flexibility requirements of today's market have become more difficult to achieve (Brun & Zorzini, 2009).

It is necessary to keep in mind that these new demands force companies to break old strategic paradigms and drive their efforts toward the customer in an individualized way. In this sense, the corporate strategy selection is not enough by itself, because in this case the manufacturing strategy has an important role (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013). That is why it is necessary to find out that the manufacturing strategy not only aligns with corporate strategy (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013), but also has the ability to address the current needs that under traditional approaches represent a challenge for the configuration of the production system.

According to Miltenburg, (2009) it is possible to find seven different production system configurations: job shop, batch flow, operator-paced line flow, machine-paced line flow, continuous flow, just in time (JIT) and flexible manufacturing systems (FMS). The strategic value of these configurations is that each of them has the ability of respond in different measure to the demand of the market (Miltenburg, 2009).

For example, line flow and continuous flow systems are able to generate high volumes and low costs (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013) but are unable to offer high flexibility levels and therefore can not respond in a particular way to the customer needs (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013). In contrast, high flexibility levels achieved by systems such as the job shop are not free, which causes an increase in costs and delivery time (Squire, Brown, Readman, & Bessant, 2006). The fact that line flow systems can not generate high flexibility levels and the job shop does not provide high production velocity and low costs evidences a difficulty in the manufacturing strategy design (Miltenburg, 2009). For the particular case of current markets, the conflict between flexibility and efficiency needs is highlighted.

This is to say, while companies have to face a flexibility strategy to get adapted to the uncertainty and the rapidly changing market, they also need to optimize their production processes, to look for high efficiency levels and to decrease costs (Eisenhardt, Furr, & Bingham, 2010; Kortmann, Gelhard, Zimmermann, & Piller, 2014; Purvis, Gosling, & Naim, 2014). As a consequence, it opens the opportunity for the strategic implementation of mass customization (Rudberg & Wikner, 2004).

According to Chuang & Su (2011), mass customization has become a new frontier of business competition for both industries and services. Mass customization is one of the best suited alternatives for the current market characteristics, allowing manegment of the efficiency of mass production (Wadhwa et al. 2006; Cheng et al. 2010; Arroyo & Jimenez 2013). Therefore, mass customization allows the aligment the manufacturing strategy, which has become one of the most important factors of business competitiveness with market requirements (Chuang & Su, 2011; Fogliatto, Da Silveira, & Borenstein, 2012; Hsuan Mikkola & Skjøtt-Larsen, 2004; Rudberg & Wikner, 2004).

Although there are several approaches to drive this strategy toward the implementation of mass customization, some authors suggest postponement as the best alternative to achieve this outcome (Hoek 2001; Yang et al. 2004). The latter is a concept applicable to companies that are facing uncertain markets (Ferreira, Tomas, & Alcântara, 2015; Kumar & Wilson, 2009; Pagh & Cooper, 1998), in order to offer a better experience and quality to the customers; procuring balance between flexibility and efficiency (Brun & Zorzini, 2009; Cheng, Li, Wan, & Wang, 2010; Qin, 2012; Saghiri & Hill, 2014; Skipworth & Harrison, 2006).

In a production system, postponement is made when products have a large number of derived varieties and it tries to solve market demands by increasing the penetration point of costumers in the production system (Yang, Burns, & Backhouse, 2004). The first phase of the implementation of postponement is the placemenet of the decoupling point (identified in this thesis as DP). Aditionaly, it can identify if the postponement can be implemented (Ferreira, Tomas, & Alcântara, 2015; Yang & Burns, 2003).

The decoupling point is considered in literature as a physical designation of work in process stock from which the production system is managed under two approaches: pull, located downstream and push, located upstream (Hemmati, Rabbani, & Ebadian, 2009; Liu, Xu, Sun, Yang, & Mo, 2013; Rafiei & Rabbani, 2011; Wang, Ye, Lin, & Li, 2012).

From this point postponement reduces conflict between flexibility and efficiency. That is because segmenting the production system into two sub-systems, one “downstream” from the DP, with high flexibility levels, and an “upstream” from the DP with high efficiency levels. this strikes a balance between these two requirements in the same production system (Kortmann, Gelhard, Zimmermann, & Piller, 2014; Olhager, 2003; Rudberg & Wikner, 2004).

According to Chuang & Su (2011) and Liu et al. (2014) the DP location is the success factor of the postponement strategy since it defines the optimal balance between efficiency and flexibility (Rudberg & Wikner, 2004; Yang & Burns, 2003). The DP location determines which processes will work under a made to order production focus and which ones will work under a forecast focus. Thus, the systems will have different levels of flexibility and efficiency.

According to the above mentioned, the direct dependence among the customization level, total costs and service level with the DP causes its location to be a critical process that dictates the application of mass customization and postponement; similarly, dictates the flexibility and efficiency level that these are going to have (Cirullies, Klingebiel, & Scarvarda, 2011; Liu, Xu, Sun, Yang, & Mo, 2013; Shidpour, Da Cunha, & Bernard, 2014).

This implies that, if companies want to implement mass customization or production postponement with a view to align production strategy to the competitive characteristics of existing markets, they should apply a rigorous methodology which allows the DP location. In this sense, authors such as Xu (2007), Xu & Liang (2011) and Shidpour et al. (2014) show the need to increase the number of investigative contributions addressed to models, techniques, methods or methodologies to assist the DP location. These authors conclude that despite the importance of this topic, there is still a lag in this research topic.

1.1 Systematic literature review

The background of the problematic reveals the relevance of carrying out research processes to help companies address the conflict between flexibility and efficiency which exists among current markets and production systems. In addition, the importance of the DP location in order to achieve an effective implementation of production postponement was showed. From this point, a literature review was developed to identify how far existing solutions related to this issue have come.

For the literature review a systematic search was carried out on the ISI Web of Science and Scopus. The search was driven by the keywords: *customer order decoupling point, decoupling point, order penetration point, customer order point, postponement point, point of differentiation, delayed product differentiation, customization point, location, decision, model and placement.* The search was applied in titles, abstracts and keywords of the articles, reviews, books and book chapters; the time range was not considered as a filter in order to obtain a more complete analysis.

The selection of relevant keywords topic of interest was made from a narrative search. This contributed to specify the topic and, therefore, to develop the first question that covers the generality of the research idea. The initial question was: what models destined to the decoupling point location exist in the specialized literature?

From the final research, 210 references were detected in the bibliography tool Scopus, and 112 references on Web of Science. The Comparison between the articles obtained in both bibliography tools, showed that 80 of them were repeated. Therefore, a total of 242 articles was obtained. Among them, only 59 were closely related with the topic of interest, because they represented models, techniques or methods for the DP location. While the other references, 122 articles were related to the DP location topic but they only developed a conceptual focus without proposing any model or tool for its location. The remaining 61 articles were not related to the subject or area of study. (See Table 1-1)

The systematic search methodology turned out to be 46 articles. Since among the 59 identified articles, 13 were not accessible; 4 of them because they were written in a language out of the investigative scope and 9 because they were not available. Annex A presents a detailed explanation of the process used for systematic search and the different results on each of the steps; in addition in Annex B, the final results of the systematic search are presented.

Table 1-1: Results in the specialized literature selection process.

Clasiffication	They carry out models for the CODP	Development frameworks	Is not relevant
Web of Science and Scopus	24.38%	50.41%	25.20%
Characteristic	They offer as primary or secondary factor of their articles, models to locate the decoupling point	They highlight the importance of the decoupling point location and do an analysis or theoretical study of it, but do not offer any model for its location.	The developed topic in the article was not relevant to the research topic.

The detected models were grouped according to their approaches into qualitative, quantitative and mixed. The quantitative, the most representative In the systematic research, are those that support its decisions based on mathematical constructs that represent the relationships among different variables with which it is intended to study the behavior of systems (Bangert, 2012; Murty, 2010).

Although the versatility and frequency of quantitative alternatives is high, in the literature different limitations that compromise its performance in complex systems and making strategic decisions in companies are highlighted. For example, the relationships among the input data are not taken into account (Kasperski, 2008), stochastic models may require multiple assumptions that limit the study (Kasperski, 2008), the computational resources required (Chand & Wagner, 2015; Zhou et al., 2011) and does not involve qualitative data in their processes.

In a second instance, the qualitative models make up of the active participation of the experts when making decisions. However, involving only the expert has several limitations. For example, disagreements among experts may cause different results in evaluations (Yu, 1973), decisions in large groups can become very complex and unproductive (Rigopoulos, Karadimas, & Orsonni, 2008) and decisions made by a single expert are risky, because in big problems the analytical skills can be limited (Herrera, Herrera-Viedma, & Verdegay, 1997).

Moreover, mixed approaches allow the evaluation of qualitative and quantitative criteria existing in a system. In the case of the detected models through the systematic search, and regardless of individualized limitations that can be attributed to each of the multicriteria models, the limited participation of experts when making decisions are highlighted as a common factor.

1.2 Research question

From the literature analysis, and as it will be explored in the theoretical framework of this thesis, it is identified that despite the existence of different models, it is necessary to develop a methodology in order to locate the decoupling point in a production system, which allows not only the inclusion of qualitative and quantitative variables, but also allows the participation of expert groups when making decisions.

Then, the general research question arises:

How to develop and apply a methodology througnh the participation of experts that allows the integration of qualitative and quantitative criteria when deciding the location of the decoupling point in a production system?

This research question has been systematized as follows:

- What theoretical concepts from the mass customization strategy and production postponement are sustained? And what role does the decoupling point play in its implementation?
- What are the theoretical aspects that sustain the formulation and implementation of the methodology?
- How to involve the knowledge of expert groups in the development of the methodology to locate the decoupling point?
- How to design a methodology that is easy to implement in a real context?
- How to guide the applicability of the methodology for the decoupling point location in manufacturing companies?

1.3 Objective system

1.3.1 General Objective

To develop and implement a methodology wich by involving experts that allows integrating qualitative and quantitative criteria in the decision to locate the decoupling point in a production system.

1.3.2 Specific objectives

- To build the theoretical framework to identify trends, concepts and relevant models in the construct of the methodology for locating the decoupling point.
- To design a multicriteria methodology which involves experts, in a participative way for the decoupling point location, based on relevant aspects identified.
- To validate the performance of the methodology in two study cases executed in manufacturing companies

1.4 Justification

In today´s markets, companies have been forced to increase the variety of the products, as well as improve costs and delivery times (Chen et al. 2006; Gupta & Benjaafar 2008; Zhou et al. 2014). Therefore, companies' competitiveness has begun to see their ability to respond quickly to demand, while maintaining high variety of their products (Jewkes & Alfa, 2009).

Colombia is not excluded from the need to improve in this situation, indeed the Global Competitiveness report, shows that Colombia is in the 66th position worldwide among 144 countries (Foro Económico Mundial, 2015). Although this is a general analysis of the country´s behavior, it is influenced by the status of manufacturing companies. Another detailed analysis in the report of joint industrial opinion survey, made by Asociación Nacional de Industriales (ANDI) (2015), indicates that industry growth has been very modest and continues to lag in comparison to other activities, although in 2014, Colombian economy stood out for its good performance.

On this issue, the State, through the national planning department Departamento Nacional de Planeación, (2011) therefore, in the National development plan (p.66), identifies the need to increase competitiveness at all levels of companies with the aim of strengthening them to face more demanding and global consumers. Not only does the State show a strong interest in this issue, in fact the academy has advanced research in which the difficulties that manufacturers companies face are shown.

Escobar, Giraldo, & Cárdenas, (2012) developed a job at a fabricator, distributor and marketing company from Manizales (Colombia); in this, they highlighted the constraints and challenges faced by participating in diversified markets, which require high volumes and/or customized products. In other studies, García, Castro, & Gómez, (2010) show that companies in the metal-mechanic sector, despite their high employment levels and their high participation in local establishments, have different structural and infrastructural weaknesses in production systems.

In the textile sector Castro, Castrillón, & Giraldo, (2011) presents a study carried out in 18 companies, which shows that despite typical requirements of quality, customers are recognizing with more relevance than before the priorities of costs, speed and flexibility; evidencing the need for these companies to respond in a joint way to the requirements of flexibility and efficiency; and then to be able to compete in such a demanding and globalized market.

Despite this, companies from the Caldas region have some deficiencies in competitiveness factors, such as flexibility and delivery times (Ram, 2013; Sarache, Cárdenas, & Giraldo, 2005); Additionally, in the case of the metal-mechanic sector, not limited only to this, delays in technology and developing of procedures according to needs are presented (Cárdenas, Giraldo, Parra, & Sarache, 2007).

Macroeconomic trends resulting from globalization processes, require local companies to offer jointly a wide range of differentiating priorities (Cárdenas, Giraldo, Parra, & Sarache, 2007). That is why it is vital that companies pay greater attention to the production function, conceiving it as a source of competitive advantage (Sarache, Cárdenas, & Giraldo, 2005). Thereby, allowing it to give an effective response to the changing customer demands. (Ram, 2013).

It is does not matter what the target market is, however, it is necessary to have a strategy consistent with the characteristics of the company and its limitations (Cárdenas et al., 2007). The reason why, is that region can not ignore the reality that surrounds itself and on the contrary, the way to generate strategies for converting the production system into a distinctive competence must be found (Ram, 2013).

Despite the above difficulties mentioned, literature has shown two elements in research, as potential solutions: postponement and mass customization (Kortmann, Gelhard, Zimmermann, & Piller, 2014; Rafiei & Rabbani, 2009). Although postponement is not a new concept, nowadays, it has captured worldwide attention in the scientific and industrial community (Tang & Chen 2009; Ferreira et al. 2015). According to Hoek (2001) the increase in his research implicates that the concept has been rediscovered and, therefore, the need to develop new questions over postponement arises.

Mass customization has also become a big interest topic in recent decades (Jiao, 2009; Zhao, He, & Wu, 2008). In this sense, Fogliatto et al. (2012) states that between 2001 and 2010, the literature on this topic has increased significantly. As a result, this model has begun to be considered as a productive strategy (Hoek, 2001; Zhao et al., 2008). According to Arroyo & Jimenez (2013), it will have a speculative growth and will become one of the most relevant productive trends in XXI century. Due to this, companies are starting to increasingly adopt this strategy (Qin & Geng, 2011; Zhou, Huang, & Zhang, 2014).

Over this subject, authors like JI et al. (2007), Qin & Geng (2011) and Wang et al. (2012) ensure that the key factor to achieve success in the implementation of mass customization and postponement, is the DP location. In this way, other authors like Liu et al. (2014) and Shidpour et al. (2014) state that for the implementation of these strategies, the most important work is the DP location.

For this reason, the concept of DP has received considerable attention in literature and research in the last few years (Sun et al. 2008; Liu et al. 2013; Ngniatedema et al. 2015). In addition to mass customisation or postponement, this concept has become an element of strategical interest (Ahmadi & Teimouri, 2008; Olhager, 2003).

1.5 Characteristics of the research

From the above, it is not only demonstrated that the research topic is a subject of global concern and is being heavily studied, but also the methodological, theoretical and practical value of the development of this research, is conceptualized. Therefore, it is expected that the development of the thesis becomes convenient for both business and academia sectors.

First of all, regarding the methodological and practical value, it is emphasized that the development of the thesis starts from the design of a flexible methodology that can be easily adapted to real contexts that suround the studio system. Thus, it is intended to provide a tool which, according to current market needs, can become useful for local and international contexts.

That is to say, from the needs of the companies, it is intended to develop a methodology that facilitates the DP location under a combination of qualitative and quantitive approaches and, additionally includes the participation of the experts to improve the degree of rigor when making decisions. Since, in this case, the decision is strategic and therefore requires taking into account the views and knowledge of experts in three hierarchy decision levels: operational, tactical, and strategic (Kundu, McKay, & de Pennington, 2008).

To prove its usefulness in the thesis development, two cases study are proposed in companies from Manizales, Caldas, Colombia. This process enriches the research, mainly due to existing differences in their production systems and the characteristics of the market in which they exist. In the first Stage, the company Herragro S.A is characterized by its high efficiency, while the company Muebles Marco Gómez, is characterized by its high flexibility. Despite the fact, both companies require from companies a balance which is currently missing, between flexibility and efficiency. This requires that the DP location allows balance in varying degrees, according to the company, the current conditions of the production system and the niche market demands.

With regard to the theoretical value, this thesis was structured from two main premises that validate its relevance. First, authors like Xu (2007), Xu & Liang (2011) and Shidpour et al. (2014) conclude that despite the importance of the DP location and the worldwide recognition this has had, it is necessary to increase the number of investigative contributions addressed to models, techniques, methods or methodologies that allow obtaining its location. Secondly, the state of art study shows that, despite the developed progress in the subject, there is a knowledge gap which claims to be solved through a research process. These two premises allow the demonstration of that this researching process as it contribute to the knowledge development, responding to a need for research identified in literature.

Regarding its epistemological characteristics, this research can be classified as a mixed approach for the nature of its collected data; these will be qualitative and quantitative. For this thesis, qualitative data will be collected through participation of the experts; while quantitative data will be collected through companies' statistical case studies. In accordance, it should be clarified that qualitative and quantitate information will be collected throught interviews in the two studies cases.

About the proposed classification by Hernández Sampieri, Fernández Collado, & Baptista Lucio, (2010) it is specified that the research process is a “nested or concurrent embedded design of dominant model” due to the most representative method, this quantitative and the qualitative method, although it is involved in research, does not have a dominant participation as in the other case.

Under the approach of Phillips & Pugh (1987) it is an applied research because it includes theoretical elements that can be used in actual cases. In this sense, the research is framed under the category of problem solving research, it starts from the identification of an actual-world problem and searches its solution through a research process.

The information presented so far, evindences how the research responds to a real need. Furthermore, it is structured in a clear research methodology. In accordance, the leitmotif of this thesis is designed to take the reader concurrently to the center point of the research without leaving out the theoretical elements that frames it. For this reason this thesis will be divided into three chapters: theorical framework, methodology, methodology application. From there, it seeks to lead the reader to understand the importance of the developing research and allow him/her to understand how the theory presents the necessary foundations to develop a multicriteria methodology and its application in actual cases.

In the first chapter, the theoretical framework of the research will be shown. The theoretical elements which frame the concepts of decoupling point will be exposed giving more information over the necessary topics in order to make up a multicriteria methodology which allows expert participation in the process. It is important to underline that in this part the revision of the state of the art will be shown and the knowledge gab which supports the investigation, will be identified.

The second chapter will explain in detail the designed methodology. This consists of seven steps which allow the adapting of the methodology according to the company´s characteristics and needs, leading to the selection of the DP from these characteristics. It is noteworthy that in this chapter, all the mathematical models necessary for the operation of the methodology will be displayed; so it is inecesarsary to repeat the same models in the theoretical framework.

In the last chapter, the results obtained from the two applications are showen. In this, it will be discovered in a summarized way, the most relevant results for each proposed step in the methodology. Even so, in the annexes will be exposed in a more complete way, the different results obtained in steps 3 and 4, in case the reader wants to delve more into the subject.

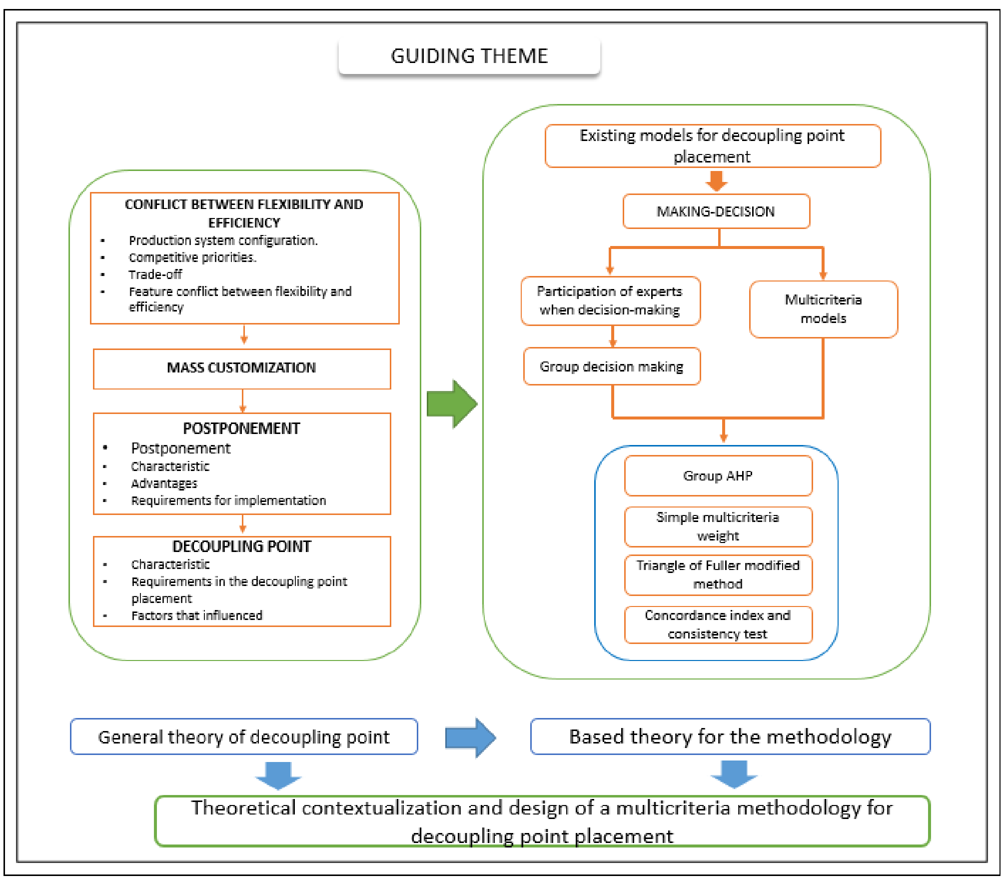
Besides the three main chapters, this document will end showing the conclusions of the research process, exhibiting the methodology limitations in a most critical way, and will propose new fronts that merit further research.

2. Chater 1 Theorical framework

With the objective of responding to the investigation problem, it is necessary to make an approach to the State of the art in the field of mass customization, postponement, decoupling point and the other necessary concepts to carry out the methodology.

As shown in Figure 2-1, the strategy utilized for this purpose was made up of two stages. In the first one, the aim is to make an approach to the general theory about the decoupling point in which a proposed solution is framed. In the second stage, a conceptual rapprochement was done on the necessary elements to make up the methodology. In this second one, the theoretical concepts involved in making up the multicriteria model and the concepts of the expert participation when making decisions is analyzed.

Figure 2-1: The guiding theme of the strategy to make up the theoretical framework.



The relevant information, to set up the theoretical framework, was collected from a systematic literature review and narrative review in the bibliographic tools ISI *Web of Science and Scopus.* This process was applied in the titles, keywords and abstract; for this purpose, the range time was not considered in order to do a complete analysis.

2.1 The decoupling point, a strategical decision for the current market conditions

2.1.1 The current market

Industrialization was originated in the early 1920's (Harmsel, 2012). This period was affected by changes in the old paradigm and changes in production systems. One example of this topic were the changes generated by Henry Ford who, with the aim of reducing production costs, revolutionized the concept of assembly lines (Di Pierri D, 2006; Selladurai, 2004); giving origin to the traditional production approach called mass production (Heinung, 2011).

Mass production allows companies to reduce production costs through economies of scale (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013; Grabot, Vallespir, Gomes, Bouras, & Kirirsis, 2014; Kotha, 1995; Selladurai, 2004). Economies of scale are obtained by product standardization (Gutierrez, Jiménez Partearroyo, & Heredero, 2015) and/or production system automatization (Coletti & Aichner, 2011).

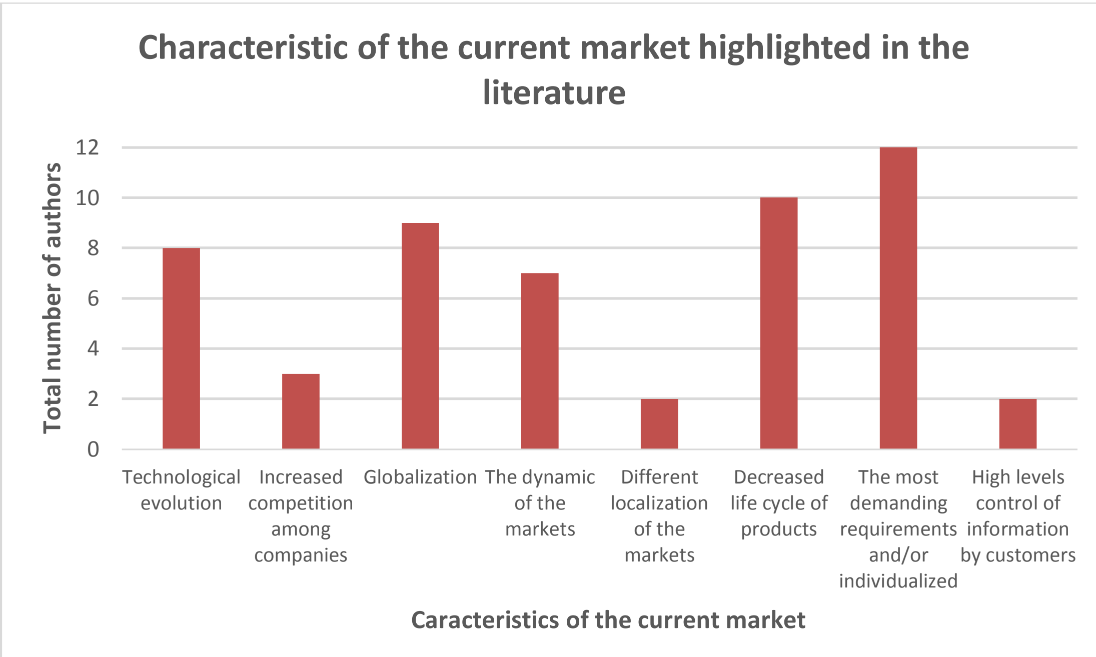
In this case, high-volume product should be manufactured by standardization (Gutierrez et al., 2015; Lin, Shi, & Wang, 2012). Subsequently, inventory was stored in high volume with the aim of meeting consumer demand on time, through cost leadership approach (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013; Gutierrez, Jiménez Partearroyo, & Heredero, 2015).

The high-volumes, which should be supported in production systems, underscores the necessity for companies to compete with big markets where they can take advantage of the economies of the scale (Di Pierri D, 2006). Nevertheless, the current literature concludes that there are some big changes in markets and perceptions of the clients which makes the achievement of this paradigm difficult (Nahmens, 2007).

The revision of the different authors, summarized in the Annex C, says that the changes in the current markets make the application of mass production difficult. As can be seen in Figure 2-2, these characteristics are: 1. Technological evolution, 2. Increased competition among companies, 3. Globalization, 4. The dynamics of the market, 5. Different localization of the market, 6. Decreased life cycle of products, 7. The most demanding requirements and/or individualized, 8. High levels control of information by customers.

It must be understood that these changes in the current markets have caused the power relationship between sellers and consumers to be modified, resulting in the strengthening of the position of consumers in the markets (Di Pierri D, 2006) and additionally, exasperating the imprecision and the difficulty in the relationship among competitors (Liu, Wang, & Liu, 2011).

Figure 2-2: Characteristics of the current markets.



This is to say, the new freedoms which have been acquired by customers and the fluctuating and highly competitive business environment have increased market complexity which typically have allowed customers to get the opportunity to select what they want it, how they want it , when they want it and where they want it (Ferreira, Tomas, & Alcântara, 2015; Muriel, Anand Somasundaram, & Yongmei Zhang, 2006; Di Pierri D, 2006). In this way, customers are no longer satisfied with the quality of the products, low costs and low production time offered by the traditional approach, but also, they require that the products are customized (Can, 2008; Kumar, 2007; Rudberg & Wikner, 2004; Stojanov & Ding, 2015; Suh, Cho, & Rim, 2011; Xiong, 2012).

The heterogeneity of markets, the globalization and the increased customer power have not only generated competitive challenges that the companies have been facing, but also have forced them to improve the innovation processes (Piller, Harzer, Ihl, & Salvador, 2014). Furthermore, they have caused companies to face volatile and unpredictable markets (Huang & Liang, 2008; Mourtzis, Doukas, & Psarommatis, 2015; Y Zheng & Mesghouni, 2011; Yahong Zheng & Mesghouni, 2011). Thus, the accuracy of sales forecasts has been decreased and the complexity of the production planning has been increased (Swaminathan, 2003; Wong, Potter, & Naim, 2011; Yang & Burns, 2003).

As a result, higher support costs for production increases in the complexity of the manufacturing and increases the risks in the processes and the risks of inventory are suffered (Can, 2008; Swaminathan & Lee, 2003). These difficulties are reflected in the increased price and decreased lead-time (Can, 2008); that means, poor competitiveness and a disadvantageous level of prices which limits the company managment (Jiang, 2012).

Clearly, current manufacturing is facing challenges that force companies to care more about setting up competitive strategies that are adapted to new market conditions (Liu, Wang, & Liu, 2011; Manupati, Deepthi, Ramakotaiah, & Rao, 2015; Modrak, Marton, & Bednar, 2015; Yang, Tian, & Li, 2007). In this way, companies should find the way to be able to satisfy each customer requirement (Can, 2008; Silveira, Borenstein, & Fogliatto, 2001); but at the same time, they must keep efficiency throughout the process (Stump & Badurdeen, 2012).

2.1.2 Flexibility and efficiency in the production system

The business strategy is the main decision which addresses company design and how it faces competition (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013; Sandrin, 2014). Hence, in current markets, the selection of the business strategy is not enough by itself because in the industrial companies the manufacturing strategy has a very important role (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013).

Manufacturing strategy is the way industry deploys its manufacturing resources of a long-term plan to use them effectively and support the business strategy (Sun & Hong, 2002; Vivares, Sarache, & Valencia Naranjo, 2013; Vivares-Vergara, Sarache, & Naranjo-Valencia, 2015). According to Miltenburg, (2009), manufacturing strategy allows companies to move away from where they are to where they want to be. To that end, it is necessary that manufacturing strategy is not only aligned with the business strategy but also that it has the capacity to solve the current requirement which, through the traditional approach, represents a challenge for the configuration of the production system (Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013).

The design of the production system includes considering the interactions presented in the machines, the workers, the infrastructure and the different control rules (Luft & Besenfelder, 2014). Therefore, this design is a critical and complex labor because it must take into account economics, financial, technological, administrative and human criteria and additionaly the customer expectations (Greschke, Schönemann, Thiede, & Herrmann, 2014; W Terkaj, Tolio, & Valente, 2009). Both the development of the manufacturing strategy and design of the production system are related to the selection of competing priorities (Kumar, 2007; Li, Zhang, Tian, & Ding, 2010).

These competing priorities denote the strategic focus of the company. This means that the objective of the production system with which the positioning of the company in the market will be improved (Boyer & Lewis, 2002; Vivares, Sarache, & Valencia Naranjo, 2013). As shown in Table 2-1, the number of the competing priorities, which are used by the authors, may vary. Nevertheless, and according to Miltenburg (2008), one of the reasons is the level of analysis which the researcher wants to have.

Table 2-1: Competing priorities used in five articles.

Author	Number of Priorities	Competitive priorities referenced by author
(Filippini, Forza, & Vinelli, 1998)	4	Cost, time, quality and flexibility
(Olhager, 2003)	4	Price, quality, delivery speed and delivery reliability
(Yang, Tian, & Li, 2007)	4	Cost, flexibility, quality and delivery
(Miltenburg, 2009)	6	Cost, quality, delivery, service, flexibility and innovation
(Choudhari, Adil, & Ananthakumar, 2012)	5	Cost, quality, delivery reliability, speed of delivery, flexibility and innovation
(Avella, Vazquez-Bustelo, and Fernandez 2014)	4	Quality, delivery, flexibility and cost efficiency
(Singh et al. 2015)	5	Cost efficiency, quality, delivery, flexibility and innovation
(Vivares-Vergara, Sarache, and Naranjo-Valencia 2015)	6	Cost, quality, flexibility, delivery, service, environmental protection

Source: my elaboration

For this thesis, and responding to the characteristics and current market requirements, two competing priorities: flexibility and efficiency will be work with. Efficiency is to obtain the results and the utilization of resources (Saruliene and Rybakovas 2012), therefore, efficiency is directly related to cost and time (Kortmann et al. 2014). Using the classification given by Miltenburg (2009) and (Vivares-Vergara, Sarache, and Naranjo-Valencia 2015), efficiency is related to cost and delivery.

On the other hand, the flexibility can be defined as the ability to adapt to major internal and external changes (Dalrymple and Spring 2000; Mourtzis, Alexopoulos, and Chryssolouris 2012; Saruliene and Rybakovas 2012); but it should be in a fast way and with a low cost (Luft and Besenfelder 2014; Mapes 2002; Metternich et al. 2013; Vickery et al. 2015).

In accordance with Miltenburg (2009), taking into consideration the technological restriction, it is possible only to find seven different production system configurations: job shop, batch flow, operator-paced line flow, machine-paced line flow, continuous flow, just in time (JIT) and flexible manufacturing systems (FMS). Job shop, batch flow, linear and continuous flow are used generically in the literature (Choudhari, Adil, and Ananthakumar 2012).

The strategy value of those configurations is that each of those have the capacity to respond to different degrees to customer expectations. According to this, each configuration can provide a unique variety of products and a certain amount of products, as well as a unique combination of competing priorities (Miltenburg, 2009). Similarly, production capacity can influence the result obtained from the production system (H. Garbie

2014; Miltenburg 2009). However, the increase of production capacity can jeopardize profitability (Greschke et al. 2014).

Through a traditional strategy vision, set up by Porter (1980), it is inconsistent to simultaneously obtain mass production and customization (Gutierrez, Jiménez Partearroyo, and Heredero 2015). Hence, it represents a conflict between flexibility, attributed to offer variability, and efficiency, attributed to the economics of the scale with high-volume (Fogliatto and Silveira 2011).

It is important say that the first five production systems, which were previously mentioned and considered traditionally as the most effective have the capacity to generate competing priorities in combinations which are related to mass production or customization (Arroyo-Gutiérrez and Jiménez-Partearroyo 2013; Fogliatto and Silveira 2011). Because a configuration tries to satisfy both requirements, it is a clear strategic disadvantage (Arroyo-Gutiérrez and Jiménez-Partearroyo 2013).

For example, the linear and continuous flow system can generate high-volume and low costs (Arroyo-Gutiérrez and Jiménez-Partearroyo 2013), but this configuration cannot offer flexibility, so it cannot respond in a particular way to the requirements of each customer (Squire et al. 2006). In contrast high levels of flexibility, which the configuration like Job shop can obtain, are not free and that is why it causes the increase of the cost and time in the process (Alford, Sackett, and Nelder 2000; Duray et al. 2000; Fogliatto and Silveira 2011; Squire et al. 2006).

In this sense, traditional systems do not always represent the more effective solution to face the new context of production (Walter Terkaj et al., 2009). As a result, these systems are incapable of providing flexibility and efficiency simultaneously (Kortmann et al. 2014; Lin, Shi, and Wang 2012; Heinung 2011; Manupati et al. 2015). Therefore, it is necessary to design production systems which integrate flexibility and efficiency at appropriate levels (Terkaj, Tolio, and Valente 2009).

This new context has opened the doors to the mass customization (Rudberg and Wikner 2004). The literature and real examples suggest that mass customization is the end of the conflict between customization and other competing priorities like efficiency (Lin, Shi, and Wang 2012; Squire et al. 2006; Stump and Badurdeen 2012). It is contemplated as an innovative solution which is convenient to customers and companies (Gutierrez, Jiménez Partearroyo, and Heredero 2015; Selladurai 2004). In effect, mass customization has become a company requirement if they want to offer customers products (Tseng, Hu, and Wang 2013; Wong, Wikner, and Naim 2010) and in addition, if they want to achieve low costs and short lead-times (Fakhrizzaki and Yasin 2010; Liu, Wang, and Liu 2011; Zhou, Zhang, and Zhou 2013).

2.1.3 Mass customization, the paradigm of current markets

The concept of mass customization was created in the early 1900's by Toffler (1971) and, according to Frutos & Borenstein, (2004) and Shen, Nie, Yuan, & Yang, (2010), later emerges as a production model by Davis, (1987). Subsequently, Pine, (1993) popularized the concept when he defined it as a strategy which involves the customer in the production system (Boër et al. 2013; Fakhrizzaki and Yasin 2010; Modrak, Marton, and Bednar 2015; Mourtzis, Doukas, and Psarommatis 2015).

This strategy emerged from natural processes caused by changes in the market (Gutierrez, Jiménez Partearroyo, and Heredero 2015; Silveira, Borenstein, and Fogliatto 2001). It breaks away from the paradigm of mass production (Di Pierri D 2006). From this point, the definition of the concepts has captured the attention of the researchers (MacCarthy, Brabazon, and Bramham 2003). Even so, there are a lot of different definitions (Can 2008; Suh, Cho, and Rim 2011; Xiong 2012); consistent with Coletti & Aichner (2011, p.21) that has caused numerous disagreements.

Therefore, many researchers have raised different approaches; some of which define mass customization as a concept which should be applied only in product (Coletti and Aichner 2011). But like this definition there are others that do not consider the interconnection among mass customization, manufacturing strategy and value proposition and generation (Gutierrez, Jiménez Partearroyo, and Heredero 2015; Modrak, Marton, and Bednar 2015).

Some definitions taken from the analysis of the literature are shown in the Annex D. From this point on, mass customization is defined as the strategy which allows companies to offer markets custom products that customers want, and in the quantity that the customers want, simultaneously keeping low costs and short lead-times.

This definition already considers mass customization's capacity to generate value and provides companies competitive advantage and improve their performance (Gutierrez, Jiménez Partearroyo, and Heredero 2015; Watcharapanyawong, Sirisoponsilp, and Sophatsathit 2011; Zhang et al. 2015). These results are obtained through the high-volume of production, the short time and the flexibility in the process (Giovannini et al. 2013; Salvador, Rungtusanatham, and Madiedo Montanez 2015).

This new paradigm has become a reality for many industrial companies, due to the presence of new market requirements and technology constraints (Boër et al. 2013; Chuang and Su 2011; Grabot et al. 2014; Stump and Badurdeen 2012). Simultaneously Joanna Daaboul, Da Cunha, Bernard, & Laroche, (2011) conclude that mass customization has become the leading strategy in which the customer satisfaction is achieved. Consequently the companies which face dynamic markets and changes in customer requirements regardless of size, meet the conditions (Pine II and Victor 1993) and have the necessity to implement mass customization (Di Pierri D 2006; Tseng, Hu, and Wang 2013).

In contrast to mass production, mass customization has the potential to generate high-volume production and offers simultaneously personalization in the products (B. Dong et al. 2012; Duray et al. 2000; Liao, Deng, and Marsillac 2013; Sandrin 2014; Shen et al. 2010). One of the great achievements of this strategy is that from an early of product development, it takes advantage of economies of scale (Can 2008; Jørgensen and Hauschild 2014; Xiong 2012) and economies of scope (Y. Dong et al. 2010; Harmsel 2012; Tseng, Hu, and Wang 2013).

Considering that the needs and requirements of products and processes are growing all the time (Chuang and Su 2011), it is important to develop production systems and products according to information and customer expectations (Jiao and Tseng 2004)(Gutierrez, Jiménez Partearroyo, and Heredero 2015). Despite the great opportunities that are given by this strategy, there are also accompanied by limitations, and there are not always the best alternative (Daaboul, Bernard, and Laroche 2012; Hart 1995; Trentin, Forza, and Perin 2012; Zipkin 2001). Therefore, this strategy must be implemented carefully (Salvador, Holan, and Piller 2009).

This is to say, it is necessary that companies ensure that the additional benefits are bigger than the cost overruns on personalization (Gutierrez, Jiménez Partearroyo, and Heredero 2015). Taking into account these risks and limitations, the literature shows a different strategy which is related to mass customization and, additionally, has shown great results (Nahmens 2007). About this subject, it must be understood that each strategy has characteristics that can strategically enable its application in different external and internal contexts.

Despite this, for the perspective of process design, postponement has been taken into consideration as a very important methodology which contributes to the achievement of mass customization (Brun and Zorzini 2009; Jørgensen and Hauschild 2014; Liao, Deng, and Marsillac 2013; Qin 2011; Wong, Wikner, and Naim 2010). Consequentially, some authors affirm that postponement is one of the principal strategies or characteristics of mass customization (Chuang and Su 2011; Kisperska-Moron and Swierczek 2011; Zhang et al. 2010).

According to Chuang & Su (2011), once the level of mass customization has been determined, the adequate postponement is proposed. On the other hand, Swaminathan (2003) and Wikner & Wong (2007) agree that postponement is a powerful way to obtain the personalization without any disadvantage from high operation costs associated with product proliferation. Additionally, postponement positions itself as a best alternative to implement when markets have high uncertainty (Tseng, Hu, and Wang 2013).

2.1.4 Postponement, a strategy which seeks to balance flexibility and efficiency

Postponement is a concept which was incorporated into the literature by Alderson (1950). It is defined as an element of mass customization implemented for giving a better experience and quality to customers; all of these foster a balance between flexibility and efficiency (Brun and Zorzini 2009; Chuang and Su 2011; Qin 2012; Saghiri and Hill 2014; Skipworth and Harrison 2006). It is especially useful when the fluctuation of the market impedes the establishment of the final inventory levels in accordance with customer requirements (Cheng et al. 2010; Ferreira, Tomas, and Alcântara 2015; Kumar and Wilson 2009).

In this respect, postponement can adapt easily and can reduce the risks associated with the market uncertainty. In that way, the production costs and inventory levels can be reduced (Jørgensen and Hauschild 2014; Ngniatedema, Fono, and Mbondo 2015; Saghiri and Hill 2013; Tseng, Hu, and Wang 2013).

The general concept of this strategy is to delay the production or the service until customer demand is known precisely; this happens when the customer order is already sent (Brun and Zorzini 2009; Wong, Wikner, and Naim 2010). With this concept, activities like: distribution, packing, labeling, assembly and manufacturing can be postponed (Huang and Liang 2008; Yang and Yang 2010). In this way, companies can respond to customer needs opportunely and reduce costs, losses and obsolescence of the inventory (Ji and Sun 2011; Liao, Deng, and Marsillac 2013; Heinung 2011; Wadhwa et al. 2008).

Different categories of postponement are featured in the literature (See Annex E). Even so, these features can be grouped into two categories: logistics postponement and form postponement (Wong, Wikner, and Naim 2010; Zhou, Huang, and Zhang 2014). Place postponement and time postponement are part of logistics postponement (Jørgensen and Hauschild 2014); and labeling, packaging, assembly, manufacturing and production are part of form postponement (Chuang and Su 2011; Guericke et al. 2012; Jørgensen and Hauschild 2014; Yohanes 2008). The classification depends on the products, the process, the technology and the market (Ferreira, Tomas, and Alcântara 2015).

In the particular cases of production postponement products have a high number of derivative references and the market requirement is solved by increasing customer penetration into the production system (Yang, Burns, and Backhouse 2004). Thus, the implementation of production postponement directly influences the production system (Rodrigues, Marins, and De Souza 2011), and it demands products according to the strategy (Hsuan Mikkola and Skjøtt-Larsen 2004).

In this respect, there are two concepts that allow application of production postponement; modularization and the decoupling point (DP) (Ahmed and Mohammed 2010; Dong 2010; Purvis, Gosling, and Naim 2014; Saghiri and Hill 2013; Suh, Cho, and Rim 2011). Modularization is the design of the products and the process through independent parts in such way that it can solve customer needs with the assembly of standardized parts and/or the differences in the process (Brun and Zorzini 2009; Chuang and Su 2011; Harmsel 2012; Jørgensen and Hauschild 2014).This approach allows a rapid and innovative change in the system (Vickery et al., 2015).

Moreover, the decoupling point represents a strategic break from the production system into two segments (Lin, Shi, and Wang 2012). The first one responsible for the production of standardized parts (with a push approach) and the second one responsible for the personalization (with a pull approach) (Hoek 2001; Huang and Liang 2008). All of these satisfy the necessity to respond to the conflict between flexibility and efficiency (Choi, Narasimhan, and Kim 2012; Purvis, Gosling, and Naim 2014; Yao 2011).

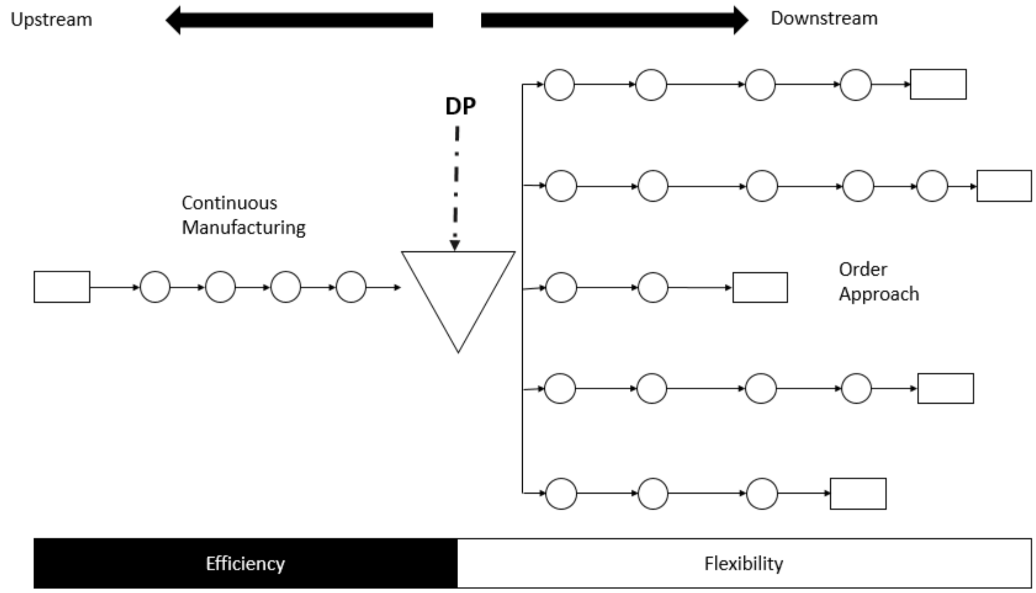
The direct dependency of the postponement strategy with the decoupling point has caused it to be considered as the most important concept and decision of production (Lin, Shi, and Wang 2012; Tang and Chen 2010). In agreement with Zhou et al. (2013) companies have increased their interest in incorporating the decoupling point as an important decision in the design of the strategy; all of these with the aim of maximizing the efficiency of the implementation of postponement.

2.1.5 The importance of decoupling point placement

The decoupling point placement is not only a meaning for decision for the postponement implementation, but also it is the first initial phase because this placement determines the position from which the application of postponement is structured and, additionally, it checks if the designing methodology can be applied to the postponement implementation (Ferreira, Tomas, and Alcântara 2015; Yang and Burns 2003).

The decoupling point is considered, in the literature, as the physical designation of work in process from where the production system is managed through two approaches: pull, located downstream and push, located upstream (Hemmati, Rabbani, and Ebadian 2009; Liu et al. 2013; Rafiei and Rabbani 2011; Wang et al. 2012). As it can be seen in Figure 2-3, from this point on, postponement faces the conflict between flexibility and efficiency. This divides the production system into two sub-systems: the first one, downstream of the DP which is responsible for the flexibility; and the second one up stream of the DP which is responsible for the efficiency.

Figure 2-3: Schematic representation of Production postponement.



Source: my elaboration

As show in Figure 2-3, beginning with this point the postponement faces the conflict between flexibility and efficiency. It means, through the segmentation of the production system into two sub-systems, the first one downstream of the decoupling point which is responsible for flexibility and the second one up stream of the decoupling point which is responsible for efficiency, can balance both flexibility and efficiency requirements (Kortmann et al. 2014; Olhager 2003; Rudberg and Wikner 2004).

According to Chuang & Su (2011) and Liu et al. (2014) the placement of the decoupling point is the success factor in the postponement strategy because it defines the optimal balance between efficiency and flexibility (Rudberg and Wikner 2004; Yang and Burns 2003). As is shown in the Figura 2-3, the location of this point determines which processes will work through inventory approach (up stream of DP) and which ones will work through an order approach (downstream of DP) (Olhager 2010; Qin 2011; Tien 2011).

Depending on the process which is divided by the decoupling point, the literature offers different classifications (Chuang and Su 2011; Fogliatto, Da Silveira, and Borenstein 2012). With an analysis of approach classification, depending on the division given by different authors (See Annex F), the Table 2-2 was make up. The designation based on the position of the decoupling point in the production system.

Table 2-2: Production approach depending on decoupling point placement.

Focus	Definition
Engineer to order	Personalization occurs after the design production process.
Purchase to order	Personalization occurs after the purchase of raw materials process.
Manufacture to order	Personalization occurs after the manufacturing process.
Make to order	Personalization occurs after the assembly process or the finals process of the production systems.
Packing to order	Personalization occurs after the packing process.
Continuous manufacturing	It occurs when there is not personalization process in the systems and the production planning is set up through the markets forecast.

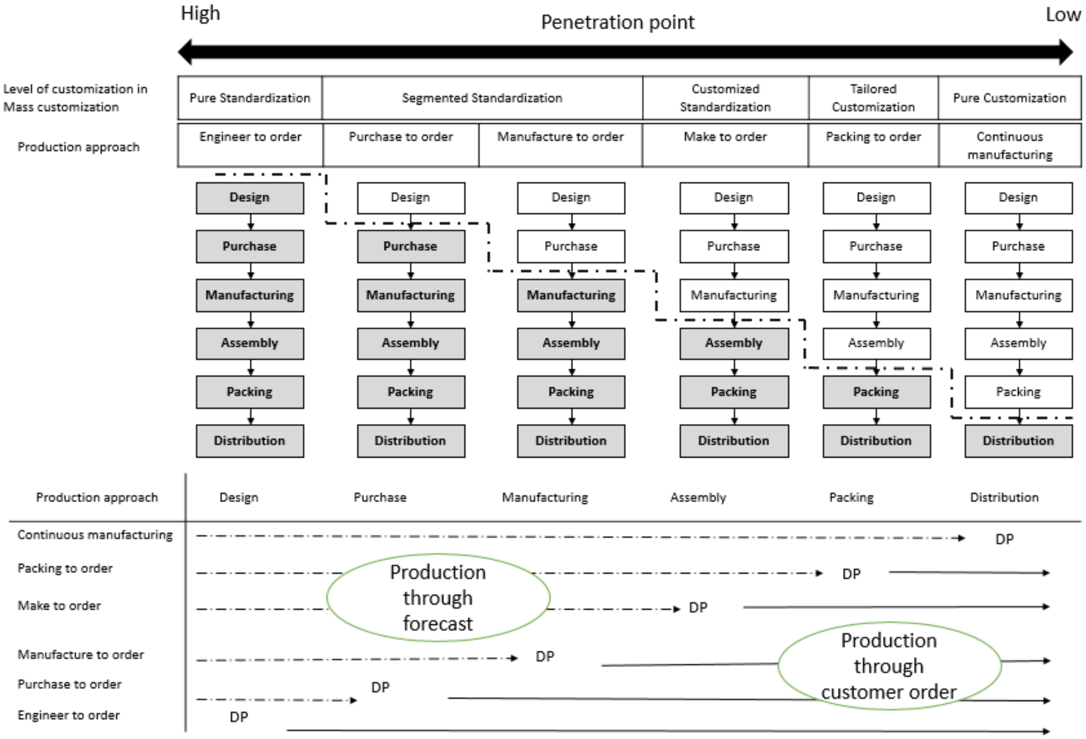
Source: Source: my elaboration with contributions of the Annex F

In referring to Table 2-2, it is necessary note that order approach (Pull) does not begin the process until the customer order has come (Jørgensen and Hauschild 2014; Muriel, Anand Somasundaram, and Yongmei Zhang 2006). As long as the inventory approach (Push) have high inventory of WIP (work in progress) and it works through markets forecast (Jørgensen and Hauschild 2014; Rafiei and Rabbani 2011; Wong, Wikner, and Naim 2010).

This is to say, and as shown in the Figure 2-4, the decoupling point is related to the influence level of the customer in the production process and, therefore, the level at which the strategy is aligned with the market requirements (Donk and Doorne 2015; Fogliatto, Da Silveira, and Borenstein 2012; Modrak, Marton, and Bednar 2015; Sandrin 2014). Consequently, it is assigned the efficiency and flexibility levels that the production system will have; providing a competitive mix of these priorities that respond to necessities of cost, time and personalization of the products (Qin and Wei 2012).

In this respect, authors as Xu (2007), Xu & Liang (2011) and Shidpour et al. (2014) expose the necessity to increase the number of research contributions about models, techniques, methods and methodologies which help the decoupling point placement. Then they say, although the topic is important, such contributions are lagging. It is necessary to say that the decoupling point localization is a strategy decision which involves the product, process and market characteristics (Brun and Zorzini 2009; Olhager 2003; Swaminathan 2003; X. G. Xu 2007; Yang and Burns 2003). Therefore, the investigation has been focused on integrating these requirements in the decision made.

Figure 2-4: Implication of the decoupling point placement in the production system.



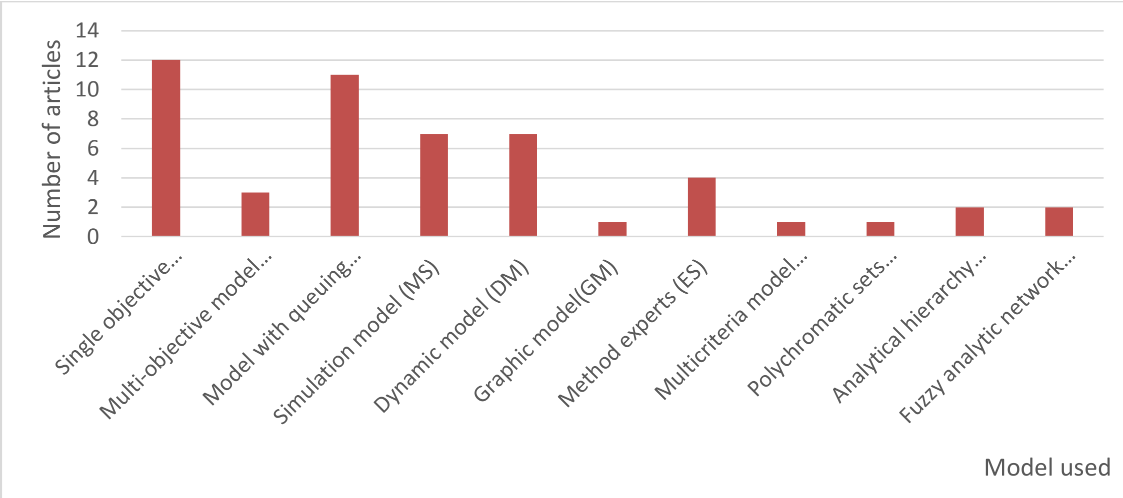
Source: Source: elaboration through contributions of Olhager (2003), Harmsel (2012) y Chuang & Su (2011)

2.2 The decision made and the roll of the multicriteria models

The importance which the decoupling point localization has is the source of interest which addressed the research process mentioned in this thesis. Therefore, then, the state of the art analysis of this topic is exposed from which a knowledge gap is discovered that this thesis has helped to solve. After, the theoretical relevant information to make up the methodology, according to the detected requirement, is summarized and documented.

A systematic literature review undertaken in the present thesis identified 46 papers addressing this problem. In general, the identified solution methods can be grouped into the following categories (See Annex B): Single objective optimization (SO), multi-objective model (MO), model with queuing theory (QT), simulation model (MS), dynamic model (DM), graphic model (GM), method experts (ES), multicriteria model based on entropy technology (ME), polychromatic sets theory (PST), analytical hierarchy process (AHP) and fuzzy analytic network process (FANP). Additionally, as is shown in Figure 2-5, it was identified that there is a major representatively in the quantitative approach. In this case, the user model is the single objective optimization, followed by the queuing theory, simulation model, and dynamic model.

Figure 2-5: Classification of the articles reviewed according to its model.



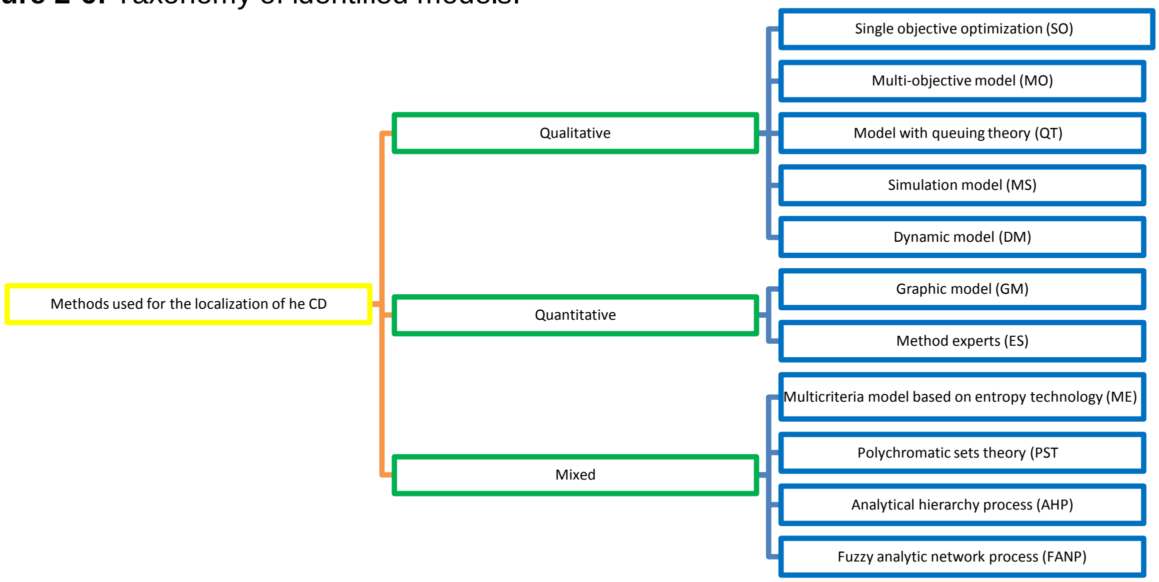
Source: my elaboration

Based on these results, the different types of models were grouped according to their approach. They are quantitative, qualitative and mixed. A graphic scheme of this aggrupation is shown in the Figure 2-6. For the case of the quantitative approach, Single objective optimization (SO), multi-objective model (MO), model with queuing theory (QT), simulation model (MS), dynamic model (DM), it is highlighted that they are not necessarily mutually exclusive because the implementation of one model does not imply the absence of the other one.

For example, a model with queuing theory also could be single objective optimization, which implies that this model should be considered on both categories. Even so, it has been decided to use this aggrupation with the objective to analyze these models in detail, and can view their differences.

In contrast, the graphic model (GM) and the method experts (ES) are classified in the qualitative approach in which the expert participation is prioritized when making decisions. In the last case, the multicriteria model is grouped based on entropy technology (ME), polychromatic sets theory (PST), analytical hierarchy process (AHP) and fuzzy analytic network process (FANP) in a mixed approach. This decision is because these models allow the inclusion of qualitative and quantitative variables for the decoupling point localization.

Figure 2-6: Taxonomy of identified models.



Source: my elaboration

2.2.1 Analysis of the identified models

The implementation of production postponement, moreover being a strategical decision, it implies the existence of uncertainty in the market analysis, in the markets forecasts and in the management and control of the production (Ferreira, Tomas, and Alcântara 2015). Having this in mind and from the checking and analysis of the state of the art, different characteristics presented in the models were identified that address the knowledge gap detection.

The quantitative models are mathematical constructs that represent the relation among different variables in which it is intended to study the systems behavior (Bangert 2012; Murty 2010). This kind of analysis starts from the representations of the quantities, physically measurable, through symbols (Murty 2010).

One of the most common types used is the Single objective optimization (SO). It is set up through a function of maximization or minimization, linear or not linear. All of this depends on the complexity level which the research wants (Zakaria et al. 2012). Even so, and due to the limitatios of studying a complex system, the researchers have found better opportunities, to study the reality, with the multi-objective model (MO) (Chand and Wagner 2015).

Another detected category was the model with queuing theory (QT). This model is centered on the mathematical study of the time out on the production lines. This means, it analyzes different process as the arrivals order to queues, the waiting time in the queues and the lead time. With this the measures of the production system behavior are obtained and, consequently, its studies and analysis are more easily attained (Cruz and Van Woensel 2014; Li and Zhang 2015).

Additionally, there are a lot of real optimization problems that are subject to dynamic phenomena impossible to eliminate in the practice (Siarry 2013; Yang and Yao 2013). As a result, a lot of systems to be studied change, in different levels, over time (Bui and Alam 2008). At this point, the static models become limited and the dynamics models become to have greater preponderance. This last one is a mathematical structure with Single objective optimization (so) or multi-objective model (MO) approach which has the special distinction of changing over time (Friesz 2010; Zhou et al. 2011).

Moreover, the simulation model (MS) is an informatics tool which is based on mathematical models of the system to make changes and analyze its behavior. Hence, the simulation based on optimization models is a tool which has become popular and allows solving of the different problems with the computer Software (Musa, Arnaout, and Frank Chen 2012).

Despite the high versatility and high representativeness of the quantitative alternatives, in the literature it is shown that different limitations that jeopardize its operation in a complex systems and in the strategical decision making in companies. According to Kasperski (2008), the main weakness of the deterministic models is that they do not consider the possible relationship among the incoming dates. Therefore, the results could be unacceptable in a complex and uncertain atmosphere.

For Chand & Wagner (2015), another difficulty in the optimization models is the level of the physical and computational resource which is required to the analyze and the study of the complex systems (Zhou et al. 2011). This difficulty can cause the local optimal result found by the heuristics is nothing more than a poor result or, worse, that the global optimal result does not exist (Bangert 2012; Siarry 2013).

Although the stochastic formulation allows the reduction of the impact of the uncertainty in the studies, in this case, the models which have an inaccurate date, force the researchers to make multiple assumptions that limit the analysis of the real system conditions (Kasperski 2008). Furthermore, one of the main limitations of the quantitative models is that it does not involve qualitative variable in its process. And according to Saaty (2008), the manufacturing decision involved many intangibles that require careful handling.

In a second instance, the qualitative models, identified in the systematic revision of the literature, is structured through the active participation of the experts when making decisions. This offers great advantages because, in an agreement with Perera et al. (2012) and Pereira et al. (2015), working adequately with the experts knowledge can help reduce the uncertainty level in the process.

Nevertheless, involving only experts when making decisions has several limitations. For example, the disagreements among experts can cause different results in the study (Yu 1973). Additionally, the group decision is a more complex process than the individual decision; because there is the possibility that the experts have conflicts over their personal objectives, inefficiency in knowledge, difficulties in the validation of information and different perceptions and opinions (Rigopoulos, Karadimas, and Orsonni 2008). Nonetheless, leaving the strategy alternatives analysis to only one person is a risk because in big problems the individual’s analysis capacity would be limited (Herrera, Herrera-Viedma, and Verdegay 1997).

Furthermore, the mixed approach allows the inclusion of the evaluation of qualitative criteria and quantitative criteria present in the system both together. In this way, it is expected to decrease the levels of risk attributed to internal and external uncertainty and to the complexity of the system studied (Mendoza and Martins 2006).

One example of this approach in polychromatic sets theory (PST). This is a mathematical structure composed by a collection of mutually exclusive elements (Liu, Wang, and Fu 2009). In this case, the picture is a character which allows the differentiation the each element; therefore, allowing the description of the set and elements characteristics and, additionally, the relationship of all its elements (Gao et al. 2006; Li, Xu, and Zhao 2006; Xu et al. 2005). It is necessary have in consideration that, this is a model which includes qualitative and quantitative criteria, but it does not consider the relative weight for each criterion which implies that it is not possible to assure that the model will be adapted completely to the system.

In the particular case of multicriteria model based on entropy technology (ME), the criteria relative weight is set up through the certificated dates dispersion level (Chen et al. 2013). It means this model allows the criteria weighting to be detected through a mathematical function which analyses the characteristics of the data assigned to each criterion. Hence, this model, in the evaluation of the representativeness of the criteria, leaves out the expert opinion (Wang, Wang, and Feng 2011).

Furthermore, it highlights the model which allows involving the expert judgment. For example the AHP; in general terms, is a multicriteria model used to make the decision in which the criteria weight is obtained through paired comparisons (Wicher & Lenort, 2014). As long as the criteria quantification could be set up through statistical records or fundamental scales that reflect degrees preferences (T. L. Saaty 2008; T. Saaty and Vargas 2001).

In contrast, the ANP, which is an AHP generalization made up by Saaty, takes into consideration the possible relation among the different criteria and it does not take into consideration unidirectional hierarchies (Saaty 2008b). With respect to the ANP method, it is highlighted that although this one has a greater generality in its studies and has more accurate results, its application is more laborious and requires more time than the AHP (Kangas and Kangas 2005; Wicher & Lenort 2014).

Another alternative, of the AHP and ANP models, is the inclusion of fuzzy theory (Ayağ and Özdemir 2009; Mikhailov and Singh 2003). The models fuzzy AHP and fuzzy ANP preserve the general characteristics of their referential models but it modifies the ponderation scales, all of this with the objective of decreasing vagueness in the judgements of experts (Mohanty et al. 2005). In this new scale, the expert must give a triangular judgement about some factor, assigning three different values to the same comparison criteria (Dağdeviren and Yüksel 2010). Nonetheless, in agreement with Saaty & Tran (2007), the implementation of fuzzy set theory in this model not only increases the complexity of the valorization, but also it omits the simplicity and elegance with which the judgment is represented through the fundamental scale.

In spite of the different individualized limitations shown in this study which could be assigned to each multicriteria model, it is highlighted as a common factor the limitation participation of the expert in the process. In this regard, the multicriteria model based on entropy technology (ME) and polychromatic sets theory (PST) are characterized by the absence of the participation of experts; while, for the case of the models analytical hierarchy process (AHP) and fuzzy analytic network process (FANP), although these have the capacity to include group experts in their process in the articles, analyses in this thesis, evidence of the use of this alternative was not detected.

This implies that the application of these multicriteria models require that the expert understands completely the behavior of the entire system to set up a precise judgment; in which clearly could be demanding and engaging to be made by just one person (Herrera, Herrera-Viedma, and Verdegay 1997). Therefore, the limitation of not considerating the judgment of different experts conditions the decision that could be made through some of these models (Saaty 2008b).

Additionally, Saaty (2008a) suggests that the best alternative to decreasing the different risks, which the models AHP and ANP have, is through the collaborative work of experts; all of whom are searching for coupling the different knowledges of the greatest number of experts who are involved in the systems. Thus, the quality, consistency and pertinence of the process information is increased.

On the basis of the above mentioned it is identified that although there are different models, it is necessary to make up a methodology with a view to finding the decoupling point location, which allows not only the inclusion of qualitative and quantitative criteria, but also allows a more active participation of the expert when making decisions.

2.2.2 Decision making

Making a decision is a structured process which allows solving problems through the analysis of the information. Among companies, this process has a critical character to decrease cost and the companies projects and strategies success (De Almeida et al. 2015; Dowlatshahi, Karimi-Nasab, and Bahrololum 2015). Because of this, and its relevance to the real world, the decision making has become in an interesting research topic presented in the literature (Merigó, Palacios-marqués, and Zeng 2016)**.**

This process is affected by three main aspects: the alternatives, the criteria and the decision makers (Zarghami and Szidarovszky 2011). Initially, the alternative is the models solution space. Accordingly, when it is discreet it is because there is a limited number of alternative, while it is continuous it is because there is an infinite alternative (Triantaphyllou & Mann 1995; Zarghami and Szidarovszky 2011).

The second aspect, the criteria are the characteristics or requirements that the alternatives must fulfill in acceptable degrees. These criteria are used to measure the relevance of each alternative for the objective to achieve (Zarghami and Szidarovszky 2011). This one is a major process when decision making because this defines how the alternatives will be evaluated (Munier 2011).

One of the tasks which requires more creativity in its process is to select the criteria which will be taken into consideration and their hierarchy (Saaty and Vargas 2001). In these cases, it is recommended that the designed model have the capacity to integrate all the criteria in the same analysis where normally, the multicriteria models are used (Zarghami and Szidarovszky 2011). Even so, in the decision making not only is important to set up an analysis and weighting model but also to set up a strategy which allows obtaining, classifying and evaluating the relevant information for achieving goals (Munier 2011).

Many methodologies and algorithms have been designed to extract expert knowledge and make a decision (Kim, Yang, and Kim 2008). These aim to provide appropriate mechanisms to make a decision in real problems conditions (Campanella and Ribeiro 2011; Merigó, Palacios-marqués, and Zeng 2016), because in many cases, these problems are dynamic and hard to solve (Campanella and Ribeiro 2011; Merigó, Palacios-marqués, and Zeng 2016). Hence, it is almost impossible to make a decision without indicators, proportions, weight, procedures and/ or algorithms (Munier 2011).

As it turns out, the decision making it is not an easy task; in fact, every day it is becoming a more complex process (Busemeyer and Pleskac 2009). Moreover, the main problem is that the results, in many cases, have strong consequences (Zarghami and Szidarovszky 2011). For companies, the strategy decision making is mentioned because it can cause a high impact (Lewandowski, Co-investigator, and Lewandowski 2015); therefore this topic has become an important research área in multicriteria analysis (Lewandowski, Co-investigator, and Lewandowski 2015; Munier 2011).

Likewise, the obtaining and analyzing of intangible information could be important for this kind of decision (Saaty 2008; Vanek, Mikoláš, and Bora 2013). Therefore, the knowledge management is recognized as one of the more important factors in orderto obtain competitive advantages (Kazemi and Zafar Allahyari 2010) (Xu, Xu, and Bernard 2013). One of the more effective ways to manage knowledge is to encourage the active participation of experts when decision making (Kim and Choi 2001). This group process refers to the recompilation and utilization of the information that the people have about the systems (Kazemi and Zafar Allahyari 2010).

That is why, the inclusion of experts when making decision process is an important factor (Vanek, Mikoláš, and Bora 2013). Although the decision making does not have a set of laws which characterizes the process for all the problems (Saaty 2008), it is emphasized that in strategy decisions its not only important to make up an appropriate methodology but also to allow the participation of experts (Kundu, McKay, and de Pennington 2008).

With respect to this third aspect, the decision maker could participate as a single person or a group of people (Pedrycz, Ekel, and Parreiras 2010; Zarghami and Szidarovszky 2011). In the group decisions, once they are selected the set of alternatives keeps going on the process in which the experts express their opinions or preferences about the alternatives set (Ureña et al. 2015). Normally, this process carries out different opinions, judgments and objectives in which the need arises to take into consideration all the opinions (Zarghami and Szidarovszky 2011). Even so, it is possible to aggregate the expert preference in a brainstorm, and so on, taking into consideration the judgment of each expert (Yang et al. 2015).

The analyzsis of the state of the art has shown that many of the models present strong gains in two of the three aspects of the decision making because these models select and evaluate the alternatives through multiple criteria, both qualitative and quantitative. Furthermore, these ones show an opportunity to research to contribute to the knowledge, because in the detected articles, there is no evidence about the active participation of more than one expert in the decision making.

Accordingly, the methodology designed to place the decoupling point had to respond to two principal necessities. First, making up a multicriteria model in which different alternatives could be analyzed through different criteria; and, second, integrating the group of experts into the process.

2.2.3 Group decision making

A group decision could be defined as problem solution through the joint participation of different experts who give their opinions and judgment. In this process a set of alternatives is assessed to reach a mutual solution (Dong and Saaty 2014; Munier 2011; Pedrycz, Ekel, and Parreiras 2010; Wu, Xu, and Xu 2015; Zhang 2015). the mean objective of this process collects different opinions of each expert individually and searches alternatives that are better suited to all perceptions (Perez et al. 2014; Sun and Ma 2015).

Usually, the group is made up of people who have different perceptions, attitudes, motivations and personalities (Bouzarour-Amokrane, Tchangani, and Peres 2015; Development Federal Ministry for Economic Cooperation 2011; Grabot et al. 2014); therefore, information on different perspectives are collected (Jing 2013). Often, this characteristic prevents a consensus among the participants (Bouzarour-Amokrane, Tchangani, and Peres 2015; Yang et al. 2015) and forters conflicts among them (Lavasani et al. 2012). Nevertheless, the joint participation of different interests, in the current competitive condition enriches the decision being made (Perez et al. 2014; Sun and Ma 2015).

In business, many decisions are involved in a complex socio-economic atmosphere (Bouzarour-Amokrane, Tchangani, and Peres 2015; Perez et al. 2014; Sun and Ma 2015). It means, at the strategic level the decision implies the dominion of many and different knowledges and information, so that it is out of the control of just one person; consequently, it could be necessary assigning more than one person in the make decision process (Bouzarour-Amokrane, Tchangani, and Peres 2015; Kar and Rakshit 2015; Pedrycz, Ekel, and Parreiras 2010; Sun and Ma 2015). Therefore, consulting more than one expert is better, because this group process avoids bias that could be present when it involves just one person (Merigó, Palacios-marqués, and Zeng 2016; Ramanathan 2001).

In the last years, related to the group decision, the multicriteria decision and the methods for making decisions have taken great importance (Park, Cho, and Kremer 2014; Zhang et al. 2015). These methods have been called: group decision making with multiciteria (Xia and Chen 2015) or group decision making with multi-attributes (Zhang et al. 2015). Both of them have the objective that a group of experts obtain consensus in the process of select the best alternative (Wu, Xu, and Xu 2015; Xu and Wu 2011).

Thus, the main group decision necessities are reached and a mutual solution in which the participant opinion will be taken into consideration (Lewandowski, Co-investigator, and Lewandowski 2015; Saaty and Vargas 2001; Sun and Ma 2015; Wu, Xu, and Xu 2015). This involves the necessity to make up a process which allows the participant to make a mutual decision (Bouzarour-Amokrane, Tchangani, and Peres 2015).

2.2.4 Multicriterial model when decisión making

The multicriteria models facilitate the decision making through the extraction of useful information (Del Amo et al. 2007; Pedrycz, Ekel, and Parreiras 2010). These models are presented, in the current business landscape, as a practical help when decision making (Sarache, Hoyos Montoya, and Burbano J 2004). This one facilitate the decision process in any area of the research and human life (Sarache, Hoyos Montoya, and Burbano J 2004; Yang et al. 2015). Additionally, this is useful for groups who require making a strategy decision (Lewandowski, Co-investigator, and Lewandowski 2015).

Usually, the alternatives could have a continuous or discreet approach (De Almeida et al. 2015). For the cases of discreet, the alternatives are selected by the decision maker while, the continueous alternatives are generated in the moment when the model is set up (De Almeida et al. 2015; Pedrycz, Ekel, and Parreiras 2010). Although in the literature there are different multicriteria methodologies, all of these fulfil three principal conditions: they must have multiple criteria, these criteria must be in conflict and these criteria are selected to support the decision process (De Almeida et al. 2015; Kazemi and Zafar Allahyari 2010; Pedrycz, Ekel, and Parreiras 2010).

Additionally, in agreement with (Toloie-Eshlaghy et al. 2011), the multicriteria methods are constituted by three steps: structuring the decision-making problem, acquiring the preference information and aggregating the preference to obtain a unified value in which is taking in to consideration the multicriteria. In the first step, the problem is characterized and the criteria hierarchy is identified. Subsequently, the alternatives are evaluated, which could be made based on quantitative dates, through outputs of the companies, or qualitative, through expert judgments. Finally, the meaning alternative is selected using a model which allows obtaining their relative weight (Lewandowski, Co-investigator, and Lewandowski 2015).

For a further evaluation of the alternatives, it is necessary to take into consideration the weight or importance of the criteria (Toloie-Eshlaghy et al. 2011). Therefore, the criteria weight must affect the alternatives analysis (Chen and Li 2009). For this purpose the multicriteria problems with m alternatives (a_1) and n criteria (c_1), are modeled from the following matrix (Campanella and Ribeiro 2011; Lavasani et al. 2012) (See Table 2-3).

Table 2-3: Matrix to the criteria and alternatives to mulicriteria ponderation.

	c_1	c_2	c_3	...	c_n		
a_1	X_{11}	X_{12}	X_{13}	...	X_{1n}		X_1
a_2	X_{21}	X_{22}	X_{23}	...	X_{2n}		X_2
⋮	⋮	⋮	⋮	⋮	⋮	–	⋮
a_m	X_{m1}	X_{m2}	X_{m3}	...	X_{mn}		X_m

$X_{mn} = Evaluation\ of\ the\ alternative\ a_m\ with\ respect\ to\ the\ criterion\ c_n$

One way to evaluate multicriteria is shown by (Munier 2011). In this one the weight vector is calculated through the ponderation of X_{mn} and the relative importance that each criterion has (See Equation 1).

$$W_i = \sum_{j=1}^{n} w_j\, X_{ji} \quad (1)$$

$$w_j = criterion\ wheigh\ \ j$$

$$X_{ji} = value\ of\ alternative\ i\ respect\ the\ criterion\ j$$

Consequently, the weight vector associated to the alternative (a_j) could be calculated (See Equation 1) (Campanella and Ribeiro 2011); in which the representation of each alternative is evaluated and the alternative with the high weight is selected as the best option. In this part, it is necessary to understand that the sum of all alternative weight is equal to 1 (See Equation 2).

$$W \in\ [0,1]^n, \qquad \sum_{j=1}^{n} W_i = 1 \quad (2)$$

The weighting methods are classified as subjective and objective (Chen and Li 2009; Toloie-Eshlaghy et al. 2011; Tzeng, Chen T.Y, and Wang 1998; Xuan et al. 2015). The objective weighting is represented by obtaining the vector weight through mathematical models such as the entropy process. In this approach the dispersion or characterized data are measured (Chen and Li 2009; Toloie-Eshlaghy et al. 2011; Xuan et al. 2015). In contrast, the subjective weight is determined by the individual's judgment and their knowledge (Chen and Li 2009; Toloie-Eshlaghy et al. 2011; Xuan et al. 2015).

Authors like Chen & Li (2009) and Sarache et al. (2004) show the possibility to mix these two weights in order to obtain just one ponderation. This model is known as combined weight (Alemi-Ardakani et al. 2016). Furthermore, this thesis exposes the necessity to include the active participation of experts in the decoupling point placement. That is why, the authors write, two weights are joined but in this case both of them are subjective weights.

Two weights which allow this integration are simple multicriteria weight (SMARTS) (Toloie-Eshlaghy et al. 2011) and the triangle of Fuller modified method (Sarache, Hoyos Montoya, and Burbano J 2004). The simple multicriteria weight allows a group of experts to value the relative importance which the criteria have. Hence, a value among 1 and n is assigned to the each criterion depending on its relative importance, but without repeating the value. The triangle of Fuller modified method is a paired comparison among all the criteria; in this comparison the value between 1, to the best criterion, and 0, to the worst criterion, is assigned (Sarache, Hoyos Montoya, and Burbano J 2004; Vanek, Mikoláš, and Bora 2013). The recompilation of all the comparisons, among the different criteria, allows generating a weight vector related.

2.2.5 Group AHP model

In general, the AHP is a multicriteria method created by Saaty (1977) is used to make a decision through the qualitative and quantitative evaluation of systems (Bana e Costa and Vansnick 2008; Dong and Saaty 2014; Noh and Lee 2003). Since the AHP creation has been a heavily researched topic (Ho 2008) it has been considered as the most popular method (Brestovac and Grgurina 2013; Dong and Saaty 2014) and the most powerful to make decisions (Forman and Peniwati 1998; Vaidya and Kumar 2006; Xu 2000; Zhu and Xu 2014). This method has been ascertaining its performance in different topics (Vaidya and Kumar 2006; Xu 2000). This one has been achieving high results when complex decision making or in complex atmospheres (Kazemi and Zafar Allahyari 2010; Scala et al. 2015).

The main objective of this model has obtained a finite qualification of a set of alternatives through the finite numbers of criteria (Brestovac and Grgurina 2013; Kwiesielewicz and van Uden 2004). All of this, organizing, in a hierarchy way, to identify the precedence (Altuzarra, Moreno-Jiménez, and Salvador 2007; Scala et al. 2015). The criteria weight are obtained from the pair comparison (Wicher & Lenort 2014; T. L. Saaty and Tran 2007; Vidal, Marle, and Bocquet 2011; Zhu and Xu 2014). While the evaluation of the criteria could be made through system indicators or the preference of the expert value with the fundamental scale (Dong et al. 2008; T. Saaty and Vargas 2001).

The AHP model is used when the criteria to evaluate are mutually independent and it is hirarchically unidirectional through the multilevel hierarchical relationship (Saaty and Vargas 2001; Yang, Chuang, and Huang 2009). That is to say, a bottom-up relationship is produced where the criteria are the upper level and qualify the lower levels (Dağdeviren and Yüksel 2010).

Although this model has steps previously established, this one is flexible. Therefore, it could be jointed with another model easily (Altuzarra, Moreno-Jiménez, and Salvador 2007; Ramanathan 2001; Vaidya and Kumar 2006). With concordance with this characteristic, Stojanov and Ding (2015) set up a study of the literature between 2008 to 2012 which shows the AHP is often applied in combination with other models or methodologies. Saaty & Vargas (2001) say that the hierarchical process not necessarily must be resolved with the same process; hence, this could be divided into sub-hierarchical and each of these ones can be solved by one particular model.

Another part of the AHP flexibility is that it could be applied to just one expert or a group of experts (Lai, Wong, and Cheung 2002). In a group of experts, both the tangible and intangible criteria could be evaluated through the integration of the individual values in a group process. This opportunity has been used by a lot of researchers (Lai, Wong, and Cheung 2002). And in this one, the main condition is that just one result has to be obtained with the opinion of all the experts (Zhu and Xu 2014)(Lewandowski, Co-investigator, and Lewandowski 2015).

Accordingly, it must be taken into account two characteristics; first, how to aggregate the individual judgments of the experts and, second, how to build a group decision through the individual perceptions (Ramanathan 2001; Saaty 2008). In the group decision making, there are a lot of methods that could be used to integrate the different participants points of view and judgements through a prioritization process (Lai, Wong, and Cheung 2002; Xu 2000). Even so, two models, into the group AHP, are highlighted (Altuzarra, Moreno-Jiménez, and Salvador 2007; Dong and Saaty 2014; Escobar, Aguarón, and Moreno-Jiménez 2004; Zhu and Xu 2014); Agregation of individual judgments (AIJ) (Equation 4) and Agregation of the individual priorities (AIP)(Equation 5 and 6).

Agregation of individual judgments

$$(AIJ)\ X_{ij} = \prod_{k}^{m} (X_{ij}^{k})^{\gamma} \qquad (3)$$

Agregation of the individual priorities

Geometric weighting

$$(AIP)\ W_i = \frac{\prod_{k}^{m} \left(W_i^k\right)^{\gamma}}{\sum_{i=1}^{n} \prod_{k}^{m} \left(W_i^k\right)^{\gamma}} \quad (4)$$

Arithmetic weighting

$$(AIP)\ W_i = \frac{\sum_{k}^{m} (W_i^k)\, \gamma}{\sum_{i=1}^{n} \sum_{k}^{m} (W_i^k)\, \gamma} \quad (5)$$

$$k\ = Counter\ thet\ represents\ the\ judgment\ given\ by\ the\ expert\ k$$

$$\gamma\ = Relative\ weight\ by\ the\ expert\ k$$

In the AIJ, the methods of the geometric weight is used for adding the individual judgment in the pairwise comparison matrix. With this process, a new matrix is made in which the relative group weight is obtained by the methods of eigenvalues (Altuzarra, Moreno-Jiménez, and Salvador 2007; Dong et al. 2010). Moreover, the AIP is different, in this method, the geometric or arithmetic weighting is used in the eigenvector to obtain just one weight vector with expert judgment (Altuzarra, Moreno-Jiménez, and Salvador 2007; Dong et al. 2010). This means, in this case, the final eigenvector of each expert is obtained and later they are added mathematically.

Each of the above methods has different philosophies and therefore, they should be used as well depending on the group behavior that is expected or wanted. This is to say, it is expected that the group process will be just a unit or a synergistic connection of individuals (Dong et al. 2010). It means the selection depends on whether the group wants to be considered as just one individual or, simply, as a connection of individual judgements (Forman and Peniwati 1998).

In the last case, the aim is to have a synergistic added in which all the comparison becomes just one as if it had been made by one expert. Whilst the AIP objective is that all the judgements will take into consideration separately (Forman and Peniwati 1998). The AIP was used for this thesis methodology designed, because when the individuals of the group are experts, according to (Saaty 2008), they prefer the combination of the judgement until their own final hierarchy is obtained.

Additionally, for the methodology designed, and as will be discussed in the next chapter, the AHP will just be used in the first level of the hierarchy, as long as the other levels will be used the simple multicriteria weight (SMARTS), the triangle of Fuller modified method and the ponderation method cited above. Accordingly, it should be noted that these three models have been selected for two main reasons. First, because they allow the integration of group experts in the process and second, because their flexibility allows the ability to be combined easily to obtain a new joint methodology with the aim exploting each of their comparative advantages.

Due to the presence of differences in personal perceptions, before accepting a multicriteria solution as feasible, it is necessary to measure the consensus among the experts judgement. Besides this, before the consensus it is necessary measure the consistency which identifies whether each expert judgment is intrinsically logical. Therefore, the group decision making requires measuring the individual consistency and the consensus (Dong et al. 2010; Zhang 2015).

2.2.6 Consistency test

The presence of subjective judgments of each expert forces rigorous actions which allow the validation results. For this purpose, the consistency test is used which measures whether the judgment given by each expert is logical (Dong and Saaty 2014; Kou et al. 2013). Therefore, the criteria evaluation only is accepted if the comparative matrix passes the consistency test (Karapetrovic and Rosenbloom 1999; Saaty 2008; Zarghami and Szidarovszky 2011). Hence, the consistency is an important factor to make decisions (Xia and Chen 2015; Zhang 2015).

The test is so difficult that it shows a perfect consistency in the expert judgment (Ho 2008). Tthat is why it is considered to establish a boundary which should be satisfied; in this case, the judgment is acceptable if the consistency test is over 10% (Bana e Costa and Vansnick 2008; Kazemi and Zafar Allahyari 2010; W. J. Xu, Dong, and Xiao 2008). If the judgment does not satisfy this condition, it is therefore inconsistent and implies that almost one of the experts judgment is not logical and it is not accepted (Scala et al. 2015; Yang et al. 2015).

When the test has negative results there is just one alternative which is to repeat the comparison with the aim to eliminate the logical inconsistencies present in the previous test (Saaty 2008; Z. Xu 2000). For the case of the group decision, it is necessary to understand that the consistency is accepted if and only if the judgment of each expert has an accepted consistency test (Dong and Saaty 2014).

2.2.7 Consensus in the group decisión making

The Unanimity is too difficult to obtain, more if it is taken into consideration that each person has their own criteria; that this why the best solution is to search for a high level of consensus (Bouzarour-Amokrane, Tchangani, and Peres 2015). The consensus represents the achievement of an agreement among a group to make a decision (Lai, Wong, and Cheung 2002). Hence, the validation of the result requires a minimal consensus level (Dong and Saaty 2014).

Thus, the consensus is another highly important measure in order to make a group decision (Dong and Saaty 2014; Hahn 2010). Because, with this process it is validated if the judgment given by the different experts are agreement with each other (Dong and Saaty 2014). If these judgments do not satisfy the consensus condition, the final result must be considered invalid. Consequentially, the group decision making requires a consensus process to obtain an acceptable solution (Bouzarour-Amokrane, Tchangani, and Peres 2015).

According to Hahn (2010), the consensus is a measure equal to the consistency; the difference is that the consensus search for homogeneity among the decision is given by the different experts, as long as the consistency search for homogeneity in the particular judgment of just one experts (Zhang 2015). Following this line of thought, one alternative to measure whether the judgment given by each expert is agrees with each other is through the concordance Kendall index. This test offers a model to measure the level of agreement among the experts (Sarache-castro, Costa-salas, and Martínez-giraldo 2015).

2.3 Partial conclusions

The characteristics of the current markets have forced companies to face the necessities of offering customers high levels of efficiency and high levels of flexibility simultaneously. In response, the literature has shown strong tendencies to investigate solution toward this problem through the manufacturing strategy. Two of the strongest topic have been the mass customization and postponement.

The positive results of these two topics have been caused by the researchers not only having a high interest on these topics but also that different authors say that these topics are the new paradigm in production. Therefore, it is important to make a new investigation about them which can evolve into the concept.

The alternative research which inspired the building of this thesis was the localization of the decoupling point. This interest is because the literature has shown that the decoupling point is the success factor and the most important decision to implement mass customization or postponement. Therefore, it is important to have a tool which allows the location of this point in production systems.

The revision of the state of the art has identified three factors that reveal the existence of a gap in knowledge. First, although there are different models to place the decoupling point, they can be classified in three groups, models with a qualitative, quantitative or mixed approach. Second, the mixed approach or multicriteria models decrease the risks when decision making; this model type mitigates some difficulties that present in qualitative and quantitative approach, because these models allow the integration of the record data and the knowledge and experience of individuals when making decisions.

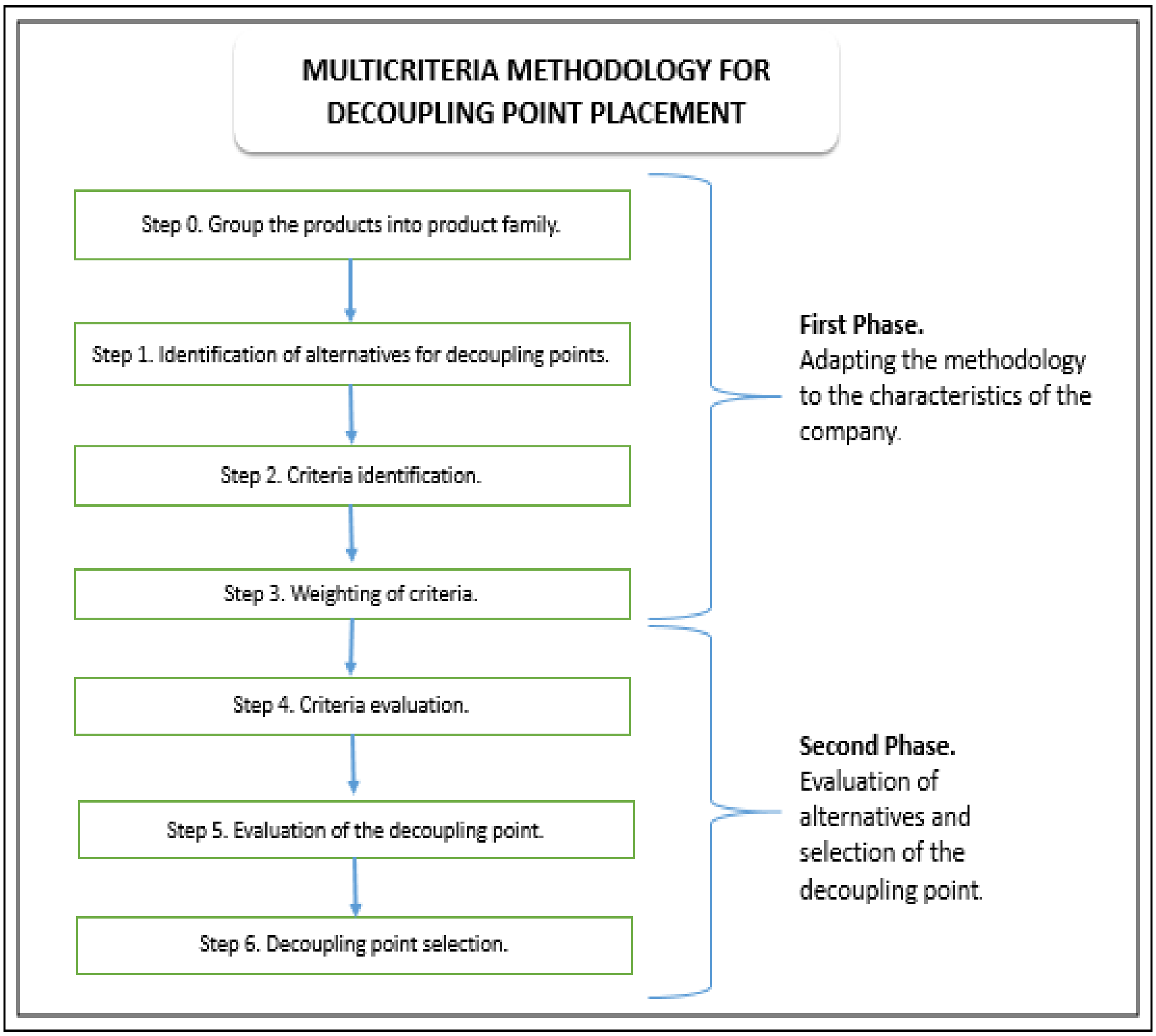
Third, although the mixed approach has the opportunity to integrate more than one expert when decision making, the articles have not identified the participation of a group of experts in this process. In this connection, it is crucial to understand that the decoupling point placement is a strategy decision which dictates how the company will be in the long and short term, that is why is important the participation of the experts in this process.

These test have identified the necessity to make up a methodology for decoupling point placement which take into consideration qualitative and quantitative criteria in its process but also allows the active participation of a group of experts when making decisions. Additionality, it is important that this methodology is flexible and so it can be applied in different contexts and give an effective answer to the particular necessities of companies in which the methodology will be applied. For this aim, the methodology was built, taking into consideration the group AHP, the simple multicriteria weight, the triangle of Fuller modified method and the concordance index and consistency test.

3. Chapter 2. Methodology

The proposed methodology provides a new alternative for DP placement in production systems. The structure takes into consideration the fundamentals of multicriteria techniques, expert methods and the theoretical needs of DP location. Also, the scope and company needs must be considered in order to get a proper solution according to the technical capabilities of the production system. Some topics typically involved in the decision-making could be: unpredictable demand, wide variety of products, products with similar characteristics and inventory cost, among others.

Figure 3-1: The guiding theme.



In order to respond to the requirement exposed in the literature, the methodology consists of two vital parts (See Figure 3-1). In the first part, the alternative decoupling point (ADP) is selected from which the process of evaluation and the criteria are selected. This is a critical process, influenced by experts, because it is in this part that the methodology is adapted to the company requirement and capacities.

In the second part, each alternative is evaluated through the selected criteria. One of the main characteristics is that these criteria could be qualitative or quantitative. In the case of the quantitative data, the relevant information is collected through company historical data or statistical. In the case of quantitative data, the AHP method is utilized; this approach allows access to the judgment of the experts with which to set up the eigenvector or weight vector; in this way, a hierarchy of the importance of each alternative respect the criterion is made up and after, the best alternative could be selected.

As can be seen in Figure 3-1, these two parts are distributed in seven steps. The objective of this structure is to keep carrying the implementation of the methodology easily to the selection of the decoupling point. A complete explanation of each step and the mathematical models are as follows:

3.1 Step 0. Make group of product families

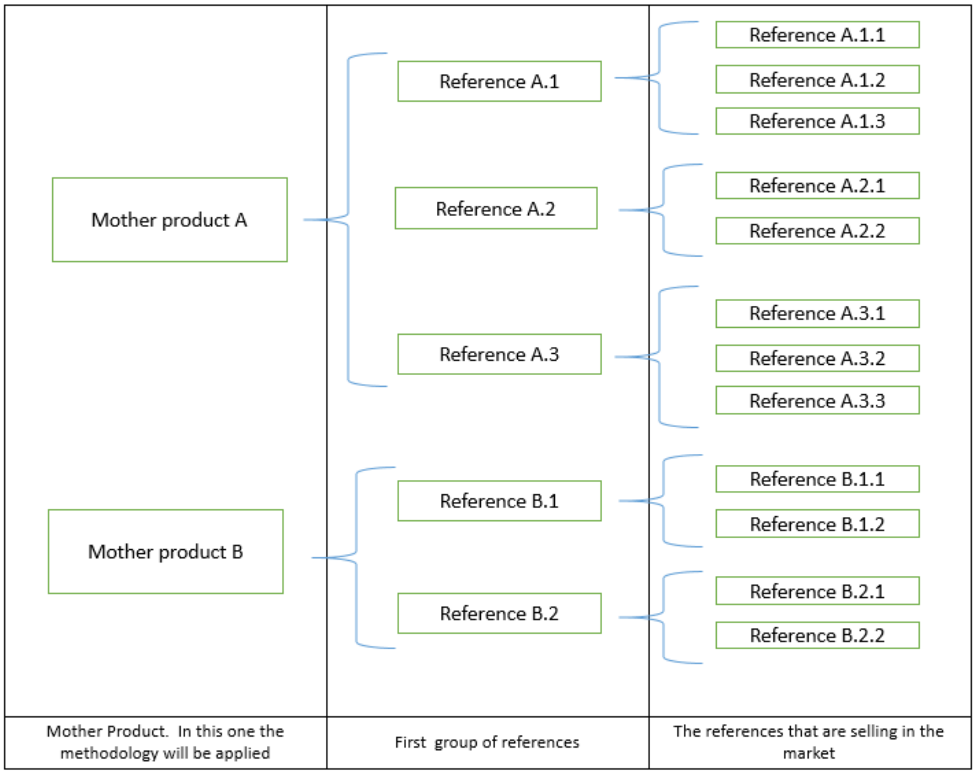
As it was shown in the previous chapter, one of the most important requirements is to identify the product which satisfies the requirements to be postponed. In this regard, the literature offers a concept call products family (Wanke et al. 2001). This concept says that the products references must be grouped in to a set of products; but it is necessary to understand that the products, which are part of a new family, have to be similar which means they have to be made up by a similar piece and/or have a similar production process.

The Figure 3-2 shows that companies which have modularized products usually offer a high products variety to the market; these products could have different finishes and/or have different pieces which are assembled in the last process. This implies that there is a first product (mother product) which is modified to obtain the different products references.

Therefore the methodology could be implemented in these products mother and then the result could be generalized to all the referenced products (children products). Thus, if the family products are selected precisely, the methodology will be easier to carry out because there would be less products that carry out the methodology, and the result could be general for all the products references.

Consequently the methodology has to start with the group of the referenced products in products families and, after, select the products mother in which the whole methodology will be applied. It is necessary to clarify that the group of products families depends on the company, the productions and the products characteristics but additionally also depend on the level of detail with which the methodology wants to be applied.

Figure 3-2: Schematic explanation of the products mother.



3.2 Step 1. Identification of alternatives for decoupling points (ADP)

The DP placement is a decision affected by many factors related to the production system particularities and in general, the characteristics of the whole system (Verdouw et al. 2008). Therefore, on this step the methodology intends to identify the different alternatives of decoupling points (ADP) for each factor. This step is divided into three sections. All of these sections are addressed to select the alternative decoupling points according to the requirements and capacities of the companies; for this purpose the experts are involved directly.

3.2.1 Factors selection

It is necessary to identify the factors affecting the ADP placement for each particular company. Thus, the ADP selection must be done according to the characteristics and company requirements. As it was shown in the previous chapter, typical factors such as product characteristics (design, materials), process configuration (operations sequence, critical operations and assembly operations) and requirements of the customers (customization) can be considered (Verdouw et al. 2008; Xu 2007). A technical analysis of the production system can be useful in this step.

It is should be understood that the factors were not selected previously with the objective of each company selecting them according to their own characteristics. Because as there are companies in which the production system is the restriction and the most important resource, there are other companies that have different restrictions. For example, there could be a company which its restriction as the human resources, hence in this case its factors should be reevaluated.

3.2.2 Expert selection for ADP identification

After identifying the decision factors for the ADP placement, it is necessary to choose a group of experts in order to make an informed judgment by which the different ADP for each product mother will be assigned. An expert is an experienced decision maker able to give proper information about a particular issue (Cruz and Martínez 2012; Perera, Drew, and Johnson 2012).

As might have been inferred, the selection of the alternative decoupling point is necessarily chosen by a group of experts who have a precise information about the factor. It is possible that one expert who knows much about the products design but does not have precise information about the production system, therefore this person should make judgment about the products and not about the production systems. Hence, the experts for each factor should be selected according to the experience of the expert and the characteristics of the company.

3.2.3 ADP selection

Based on their knowledge and experience, each group of experts should establishes a list of ADP for each product mother under analysis. Some group work techniques can be used to support this activity.

3.3 Step 2. Criteria identification

A preliminary group of criteria can be defined from relevant contributions based on the state of art or previous experience of the company. However, a list of final criteria must be defined by contrasting the preliminary group with the company characteristics and requirements. In this case, it is recommended to be accompanied by an expert who knows the majority of company.

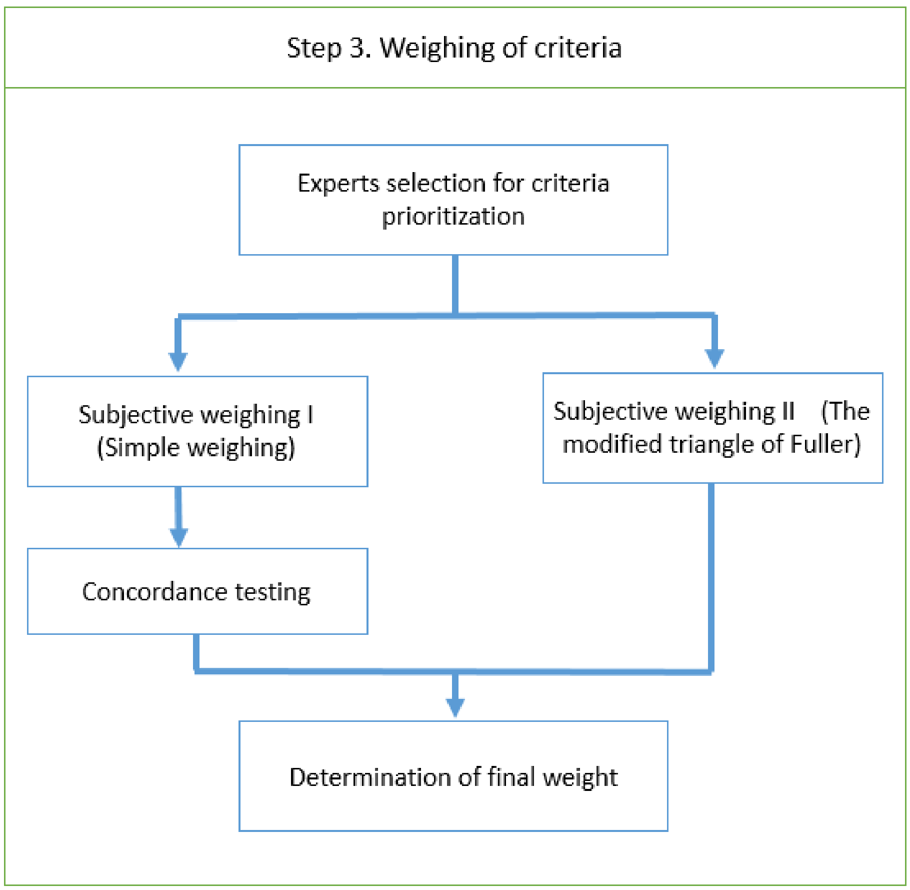
3.4 Step 3. Weighting of criteria

This process allows weighting the relative importance of each selected criterion according to the company characteristics and requirements. Thus, not only is the appropriate criteria selected but also these ones are aligned with the condition, characteristics and capacities of the company which allows the methodology to adjust to the system.

Aimed to identify the relative importance among criteria and based on previous contributions of (Sarache, Hoyos Montoya, and Burbano J 2004), in this thesis two models of subjective weight are used because it is hoped to increase the participation of the experts. Additionally, as was explained in the previous chapter, it prevents the misalignment of the criteria from the company characteristics, which is an objective weight risk.

As can be seen in Figure 3-3 two weighting techniques are proposed. In the first one, the criteria prioritization through a simple weighting and the modified triangle of Fuller is obtained. In the second one, the two obtained weighting are combined to get a more accurate result. The particular sub-procedure is as follows:

Figure 3-3: Sub-procedure for Step 3.



3.4.1 Expert selection for criteria prioritization

In this step, a new expert's selection process should be done. These experts have to evaluate the different criteria required to select the best ADP. Regarding the number of experts, they can range from 7 to 50 (Muskat, Blackman, and Muskat 2012; Sarache-castro, Costa-salas, and Martínez-giraldo 2015).

3.4.2 Subjective weighting I (Simple weighting)

Each expert should establish the relative importance among criteria. By using a scale from 1 to *n (n= number of criteria)*, each expert assigns *n* to the most important criterion and 1 to the less important. In this way, the higher the number, the greater the importance of the criteria.

It is necessary to take into consideration two important recommendations. The number should not be repeated when the experts consider this process necessarily, in this case there should be an average between the two possible qualifications (so the first qualification n and the second one n-1), therefore each criteria has the qualification of (n + (n-1))/2.

After the qualification of each criterion given by each experts it is applied the Equation 6; hence, the subjective weighting I per each criterion can be obtained.

$$W_{jA} = \frac{\sum_k C_{jk}}{\sum_j \sum_k C_{jk}} \quad (6)$$

Where:

C_{jk}: Relative importance of criterion *j* given by the expert *k*.

W_{jA}: Subjective weighting I of criterion j.

3.4.3 Concordance testing

The Kendal index (W) is used for testing the level of agreement among experts. If W is equal or greater than 0.5, the weighting is validated. W can be calculated as follows (Sarache-castro et al., 2015):

Calculation of mean value of ranges (T):

$$T = \frac{M(\,n+1)}{2} \quad (7)$$

Calculation of deviation for each criterion (D^2).

$$D^2 = \sum_{j=1}^{n}(\sum_{k=1}^{M}(C_{jk}) - T)^2 \quad (8)$$

Calculation of Kendall's index (W):

$$W = \frac{12 \sum D^2}{M^2 \, (n^3 - n)} \quad (9)$$

Where:

n: Number of criteria.

M: Number of experts.

3.4.4 Subjective weighting II (the modified triangle of Fuller)

To obtain this weight, the modified triangle of Fuller is used (Sarache, Hoyos Montoya, and Burbano J 2004). By applying this method, a paired comparison among criteria is performed. A value of 1 is assigned to a criterion when the decision maker considers that it is more important than the other one; otherwise, a zero (0) must be assigned.

This methodology is designed to qualify, only the upper triangular matrix (See Table 3-1). The lower triangular matrix is calculated through the binary logical complement of the last one. In the comparison between the $criterion_1$ y $criterion_2$, the first criterion is identified as the best (P_{12k} equal to 1), for the lower triangular matrix the are $criterion_2$ is evaluated as the worst (P'_{12k} equal to 0).

Table 3-1: Paired comparison among criteria given by expert k.

Criterion	Criterion $_1$	Criterion$_2$	Criterion$_3$	…	Criterion$_n$
Criterion$_1$	1	P_{12k}	P_{13k}	…	P_{1nk}
Criterion$_2$	P'_{12k}	1	P_{23k}	…	P_{2nk}
Criterion$_3$	P'_{13k}	P'_{23k}	1	…	P_{3nk}
⋮	⋮	⋮	⋮	⋮	⋮
Criterion$_n$	P'_{1nk}	P'_{2nk}	P'_{3nk}	…	1

Where:

P_{jik}: Preference of criterion *j* respect to criterion *i*, according to expert *k*.

P'_{jik}: Binary logical complement of P_{jik}.

[i,j]: Subscripts count for criteria *i,j* = 1,2,3,..,n

$$0 \leq P_{jik} \leq 1$$

$$\text{If} \quad P_{jik} = 0 \quad \text{then} \quad P'_{jik} = 1$$

$$\text{If} \quad P_{jik} = 1 \quad \text{then} \quad P'_{jik} = 0$$

By applying Equations 10, the total subjective weight II for each criterion must be obtained.

$$W_{jBk} = \frac{\sum_i P_{jik}}{\sum_j \sum_i P_{jik}} \quad (10)$$

Where:

W_{jBk}: subjective weighting II of criterion *j*, given by expert *k.*

It is necessary take into consideration Table 3-1, the paired comparison matrix must be carried out by each expert. As a result each expert will obtain one weight vector and then these vectors will be combined with an arithmetic weight to set up the final weight vector (See Equation 11).

$$W_{jB} = \frac{\sum_k W_{jBk}}{\sum_j \sum_k W_{jBk}} \quad (11)$$

Where:

W_{jB}: Subjective weighting II of criterion *j*.

3.4.5 Determination of final weight

To obtain the final weight of each criterion, the results of the previous two techniques are combined by applying Equation 12 (Sarache, Hoyos Montoya, and Burbano J 2004):

$$W_{jD} = \frac{W_{jA} \;\; W_{jB}}{\sum_{j=1}^{n} (\; W_{jA} \;\; W_{jB})} \quad (12)$$

Where:

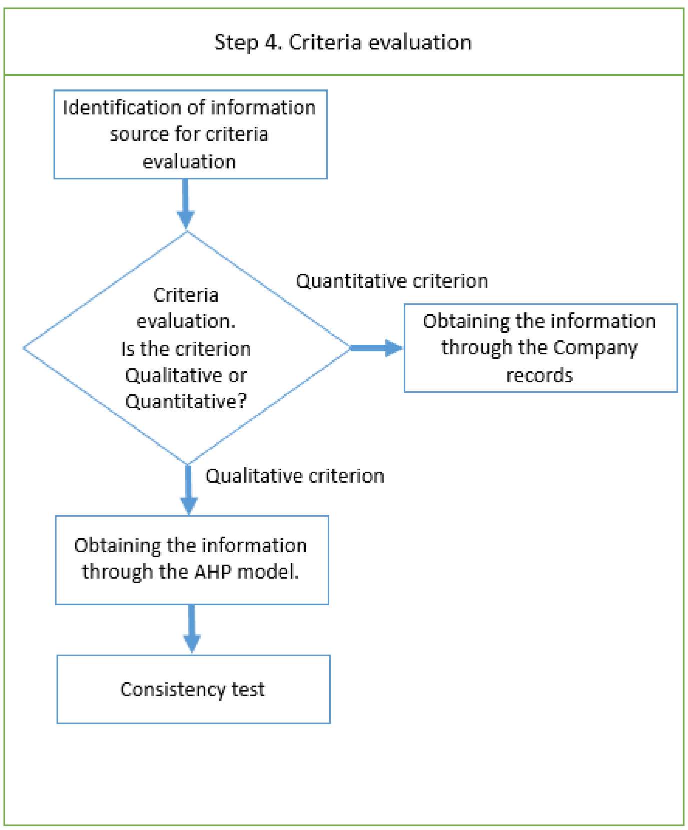
W_{jD}: Final weighting of criterion *j*.

3.5 Step 4. Criteria evaluation

Typical criteria can be made up of qualitative or quantitative characteristics. Hence, the identification of the proper source to collect the relevant data for each ADP must be performed. The quantitative criteria can be measured easily and, typically, their information is saved in company statistical records. While the qualitative criteria are intangible company elements which cannot be registered, this information is part of the knowledge of the experts.

These differences in the criteria approach forces one to analyze each criterion with the aim of identifying how to collect the required information to evaluate the alternative decoupling point. As can be seen in Figure 3-4, the methodology offers two alternatives. For the quantitative criteria, the information is collected directly through the company registry or, if this fails, set up the registry to measure the system behavior. For the qualitative criteria the methods AHP is used because it allows the conversion of the knowledge and experience of the people involved in the system into numerical dates.

Figure 3-4: Sub-procedure for Step 4.



3.5.1 Identification of information sources for criteria evaluation

In this step, through an appropriate data collecting process, the criteria characteristics must be identified. For quantitative data, information can be obtained from company statistical records, while for the qualitative ones, expert involvement is proposed (T. L. Saaty 2008; T. Saaty 1980).

3.5.2 Criterion evaluation

For quantitative data, information is collected from company statistics. For qualitative criteria, company managers (experts) perform the evaluation (T. L. Saaty 2008; T. Saaty 1980). This implies that the relevant group of experts who know the information about the criterion, must select all, with the purpose of procuring a confinable result.

These personnel should be properly informed of the process characteristics on which the ADP must be defined. In this case, experts will evaluate each alternative based on the scale proposed by Saaty (R. W. Saaty 1987) (See Table 3-2). By applying an AHP model, the judgement of each expert is analyzed to obtain the hierarchy of each criterion (priority vector).

Table 3-2: Fundamental scale.

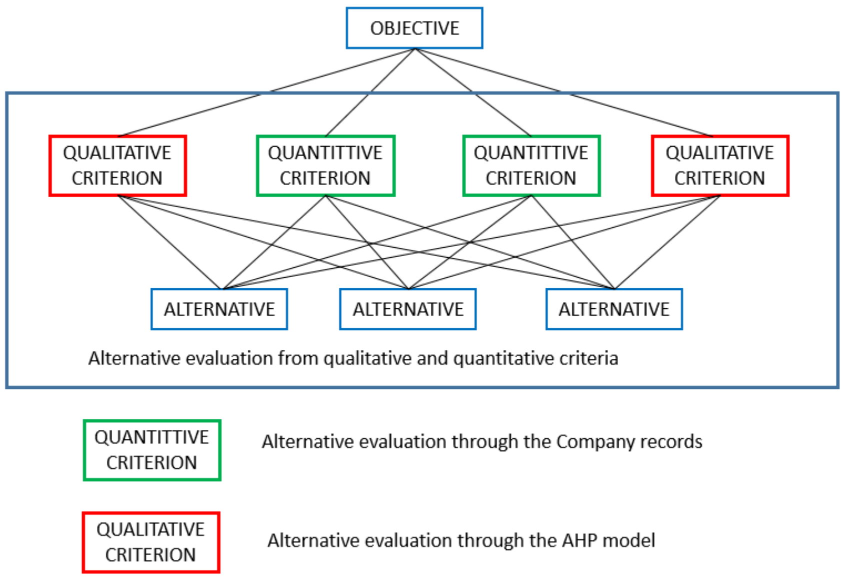
Intensity of importance on an absolute scale	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance

Source: Saaty (R. W. Saaty, 1987)

Hence, it is necessary to highlight that the AHP process is an informed judgment and that is why it is not an indispensable condition the number of experts who must participate in the process. On the contrary, it is best to consider the people who really dominate the information about the criterion, which will be evaluated, or the people who have a direct contact with the process which involves the criterion.

Clearly, as seen in Figure 3-5, the method AHP was not proposed to solve all the decoupling point selections. This one is used in the first level of the whole methodology process. Thus, AHP offers the relevant information just to evaluate the alternative through the qualitative criteria.

Figure 3-5: Hierarchy AHP methods.



Source: my elaboration base on Saaty & Vargas (2001) y Brestovac & Grgurina (2013)

The comparison among alternatives is represented in a triangular matrix (Table 3-3), where the intersection of row *f* and column *p* shows the comparison between *f* and *p* alternatives. It is necessary to keep in mind that a comparison is made for the upper triangular matrix, since the lower is mathematically reciprocal (Fedrizzi and Giove 2007; Saaty 2008; Zarghami and Szidarovszky 2011). Additionally, it should be understood that the difference between the matrix of modified triangle of Fuller and the AHP matrix is that the pairwise comparison of the AHP is carried out with the fundamental scale (See table 3-2).

Table 3-3: Triangular matrix for criteria comparison.

ADP	**ADP_1**	**ADP_2**	**ADP_3**	**…**	**ADP**
ADP_1	1	a_{12k}	a_{13k}	…	a_{1mk}
ADP_2	$1/a_{12k}$	1	a_{23k}	…	a_{2mk}
ADP_3	$1/a_{13k}$	$1/a_{23k}$	1	…	a_{3mk}
⋮	⋮	⋮	⋮	⋮	⋮
ADP_m	$1/a_{1mk}$	$1/a_{2mk}$	$1/a_{3mk}$	$1/a_{m\,m-1\,k}$	1
$\boldsymbol{sum\ a_{pk}}$	a_{1k}	a_{2k}	a_{3k}	…	a_{mk}

Where:

$$a_{pk} = \sum_{f} a_{pfK} \quad (13)$$

m: Number of ADP's.

[p,f]: Subscripts count for ADP's; p,f = 1,2,3,…, m.

a_{pfk} : Value of the paired comparison between ADP_p and ADP_f made by expert *k*.

As shown in Equation 14, the results must be normalized to obtain the relative weight for each cell:

$$n_{pfk} = \frac{a_{pfk}}{a_{pk}} \quad (14)$$

Where:

n_{pfk}: Normalized value of comparison between ADP_p respects to ADP_f made by expert *k*.

With the Equation 15 is procured the eigenvector or priority vector (vector S) with dimension *m* for each expert and formed by S_{fk} elements.

$$S_{fk} = \frac{\sum_p n_{pfk}}{m} \quad (15)$$

Therefore, until this part, there is one eigenvector for each expert. These results are used at the AIP (Add individual priorities), shown in the previous chapter. Thus, utilizing the Equation 16 a combination of the last eigenvectors is obtained with which evaluates the alternative decoupling points by each qualitative criterion.

$$S_f = \frac{\sum_k S_{fk}}{\sum_f \sum_k S_{fk}} \quad (16)$$

3.6 Consistency testing

The information about the consistency, explained in the previous chapter, should be remembered. In this section it was explained that if the consistency of each expert is accepted consequently, the group consistency should be accepted. Consequently, the method for devaluing the consistency of each expert is explained as following:

The consistency of the expert rating must be tested through the Random Consistence Index (RI). If RI is equal or lower than 0.1, the rating is accepted; otherwise, the process must be repeated. The mathematical formulation is as follows (Dong and Saaty 2014; Kazemi and Zafar Allahyari 2010; Marrero Delgado 2011; Zarghami and Szidarovszky 2011):

- Based on the non-normalized matrix and the priority vector, a resulting vector (R) is obtained. This is made up of the relative weight for each ADP (Equation 17).

$$R = R_{n\,x\,1} = A_{n\,x\,n} \cdot \boldsymbol{S_{n\,x\,1}} \quad (17)$$

Where

A: Comparison matrix. $A = A_{n\,x\,n} = [a_{pf}]$

- Largest or principal eigenvalue (d_{Max}) is calculated by applying Equation 18.

$$d_{Max} = \frac{R}{n\,S} \quad (18)$$

- Consistency index calculation (CI):

$$\mathrm{CI} = \frac{d_{Max} - n}{n - 1} \quad (19)$$

- With the Equation 20 the consistency ratio calculation (CR) is calculated. Moreover it is necessary to understand that this Equation considers the random consistency index showing in Table 3-4 these values depend on the number of ADP compared.

$$\mathrm{CR} = \frac{\mathrm{CI}}{RI} \quad (20)$$

Table 3-4: Random consistency index (RI).

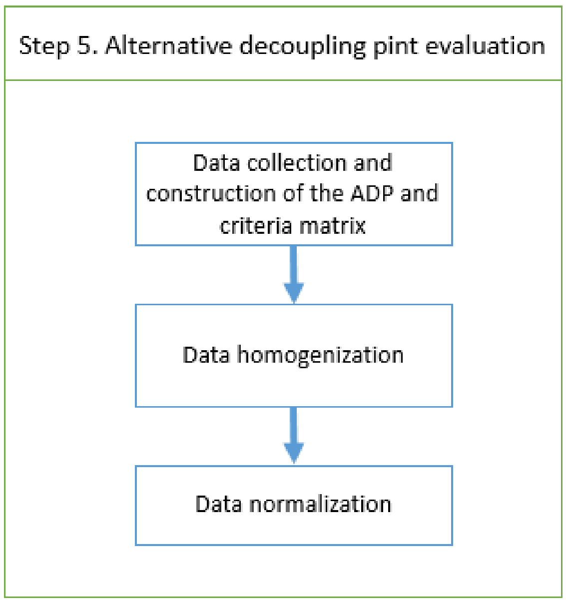
N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.11	1.24	1.32	1.40	1.45	1.49

Source: Saaty (R. W. Saaty, 1987)

3.7 Step 5. ADP evaluation

After evaluating each alternative decoupling point through the criteria, the best alternative must be selected. In order to achive this, it is necessary to make three processes (See Figure 3-6). First, the qualification of the ADP made previously has to be collected in a matrix. Second and third, the information must be homogenized and normalized, so that the obtained information can be compared and analyzed. With these processes, all the information can be transformed in uniform numerical terms.

Figure 3-6: Sub-procedure for Step 5.



3.7.1 Data collection and construction of the ADP and criteria matrix

As shown in Table 3-5, data collection is carried out through a matrix (criteria – alternative points) to record the value of each criterion for the different ADP.

Table 3-5: Matrix of ADP and criteria.

Concept	**$Criteria_1$**	**$Criteria_2$**	**…**	**$Criteria_n$**
ADP_1	AC_{11}	AC_{12}	…	AC_{1n}
ADP_2	AC_{21}	AC_{22}	…	AC_{2n}
:	:	:	:	:
ADP_m	AC_{m1}	AC_{m2}	…	AC_{mn}

Where:

AC_{pj}: Assessment of criterion *j* at ADP *p*

3.7.2 Data homogenization

This process is aimed to direct all assessments given to criteria toward the same decision approach. In other words, all criteria will be evaluated under the same perspective (minimizing or maximizing). So when AC_{ip} belongs to a vector, AC_i is oriented to an optimization perspective different to the methodology goal, it is necessary that each AC_{ip} of this particular vector is transformed by applying the mathematical complement proposed in Equation 21.

$$AC'_{pj} = \frac{1}{AC_{pj}} \quad (21)$$

Where:
AC'_{pj}: Homogenized value AC_{pj} of the vector AC_j

3.7.3 Data normalization

Normalization must be addressed for each AC_{jp}. In this case, the total sum of all ADP_m for each criterion must be calculated. Then, each AC_{jp} is expressed as a percentage of the obtained total sum (Equation 22). As result, the normalized matrix is obtained (see Table 3-6). This process is carried out with the objective of obtaining numerical data that can be compared. Hence, the differences in the measures, units or scales do not affect the comparison.

$$AC^N_{pj} = \frac{AC_{pj}}{\sum_p AC_{pj}} \quad (22)$$

Where:

AC^N_{pj}: Normalized value of AC_{pj}

Table 3-6: Normalized matrix.

Concept	$Criteria_1$	$Criteria_2$	…	$Criteria_n$
ADP_1	AC^N_{11}	AC^N_{12}	…	AC^N_{1n}
ADP_2	AC^N_{21}	AC^N_{22}	…	AC^N_{2n}
⋮	⋮	⋮	⋮	⋮
ADP_m	AC^N_{m1}	AC^N_{m2}	…	AC^N_{mn}

3.8 Step 6. Decoupling point selection

The weighted sum for each alternative must be calculated as shown in Equation 23. The outcome represents the final grade for each alternative, from which the best ADP is chosen. If data were homogenized as a minimization vector, the lesser Q_p is chosen; otherwise, the largest is chosen.

$$Q_p = \sum_j AC_{pj}^N \; W_{jD} \quad (23)$$

Where:

Q_p : Final grade for the ADP_p.

3.9 Partial conclusions

The design methodology could be adapted easily to the characteristics and necessities of the company focus of study. This adaptation is set up through of the participation of experts who profoundly know the system. They are responsible for selecting the parameters in which are made decisions.

Highlighted among these parameters is the selection of the factor which affects the decoupling point placement, the selection of the alternative decoupling point and the selection and weighting of the criteria. It means, with the definition of these characteristics parameters of each company a specialized methodology according to the company requirement is built. Another important characteristic is that this methodology is structured with a systematic process which not only allows the evaluation of the system through qualitative and quantitative criteria with the active participation of experts in all the process, but also facilitates the process of collection of information. Therefore, this systematic process guides the decision maker step by step until the best alternative for each product mother is identified.

It is necessary to point out that the participation of the expert is set up by a workgroup and each one is built specifically for the requirement of each step of the methodology. Accordingly, the step in which the participation of expert is required, it is necessary to find a group of experts who have a stranglehold on that topic.

Consequently, two new advantages are identified with this methodology. The first one allows the participation of the experts when making a decision, but it prevents an expert in a specific topic from forming an opinion about some topic which he does not have a precise knowledge. Second, the methodology does not depend on the initial group which cannot be suitable for all steps, which requires expert participation, but rather, this methodology allows that in each of these steps a group of experts will be shaped according to the characteristic of the company and the human resources who work there.

4. Chapter 3. Methodology application

To demonstrate the applicability of the designed methodology in the development of the thesis two study cases in manufacturing companies from Manizales are proposed. This process enriches the research, mainly due to differences existing in system production characteristics of each company and the specific needs of their markets.

The first company, Herragro S.A, is located in the metal-mechanic sector, it has a national and international scope, because its markets are heterogeneous and they provide the possibility to evaluate the methodology performance under the influence of globalized markets. The production system implemented by Herragro S.A, allows the company to reach high efficiency levels, but it is limited because of the demands of flexibility in the markets in which it competes.

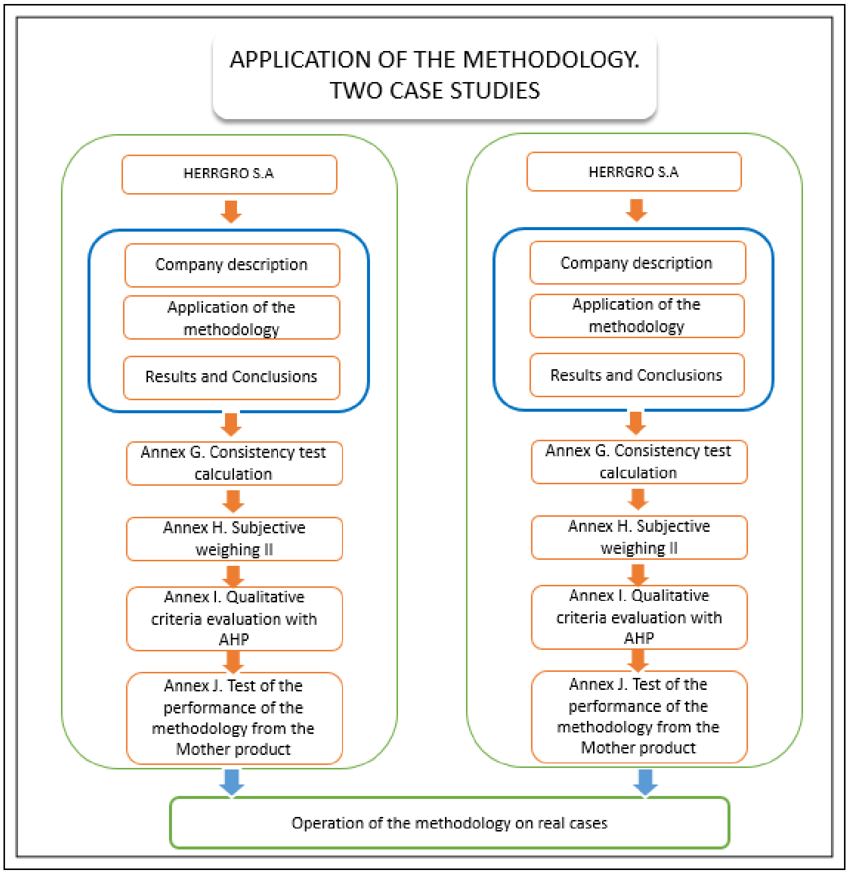
As a second stage, the methodology application is developed in Muebles Marco Gómez Company. It is a manufacturer of home furnishings. Its distinguishing characteristic is that the company has a national reach in a market that demands high efficiency. Currently, its production system offers high flexibility levels. Despite this, the highly competitive market demands high efficiency levels, which under the current conditions in the development of the study, has caused an increase in inventory levels.

According to the above, these two differences provide a great opportunity to evaluate the performance of the designed methodology because each of the companies have totally different needs. In the first stage, the company Herragro S.A is characterized by having high efficiency levels, while the company Muebles Marco Gómez is characterized by having high flexibility.

However, both markets demand that companies attain a balance, which is currently nonexistent, between flexibility and efficiency. This requires that the DP location achieves different levels of balance between these competing priorities according to every need. In the first instance, with the company Herragro S.A, it requires increased flexibility; while on the other hand, the company Muebles Marco Gómez, requires increased efficiency.

The companies' characteristics and needs will be explained in a summarized way, continuing with the step by step methodology development and the results reached for each company (see Figure 4-1) Consequently with the above, first the case of the company Herragro S.A will be described in paragraph 4.1; and second, the case of Muebles Marco Gómez will be described in section 4.2.

Figure 4-1: study case thread



4.1 Case study #1 Herragro S.A company

Herragro S.A manufactures hand tools. The manufacturing process is the forging of hot steel. Currently, the products are mainly targeted at agriculture, construction, mining and industrial markets (Flórez R, Henao A, Peña B, Restrepo V, & Villegas c, 2014) (See Figure 4-2).

Figure 4-2: Products of the HERRAGRO S.A.

Its current production is sold mainly in the internal market (70 %) and the remaining, in the international market. The company is present in 14 countries, in which it offers a product portfolio integrated by more than a thousand references. The total market has been segmented into three parts:

1. National market (Herragro brand products) is a market driven by high design quality demands, product reliability and marketing channels. Additionally, they require low esthetic qualities, because Colombian cultural characteristics offer the perception that a rustic esthetic finishe involves lower costs associated with finishing processes.

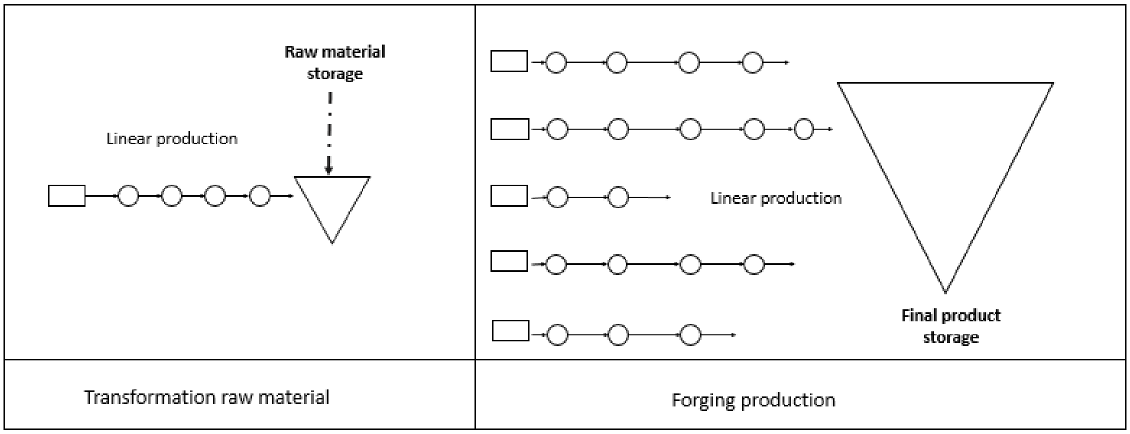
2. National Market (maquila or own brands): is a market driven by the terms of culture and national characteristics. It is subject to the demands of production levels and that is why not only quality and good service are demanded, but also productivity and effectiveness.

3. Export markets: Herragro S.A not only has the Colombian market, but also competes in competitive markets like Mexico, Ecuador, Panamá, Cuba, Honduras, Argentina, Paraguay, Venezuela, Costa Rica, Guatemala, Peru, United States and Dominican Republic. One of the biggest differences highlighted in these markets, is that they have a greater demand of product´s esthetic, and they also demand greater variety on finishing.

The company Herragro S.A has two production configurations depending on the process systematization: operator-paced line flow and machine-paced line flow. These are characterized because, despite the high technological levels in the equipment and used tools, the company still depends on the skills and knowledge of operators. The operator is responsible for handling the equipment - material relationship, to give the steel form and physical conditions required.

The system consists of a total of 13 production lines adapted to generate the manufacturing processes of a single family of products, or in some cases, products with similar characteristics. The lines are distributed through the plant separately, in order to increase system flexibility, making the manufacturing processes of different product families simultaneously and in parallel. In addition to the destined lines of the manufacture of final product, the company Herragro S.A has a production line commissioned to adapt steel billets according to the production needs (see Figure 4-3).

Figure 4-3: Schematic representation of Herragro S.A production configuration



Source: elaborated by myself

For purposes of the project, 9 family products are highlighted: plowshares and axes, pickaxes and barreones, shovels, wheelbarrows, knives, machetes and sledgehammers because, with these lines the products with multiple references are generated. Therefore many differences in the presentation regarding with the product mother.

Each production line is divided into two sub processes. The first process is forgings which is in charge of generating geometric changes from large pressures, the use of dies and timely handling of raw material by the operators. Highlighted among the main features is that this sub process has the possibility of working at low temperatures or high temperatures depending on the pressures to which the material is subjected, and the physical and geometry characteristics that are desired to obtain from this.

The second sub process is finishing which is responsible for making the final processes (polishing, encabar, painting, blasting, etc.) after they have reached a correct temperature. In addition, this sub process is responsible for generating most of the differentiating processes, achieving multiple alternatives in the final product in order to meet market demands.

The segmentation of production lines enables the visualization of the two features of the system. Within this first feature, it is emphasized that the bottleneck and the critical processes (fussiest) are performed in the forging sub process, due to the processing and transformation of material in this point, which requires precise temperature and precise geometric shape conditions. The second characteristic is that downstream of this segment, the diversification processes for different references alternatives are developed. Although the process is seemingly divided, it is necessary to point out that production is continuous and that this concept is simply used to differentiate material flows.

The variety of markets, sectors, products and countries make it difficult to get an accurate sales forecast. In addition, and as in many industries, competition with Asian countries is becoming fierce. This has forced companies to answer to the demands of customization in a short time.

As a consequence, inventory levels have increased and with it all the risks that this entails: increase inventory without rotation, overrun by restatements and increased quality deterioration, among others. On the other hand, it has affected the control and production planning and the current system does not have the ability to assimilate the requirements of flexibility.

In this regard companies have had the need to increase their competitiveness, aligning their production system to market needs. Consequently, companies have seen in postponement strategy a feasible solution to its current problems which is why it is vital to develop a rigorous process that allows the decoupling point location.

4.1.1 Step 0. Make group of product families

The methodology application in the company Herragro S.A starts with 584 product references. Moreover, the whole products were grouped into 9 products mother. Consequently, all the methodology was applied to each of these groups in which was obtained a decoupling point as a result. The main objective is that the result for each product mother will be generalized for all its product children. The products mother were: mandarria, azada, chicura, wheelbarrows, blades, axes, machetes, shovels and mattock.

4.1.2 Step 1. Identification of alternatives for decoupling points (ADP)

Factors selection

According to the company requirements and based on what was presented in the previous chapter, the three selected factors were: product characteristics, production system configuration and market requirements.

Expert selection for ADP identification

A group of four experts was selected. These experts were chosen based on their position and experience in the company (see Table 12). Each expert was assigned to select an alternative decoupling point according to its knowledge. For example, the Chief Marketing Officer selected the ADP to the factor Market demands just for this factor because its knowledge is specialized on this topic.

Table 4-1: Selected experts for ADP identification, case Herragro S.A.

Factors	Role of the selected expert
Market demands	Chief Marketing Officer
Product characteristics	Quality Manager Engineering Manager.
Production system configuration	Production Manager.

ADP selection

As can be seen in Table 13, an ADP for each factor was selected on each product mother.

Table 4-2: ADP for each Product mother, case Herragro S.A.

P. Mother	Factors	ADP
P. Mother 1	Market demands	Polish
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
P. Mother 2	Market demands	Heat treatment
	Product characteristics	Paint and label
	Production system configuration	Heat treatment
P. Mother 3	Market demands	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
P. Mother 4	Market demands.	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Polish
P. Mother 5	Market demands	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
P. Mother 6	Market demands	Punch and mark
	Product characteristics	Punch and mark
	Production system configuration	Clean
P. Mother 7	Market demands	Sharpen
	Product characteristics	Weld
	Production system configuration	Sharpen
P. Mother 8	Market demands	Straighten
	Product characteristics	Thermal treating
	Production system configuration	Straighten
P. Mother 9	Market demands	Heat Treatment
	Product characteristics	Heat Treatment
	Production system configuration	Heat Treatment

As can be seen in Table 13, all the ADP for the 9 product mother are the same, so this product does not need to continue with the application of the methodology and conversely, the decoupling point can be selected in this step because the experts agree to show this point as the best option. Furthermore, besides the Annex G, H and I where the additional information of the methodology is shown, Annex J shows the application of the methodology to this product mother but with a hypothetical alternative decoupling point. This process was created with the aim to validate the methodology performance because the methodology gives the same result which is already considered the best that could mean that the results methodology are satisfactory and according to the company characteristics.

4.1.3 Step 2. Criteria identification

The selected criteria and a brief explanation are presented in Table 4-3.

Table 4-3: Selected criteria, case Herragro S.A.

Criteria	Definition
Lead time (C_1)	Required time of an item to complete customization needs
Productivity (C_2)	Amount of products that can be produced in a shift, taking into account the allocated resources
Stock (C_3)	Unit cost per stored item on DP
Process characteristics (C_4)	Number of processes that need to be performed (downstream) to complete customization needs.
Customization costs (C_5)	It measures the added cost to obtain a customized product.
Storage (C_6)	It evaluates the ADP_m capability to offer proper conditions for work in process storage.
Risk of product damage (C_7)	It evaluates the ADP_m capability to the avoid product damages that affect the quality.
Ease of restarting the production process (C_8)	It evaluates the ADP_m capability to facilitate the process restart without utilizing reworking operations.

4.1.4 Step 3. Weighting of criteria

Expert selection for criteria prioritization

Seven people considered the most experienced of the company were selected. The chosen roles were: engineering manager (E_1), quality manager (E_2), production manager (E_3), logistics manager (E_4), production supervisor (E_5), quality engineer (E_6) and maintenance manager (E_7).

Subjective weighting I (Simple weighting)

By applying Equation 6, the obtained results are summarized in Table 4-4.

Table 4-4: Subjective weighting I, case Herragro S.A.

Criterion	Rating assigned by the experts (C_{ik})								W_{jA}
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	$\sum_k C_{jk}$	
C_1	5	6	7	7	7	8	7	47	0.19
C_2	6	5	8	6	6	6	8	45	0.18
C_3	7	7	3	8	5	7	4	41	0.16
C_4	4	4	2	3	2.5	3	1	19.5	0.08
C_5	1	3	5	5	4	5	5	28	0.11
C_6	2	2	1	1	1	1	2	10	0.04
C_7	8	8	4	4	8	4	8	44	0.17
C_8	3	1	6	2	2.5	2	3	19.5	0.08

Concordance testing

For this case study, 7 experts (M) and 8 criteria (n) were considered. Based on Equations 7 and 8, the obtained values for T and D^2 were 31.5 and 1431.5 respectively. As a consequence, the Kendall concordance index was 0.696 (Equation 9). The result for this process are shown in the Annex G.

Subjective weighting II (the modified triangle of Fuller)

As an example, Table 4-4 shows a paired comparison given to the selected criteria by expert 1 (E_1). In this process the Equation 10 and 11 are used.

Table 4-5: Paired comparison given by expert 1, case Herragro S.A.

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total
C_1	1	0	0	1	1	1	0	1	5
C_2	1	1	1	1	1	1	0	1	7
C_3	1	0	1	1	1	1	0	1	6
C_4	0	0	0	1	1	1	0	1	4
C_5	0	0	0	0	1	0	0	0	1
C_6	0	0	0	0	1	1	0	1	3
C_7	1	1	1	1	1	1	1	1	8
C_8	0	0	0	0	1	0	0	1	2

The same procedure is repeated for the rest of the experts. Annex H shows the pairwise comparison results carried out for all the experts. In Table 4-6 the subjective weighting II (W_{jB}) given by the group of experts is exhibited.

Table 4-6: Subjective weighting II, case Herragro S.A.

Criterion	Rating assigned by the expert (W_{jBk})							W_{jB}
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	
C_1	4	2	8	5	5	6	6	0.25
C_2	6	6	4	7	6	8	5	0.29
C_3	3	1	6	6	4	4	7	0.22
C_4	5	3	2	4	5	4	3	0.18
C_5	5	4	5	1	3	3	5	0.18
C_6	3	7	2	3	3	1	1	0.14
C_7	8	5	7	8	8	3	6	0.31
C_8	2	8	2	2	2	7	3	0.18

Determination of final weight

Based on the results of Tables 4-4 and 4-6**,** the final weighting was calculated by using Equation 12. (See Table 4-7).

Table 4-7: Final weighting, case Herragro S.A.

Criterion	W_{jA}	W_{jB}	W_{jA} x W_{jB}	W_{jD}
C_1	0.19	0.25	0.05	0.19
C_2	0.18	0.29	0.05	0.22
C_3	0.16	0.22	0.03	0.14
C_4	0.08	0.18	0.01	0.06
C_5	0.11	0.18	0.02	0.08
C_6	0.04	0.14	0.01	0.02
C_7	0.17	0.31	0.05	0.23
C_8	0.08	0.18	0.01	0.06

4.1.5 Step 4. Criteria evaluation

Identification of information sources for criteria evaluation

Table 4-8: Evaluation method for each criteria, case Herragro S.A.

Criterion	Evaluation method	Company area
C_1	Company statistical records	Processes
C_2	Company statistical records	Production
C_3	Company statistical records	Processes
C_4	Company statistical records	Processes
C_5	Company statistical records	Processes
C_6	Experts participation	Logistics, Production, Maintenance, Engineering
C_7	Experts participation	Quality, Production, Product warehouse
C_8	Experts participation	Production, Logistics, Processes

Criterion evaluation

Based on statistical records, the performance of the quantitative criteria (C_1….C_5) was obtained. Due to a confidentiality agreement, this information was omitted in the present thesis; as a substitute the normalized dates are shown.

For the case of qualitative criteria (C_6, C_7, C_8), an expert method supported by an AHP was used. As an example for the product mother 1, the evaluation given by the Production Manager to criterion C_8 is shown in Table 4-9. By Applying Equations 13, 14 and 15, the obtained priority vector for this expert can be observed in Table 4-10.

Table 4-9: Evaluation of Production Manager for C_8, case Herragro S.A.

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1/4	1/9
Sharpen	4	1	1/5
Polish	9	5	1

Table 4-10: Priority vector for ADP according to Production Manager in C_8, case Herragro S.A.

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.07	0.04	0.08	0.06
Sharpen	0.29	0.16	0.15	0.20
Polish	0.64	0.80	0.76	0.73

As exhibited in Table 4-11, the final objective weight for C_8 is obtained by repeating the same procedure with the rest of the experts (Equation 16). As can be observed, the most important ADP for product mother 1 regarding C8 is Polish. This procedure must be repeated for the rest of qualitative criteria (C_6, C_7) and the remainder product mother (See Annex I).

Table 4-11: Qualitative Weight for ADP in C_8, case Herragro S.A.

ADP	Production Manager	Logistics Manager	Process Manager	Final weighting (S_f)
Heat Treatment	0.07	0.33	0.71	0.37
Sharpen	0.20	0.33	0.14	0.23
Polish	0.73	0.33	0.14	0.40

Consistency testing

Based on results shown in Table 4-11, and according to Equation 17, the resulting relative weights (R) were 0.196, 0.608 and 2.320 for Heat Treatment, Sharpen and Polish respectively. Consequently, by applying equations 18, 19 and 20, the obtained values for d_{max}, CI and CR were 3.072, 0.0362 and 0.0624 respectively. Therefore, because the obtained value for CR was less than 0.1, it can be stated that the judgment of the Production Manager is consistent for product mother 1 and criterion C_8.

4.1.6 Step 5. ADP evaluation

The quantitative and qualitative results of the eight evaluated criteria were collected. Then, as indicated in Equations 21 and 22, the obtained data were homogenized and normalized. Subsequently, for each line and each ADP, Equation 23 allows the obtaining of the final grade (Q_p). Table 4-12 summarizes these results.

Table 4-12: Summarizes these results.

P. Mother	**ADP**	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**Final grade Q_p**
P. Mother 1	Heat Treatment	0.16	0.30	0.34	0.27	0.30	0.51	0.54	0.37	34.1%
	Sharpen	0.25	0.30	0.33	0.33	0.35	0.26	0.36	0.23	31.0%
	Polish	0.59	0.40	0.33	0.40	0.35	0.23	0.10	0.40	34.9%
P. Mother 2	Heat Treatment	0.35	0.50	0.52	0.29	0.48	0.68	0.5	0.75	48.0%
	Paint and label	0.65	0.50	0.48	0.71	0.52	0.32	0.5	0.25	52.0%
P. Mother 3	Heat Treatment	0.33	0.50	0.54	0.43	0.46	0.84	0.87	0.60	56.2%
	Sharpen	0.67	0.50	0.46	0.57	0.54	0.16	0.13	0.40	43.8%
P. Mother 4	Heat Treatment	0.31	0.50	0.53	0.43	0.37	0.86	0.87	0.37	53.7%
	Polish	0.69	0.50	0.46	0.57	0.63	0.14	0.13	0.63	46.3%
P. Mother 5	Heat Treatment	0.45	0.50	0.53	0.46	0.5	0.75	0.87	0.61	58.8%
	Sharpen	0.55	0.50	0.47	0.54	0.5	0.25	0.13	0.39	41.2%
P. Mother 6	Punch and mark	0.32	0.50	0.51	0.40	0.18	0.70	0.85	0.37	50.9%
	Clean	0.68	0.50	0.49	0.60	0.82	0.30	0.15	0.63	49.1%
P. Mother 7	Weld	0.40	0.50	0.51	0.43	0.32	0.59	0.74	0.23	50.3%
	Sharpen	0.60	0.50	0.49	0.57	0.68	0.41	0.26	0.77	49.7%
P. Mother 8	Heat Treatment	0.18	0.22	0.54	0.34	0.30	0.5	0.65	0.50	39.1%
	Straighten	0.82	0.78	0.46	0.66	0.70	0.5	0.35	0.50	60.9%
P. Mother 9	Heat Treatment according to the experts									100%

4.1.7 Step 6. Decoupling point selection

Finally, based on the results of Table 4-12, the ADP showing the greatest score for each product mother was chosen. Table 4-13 exhibits the selected decoupling points.

Table 4-13: Selected Decoupling Points, case Herragro S.A.

Production Line	Decoupling Point	Rating
P. Mother 1	Polish	34.9%
P. Mother 2	Paint and label	52.0%
P. Mother 3	Heat Treatment	56.2%
P. Mother 4	Heat Treatment	53.7%
P. Mother 5	Heat Treatment	58.8%
P. Mother 6	Punch and mark	50.9%
P. Mother 7	Weld	50.3%
P. Mother 8	Straighten	60.9%
P. Mother 9	Heat Treatment	100%

4.2 Case study #2: Muebles Marco Gomez Company

Muebles Marco Gómez (MMG) is a company belonging to the industrial sector; it is dedicated to the production and commercialization of household furniture (see figure 4-4). Currently, the company competes in a market with a wide offering of different styles. The strongest competitors are nationwide companies that have systematized the process and sell standardized products through great platform, therefore responding to the needs of high production speed and low cost. On the other hand, they are small producers who develop the product upon request with a high level of customization.

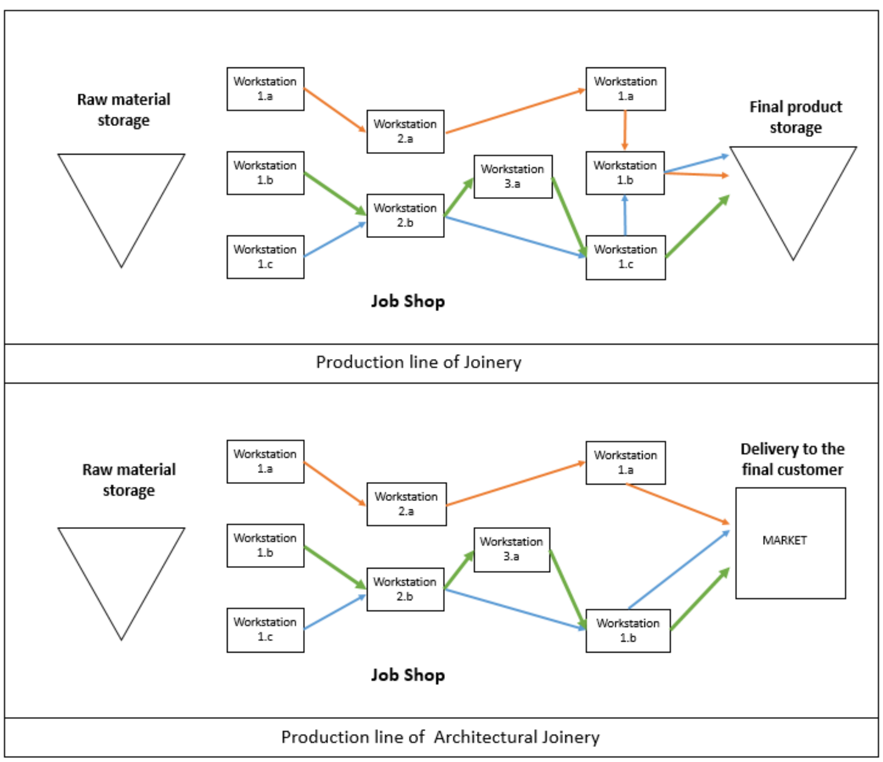
Figure 4-4: Products of the Muebles Marco Gomez.

The manufacturing of its products is based on standardized designs with small modifications in finishes such as color or esthetic changes to customer orders. Additionally, the company makes custom designs if it is requested by the customer. Although there are standardized designs, the production system is not very flexible. The reason why, is that the timely response to orders depends on high inventory levels; or, if there is no reference inventory, the costumer must wait until the production process finishes, which lags in efficiency level.

The company currently is divided into two production lines, the architectural millwork line dedicated to the manufacture of integral kitchens, bathroom furniture, closets, doors, windows and libraries which predominate the exclusive designs. And secondly, it has a cabinetmaking line that offers household products such as bedrooms, dining rooms, living rooms, beds and wardrobes that are aimed at a market generally between stratus 3 and 4, where quality and immediate delivery is important.

Both production lines have a job shop configuration. Each line is formed by different cells or workstations aimed at providing a wide range of alternatives in the process. In this one, the references do not necessary follow an established sequence, but according to customers' production requirements, the sequence can be modified to obtain different results. Despite this, it is important to note that the system maintains a standardized logic in the production process. As can be inferred, the main characteristic of this configuration is its high flexibility (see Figure 4-5).

Figure 4-5: Schematic representation of the Muebles Marco Gomez production configuration.



Source: elaborated by myself

The advantage of the carpentry line is that, the products are made to order. Therefore, customers are willing to wait until the product is finished and this same condition causes inventory to become unnecessary. Moreover, the cabinetry line must meet high flexibility levels which is derived from its production system, but additionally must meet high efficiency levels. Becuse the production system does not have the capacity to address these needs of efficiency, the company must maintain high inventory levels, assuming all risks and losses that this involves (see Figure 4-5).

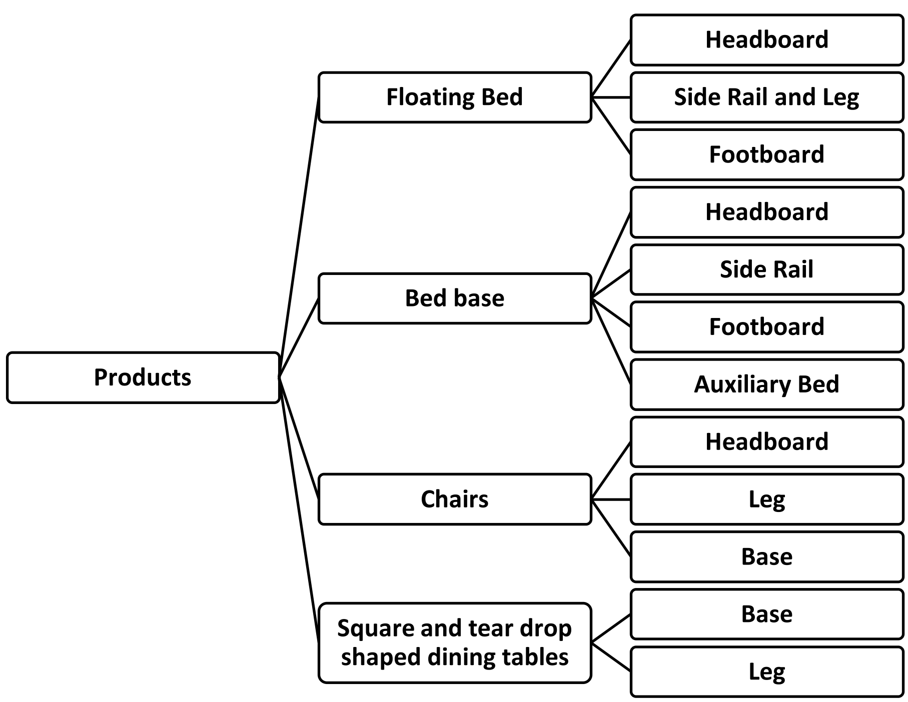
The methodology was applied in the line joinery because this requires a balance between flexibility and efficiency.

4.2.1 Step 0. Make group of product family

The methodology application in the company Muebles Marcos Gomez starts with 64 products references. Moreover, all of these products were gathered in 5 product mothers. The product mothers were: floating bed, bed base, chair and square dining tables, tear drop shaped dining tables.

Each of these products is made up with the assembly of different pieces that have a particular production process. In this case, the methodology is not only applied to the products mother but also to their principal pieces (see Figure 4-6). This means that depending on the numbers of the pieces that the product mother has, it could be the same number of decoupling points for each product mother.

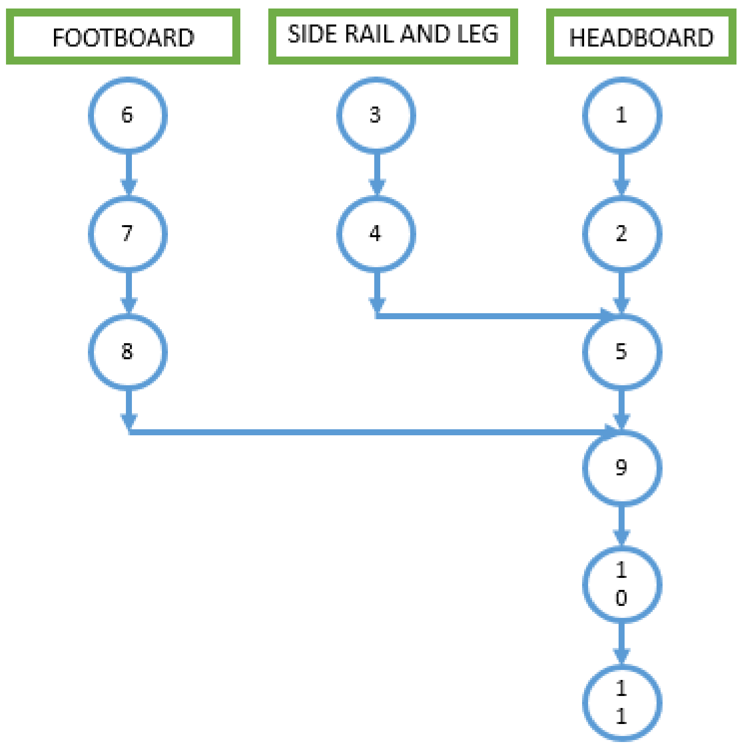
Figure 4-6: Products that were studied in the Methodology.



In this part, it is necessary to clarify that although there are different pieces for each product mother, there is just one that is the most important and the decoupling point placement in this piece can limit the existence of the decoupling point in the other pieces of the same produts mother.

For example, Figure 4-7 indicates that if it is taken into consideration that the main piece for the floating bed is the Headboard and the DP for this piece is placed after the assembly of all the other pieces (after process 9), the others pieces cannot have a DP. But if the DP for the Headboard is placed after the assembly of the Footboard (after process 5) it is necessary to select another DP for the Side Rail and Leg pieces.

Figure 4-7: Process flow diagram of the Floating Beb.



Source: elaborated by myself.

4.2.2 Step 1. Identification of alternatives for decoupling points (ADP)

Factors selection

According to the company requirements and based on what was presented in the previous chapter, the three selected factors were: product characteristics, production system configuration and market requirements.

Expert selection for ADP identification

A group of five experts was selected. These experts were chosen based on their position and experience in the company (see Table 4-14). Each expert was assigned to select an alternative decoupling point according to their knowledge.

Table 4-14: Selected experts for ADP identification, case Muebles Marco Gomez.

Factors	Role of the selected expert
Market demands	Administrative manager Machining operator
Product characteristics	Chief joinery Administrative manager
Production system configuration	Two sallers Administrative manager

ADP selection

As can be seen in Table 4-5, an ADP for each factor was selected for each product mother.

Table 4-15: *ADP for each Product mother, case Muebles Marco Gomez*

Product Mother	Pieces of Product Mother	Factors	ADP
Floating Bed	Headboard	Market demands	Router
		Product characteristics	Join
			Sheathe
		Production system configuration	Patch
	Footboard	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch
	Side Rail and Leg	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Polish
Bed base	Headboard	Market demands	Router
		Product characteristics	Router
		Production system configuration	Router
	Side Rail	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch
	Footboard	Market demands	Router
		Product characteristics	Router
		Production system configuration	Router
	Auxiliary bed	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch

Product Mother	**Pieces of Product Mother**	**Factors**	**ADP**
Chairs	Headboard	Market demands	Router
			Patch
		Product characteristics	Sheathe
			Cut MDF
		Production system configuration	Router
	Leg	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch
	Base	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch
Dining tables. Square	Base	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Join
	Leg	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch
Dining tables. Tear drop shaped	Base	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Join
	Leg	Market demands	Patch
		Product characteristics	Patch
		Production system configuration	Patch

As can be seen in Table 4-5, the only pieces that have different alternative decoupling points and, hence, continue with the methodology process are: Headboard of the floating bed, Side Rail and Leg of the floating bed, the Headboard of the chair, the base of the dining tables (square) and the base of the dining tables (tear drop shaped)

As in the previous application, the Headboard of the Bed base was selected in order to analyze the methodology performance. The results were also positive because the decoupling point obtained by the methodology was the same that the experts agreed to select. Therefore, Annex N shows the application of the methodology to this piece but with a hypothetical alternative decoupling point, and besides the Annex K, L and M where the additional information of the methodology is shown.

4.2.3 Step 2. Criteria identification

The selected criteria and a brief explanation are presented in Table 4-16.

Table 4-16: Selected criteria, case Muebles Marco Gomez.

Criteria	Definition
Lead time (Upstream) (C_1)	Required time of an item to complete customization needs
Lead time (Downstream) (C_2)	Required time of an item to produce the piece downstream of the DP
Storage (C_3)	It evaluates the ADP_m capability to offer proper conditions to work in process storage.
Process characteristics (C_4)	Number of process that needs to be performed (downstream) to complete customization needs.
Risk of product damage (C_5)	It evaluates the ADP_m capability to avoid product damages that affect the quality.
Production planning (C_6)	Evaluate the facility to plan the production up of the DP
Customization costs (C_7)	Measures the added cost to obtain a customized product.
Productivity (C_8)	Amount of products that can be produced by shift, taking into account the allocated resources

4.2.4 Step 3. Weighting of criteria

Expert selection for criteria prioritization

Eight people considered the most experienced of the company were selected. The chosen roles were: Administrative manager (E_1), joinery operator I (E_2), joinery operator II (E_3), joinery operator III (E_4), Shareholder and ex-director I (E_5), Shareholder and ex-director II (E_6) chief joinery (E_7) and production manager (E_8). The results of this process are shown in the Annex K.

Subjective weighting I (Simple weighting)

By applying Equation 6, the obtained results are summarized in Table 4-17.

Table 4-17: Subjective weighting I, case Muebles Marco Gomez.

Criterion	Rating assigned by the experts (C_{ik})									W_{jA}
	E_1	**E_2**	**E_3**	**E_4**	**E_5**	**E_6**	**E_7**	**E_8**	$\sum C_{jk}$	
C_1	6	6	6	7	6	5	7	7	50	0.1736
C_2	5	8	7	5	4	4	4	5	42	0.1458
C_3	2	1	1	2	1	1	2	1	11	0.0382
C_4	4	5	5	6	5	6	1	4	36	0.1250
C_5	7	7	8	8	7	8	8	8	61	0.2118
C_6	3	2	2	1	3	3	6	6	26	0.0903
C_7	1	3	4	4	2	2	3	3	22	0.0764
C_8	8	4	3	3	8	7	5	2	40	0.1389

Concordance testing

For this case study 8 experts (M) and 9 criteria (n) were considered. Based on Equations 7 and 8 the obtained values for T and D^2 were 40 and 2477 respectively. Consequently, the Kendall concordance index was 0.645 (Equation 10).

Subjective weighting II (the modified triangle of Fuller)

As an example, Table 4-18 shows a paired comparison given to the selected criteria by expert 1 (E_1). In this process the Equation 10 and 11 are used.

Table 4-18: Paired comparison given by expert 1, case Muebles Marco Gomez.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total
C_1	1	0	1	0	0	0	1	0	3
C_2	1	1	1	0	0	1	1	0	5
C_3	0	0	1	0	0	0	0	0	1
C_4	1	1	1	1	0	0	1	0	5
C_5	1	1	1	1	1	1	0	0	6
C_6	1	0	1	1	0	1	1	0	5
C_7	0	0	1	0	1	0	1	0	3
C_8	1	1	1	1	1	1	1	1	8

The same procedure is repeated for the rest of the experts. Annex L shows the pairwise comparison results carried out for all the experts. In Table 4-19 the subjective weighting II (W_{jB}) given by the group of experts is exhibited.

Table 4-19: Subjective weighting II, case Muebles Marco Gomez.

Criteria	Rating assigned by the expert (W_{jBk})								W_{jB}
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	
C_1	3	3	3	1	6	5	3	3	0.093
C_2	5	2	4	4	2	4	4	2	0.093
C_3	1	2	1	2	1	1	6	6	0.069
C_4	5	4	6	5	4	6	4	1	0.121
C_5	6	6	6	8	7	8	8	8	0.197
C_6	5	6	7	6	5	3	3	5	0.138
C_7	3	7	4	3	3	2	1	4	0.093
C_8	8	6	5	7	8	7	7	7	0.191

Determination of final weight

Based on the results of Tables 15 and 17**,** the final weighting was calculated by using Equation 12. (See Table 4-20).

Table 4-20: Final weighting, case Muebles Marco Gomez.

Criteria	W_{jA}	W_{jB}	W_{jA} x W_{jB}	W_{jD}
C_1	0.17	0.09	0.02	0.12
C_2	0.15	0.09	0.01	0.10
C_3	0.04	0.07	0.00	0.02
C_4	0.13	0.12	0.02	0.11
C_5	0.21	0.20	0.04	0.31
C_6	0.09	0.14	0.01	0.09
C_7	0.08	0.09	0.01	0.05
C_8	0.14	0.19	0.03	0.20

4.2.5 Step 4. Criteria evaluation

Identification of information sources for criteria evaluation

Table 4-21: Evaluation method for each criteria, case Muebles Marco Gomez.

Criteria	Evaluation method	Company area
C_1	Company statistical records	Processes
C_2	Company statistical records	Processes
C_3	Experts participation	Production manager, chief joinery and administration secretary
C_4	Company statistical records	Production
C_5	Experts participation	Production manager, chief joinery and joinery operator
C_6	Experts participation	Production manager
C_7	Company statistical records	Production
C_8	Company statistical records	Production

Criterion evaluation

Based on statistical records, the performance of the quantitative criteria (C_1, C_2, C_4, C_7, C_8, C_9) was obtained. Due to a confidentiality agreement this information was omitted in the present thesis; as a substitute it is shown the normalized dates.

For the case of qualitative criteria (C_3, C_5, C_6), an expert method supported by an AHP, was used. As an example for the product Headboard of the Bed base, the evaluation given by the Production Manager to criterion C_3 is shown in Table 4-22. By Applying Equations 13, 14 and 15, the obtained priority vector for this expert can be observed in Table 4-23.

Table 4-22: Evaluation of Production Manager for C_3, case Muebles Marco Gomez.

ADP	Router	Join	Sheathe	Patch
Router	1	3	3	9
Join	1/3	1	1	7
Sheathe	1/3	5	1	9
Patch	1/9	1/7	1/9	1

Table 4-23: Priority vector for ADP according to Production Manager in C_3, case Muebles Marco Gomez.

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.56	0.58	0.59	0.35	0.52
Join	0.19	0.19	0.20	0.27	0.21
Sheathe	0.19	0.19	0.20	0.35	0.23
Patch	0.06	0.03	0.02	0.04	0.04

As exhibited in Table 4-24, the final objective weight for C_3 is obtained by repeating the same procedure with the rest of experts (Equation 16). As can be observed, the most important ADP for the product Headboard of the Bed base regarding C_3 is Rutear. This procedure must be repeated for the rest of qualitative criteria (C_5, C_6) and the remainder product mother (see Annex M).

Table 4-24: Qualitative Weight for ADP in C_3, case Muebles Marco Gomez.

ADP	Production manager	Chief joinery	Administration secretary	Final weighting (S_f)
Router	0.52	0.38	0.56	0.49
Join	0.21	0.38	0.18	0.26
Sheathe	0.23	0.20	0.22	0.22
Patch	0.04	0.04	0.04	0.04

Consistency testing

Based on results shown in Table 35, and according to Equation 17, the resulting relative weights (R) were 0.219, 0.880, o.950 and 0.150 for router, join, sheathe and patch. Consequently, by applying equations 18, 19 and 20, the obtained values for d_{max}, CI and CR were 4.128, 0.042 and 0.038 respectively. Therefore, because the obtained value for CR was less than 0.1, it can be stated that the judgment of the Production Manager is consistent for product headboard of the bed base and criterion C_3.

4.2.6 Step 5. ADP evaluation

The quantitative and qualitative results of the eight evaluated criteria were collected. Then, as indicated in Equations 21 and 22, the obtained data were homogenized and normalized. Subsequently, for each line and each ADP, From Equation 23 the final grade is obtained (Q_p). Table 4-25 summarizes these results.

Table 4-25: Evaluation results for each ADP, case Muebles Marco Gomez.

Product	ADP	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Final grade Q_p
Floating bed. Headboard	Router	0.13	0.25	0.49	0.20	0.40	0.51	0.27	0.33	32.1%
	Joint	0.39	0.25	0.26	0.33	0.22	0.20	0.21	0.33	27.4%
	Sheathe	0.35	0.25	0.22	0.30	0.32	0.25	0.22	0.33	30.2%
	Patch	0.13	0.25	0.04	0.18	0.06	0.05	0.30	0.01	10.3%
Floating bed. Side Rail and Leg	Patch	0.19	0.81	0.86	0.68	0.87	0.88	0.68	0.50	68.0%
	Polish	0.81	0.19	0.14	0.32	0.13	0.13	0.32	0.50	32.0%
Floating bed. Footboard	Patch according to the experts									100%
Bed Base. Headboard	Router according to the experts									100%
Bed Base. Side Rail	Patch according to the experts									100%
Bed Base. Footboard	Router according to the experts									100%
Bed Base. Auxiliary bed	Patch according to the experts									100%
Chairs. Headboard	Sheathe	0.09	0.30	0.48	0.21	0.44	0.30	0.28	0.25	30.2%
	Router	0.65	0.07	0.29	0.37	0.26	0.39	0.16	0.25	30.5%
	Cut MDF	0.16	0.28	0.16	0.24	0.26	0.26	0.27	0.25	24.4%
	Patch	0.09	0.34	0.07	0.18	0.05	0.04	0.29	0.25	15.0%
Chairs. Leg	Patch according to the experts									100%
Chairs. Base	Patch according to the experts									100%
Dining tables Square. Base	Patch	0.39	0.70	0.88	0.54	0.82	0.83	0.55	0.50	65.1%
	Join	0.61	0.30	0.12	0.46	0.18	0.17	0.45	0.50	34.9%
Dining tables Square. Leg	Patch according to the experts									100%
Dining tables tear drop shaped. Base	Patch	0.43	0.69	0.88	0.54	0.82	0.83	0.58	0.50	65.6%
	Join	0.57	0.31	0.12	0.46	0.18	0.17	0.42	0.50	34.4%
Dining tables tear drop shaped. Leg	Patch according to the experts									100%

4.2.7 Step 6. Decoupling point selection

Finally, based on the results of Table 4-25, the ADP showing the greatest score for each piece for the product mother were chosen. Table 4-26 exhibit the selected decoupling points.

Table 4-26: Selected Decoupling Points.

Product	ADP	Final Result Q_p
Floating bed. Headboard	Router	32.10%
Floating bed. Side Rail and Leg	Patch	68.00%
Floating bed. Footboard	Patch	100%
Bed Base. Headboard	Router	100%
Bed Base. Side Rail	Patch	100%
Bed Base. Footboard	Router	100%
Bed Base. Auxiliary bed	Patch	100%
Chairs. Headboard	Router	30.50%
Chairs. Leg	Patch	100%
Chairs. Base	Patch	100%
Dining tables Square. Base	Patch	65.10%
Dining tables Square. Leg	Patch	100%
Dining tables tear drop shaped. Base	Patch	65.60%
Dining tables tear drop shaped. Leg	Patch	100%

4.3 Partial conclusions

The two case studies have been a source of information and one way to validate the performance of the methodology in the real companies vital for this thesis. This is principally because the difference between the two companies refers to the market requirements and the production system configuration.

In the first instance, the methodology was applied to a company which has a production system with high levels of efficiently, but in which the market requires more flexibility. In contrast, the second application was made in a company with a flexible production system, but in which the market requires more efficiency.

As expected, these differences between the strategies imply a discrepancy in the characteristics of the complete system and the human resources that work there. These differences were used to show the high level of flexibility which the design methodology has; because it can be adapted easily to be applied in both companies according to their contexts.

Therefore, these applications achieve tests that the design methodology can use when the companies require more flexibility or when they require more efficiency. This means, the methodology places the decoupling point and therefore, the production postponement searches a balance between flexibility and efficiently according to the market and production systems requirement.

Two others results were obtained. First, it was proved that the methodology application can place decoupling points precisely. On both applications, the experts agreed in a same alternative decoupling point for the one product mother, so the methodology was applied in these products which accessed the same result. This means, although the decoupling point had been already known before the methodology was used, the results of these precisely applied prove that the methodology is adapted to the system characterizes, giving a precise decoupling point.

Secondly, it highlighted that the design methodology has some advantages when placing the decoupling point simultaneously in different products mother or different productions lines. Accordingly, both applications show that in the same process many decoupling points can be determined, each of these for one product mother. Hence, this methodology not only allows making a widespread study including qualitative, quantitative criteria and the active participation of the experts but also it can be applied in different companies with different contexts and characteristics and, additionally, it can be applied in all the company product references simultaneously.

5. Conclusion and Recommendations

5.1 Conclusions

Current markets present a big challenge for companies. The increase of bargaining power by the customer has allowed them the power to make demands to manufacturing companies for high levels of efficiency and flexibility simultaneously. In addition to this, they have the ability to choose the time, place and the company for buying, causing high dynamism in the market and problems in production planning.

According with these new alternatives, the research on issues related to mass customization and postponement has begun to increase. This fact has led to the need to strengthen research contributions in the topic of decoupling point, since this is identified as the factor of success and the most important decision in alternative strategies considered within new paradigms of production.

In this thesis, it was identified that despite the advances in contributions to develop a model for the location of the decoupling point of, there is a need to develop a methodology that not only allows the inclusion of qualitative and quantitative variables in the study, but also allows active participation of experts when making decisions, which in this case has a strategic character of great importance for companies.

From this need, this thesis develops a multi-criteria methodology that provides great comparative advantages against other alternatives in the literature. First, it is a methodology that not only allows the integration of qualitative and quantitative variables in the decision making, but also is based on the strategic character of this process, which allows experts to actively integrate them selves in decision making. Second, the methodology does not select a single group of experts to evaluate all the items present in the different steps, but instead allows for each step that requires the participation of experts, make an evaluation this. Thus it is avoided the participation of people on issues which are out of their control.

Third, the designed methodology has great flexibility, so that it can be easily adapted to different kind of companies, obtaining results that facilitate decision making for individual companies. Fourth, the designed methodology can be applied simultaneously to identify the decoupling point for the entire portfolio of references of companies or for all production lines, which allows making a general study of the entire company efficiently and effectively.

This methodology was applied in two case studies. In addition to showing the relevance of its results its ability to respond effectively to different contexts and different needs was also showed. Herrago S.A needs to increase flexibility, while the company Muebles Marco Gómez needs to increase efficiency.

In this way, it is provided to the academic society and the business community a new flexible and effective tool to begin the process of adapting the manufacturing strategy to current market conditions based on the concept of postponement and mass customization.

5.2 Recommendations

Like all research and technological development processes, the described results in this thesis has limitations, which should be mentioned to understand the scope of the results offered by the methodology and, as is characteristic of scientific progress, to be sources of future researches. For this reason, the different limitations are listed below:

1. The importance of the participation of experts deserves the qualification of their level of expertise and knowledge, to identify the relevance of their participation in decision making. Even so, it should be noted that the design of the methodology requires the participation of experts in specific items. For this reason, the qualification can not start from a general method for all but instead, should be an individualized process in which their expertise is measured according to the item in which they are involved.

   As can be seen, the presence of experts in different steps of the methodologycauses that their assessment can become a tedious process that hinders the overall development. Therefore, it is necessary to develop a different and creative technique that facilitates the process without losing sight of their criticality and the need for efficiency.

2. Although there are different models to measure the consensus in the group AHP with AIJ, the review of the literature did not show a model that would measure the AHP group consensus when this is done by the AIP. Now, it considers that the designed methodology used the AIP in the participation of experts to rate the criteria and it is necessary to understand that the methodology does not have a model to establish the level of agreement among the perception of the experts about the calcification of the alternative decoupling point with the qualitative criteria.

3. The customization of a product can be given at any point in the supply chain. Even so, this document is only directed to the production system, implying a restriction on the methodology scope.

5.3 Future research lines

The research process and the obtained results, open the door to future research; which not only will contribute to improve the results obtained here but also can contribute to the advancement of general knowledge. Some research topics are suggested bellow:

1. Some authors show the possibility of locating more than one decoupling point in the seam production system or supply chain (Verdouw et al. 2008; Wang et al. 2012; Wikner and Wong 2007). This means, locating more than one decoupling point for the same product mother. From this point, an investigative process can be generated to validate or improve the applicability of the methodology in this context.

2. The popularity and usefulness of AHP method and in this particular case, the group AHP, deserves to drive research in this field. In this case, the opportunity to develop and evaluate a mathematical model to assess the consensus among experts when the AIP technique is applied either through geometrical or arithmetical weighting, was detected.

3. The growing interest in improving service systems and adapting the decoupling points to these, invite a comparison if the designed methodology can be applied in this context. Therefore, it is suggested to identify whether the scope of the method overcomes the barriers of postponement in production. In this sense it could be compared to other segments of the supply chain with “form postponement” or even verify its performance throughout the entire chain with logistics postponement.

4. Current projects and the current concerns of businesses should consider not only economic benefits but also must understand that their decisions have a social and environmental impact (Munier 2011; Trappey, Wognum, and Trappey 2011) and therefore participate in an emergent research topic: sustainable mass customization (Boër et al. 2013; Osorio et al. 2001).

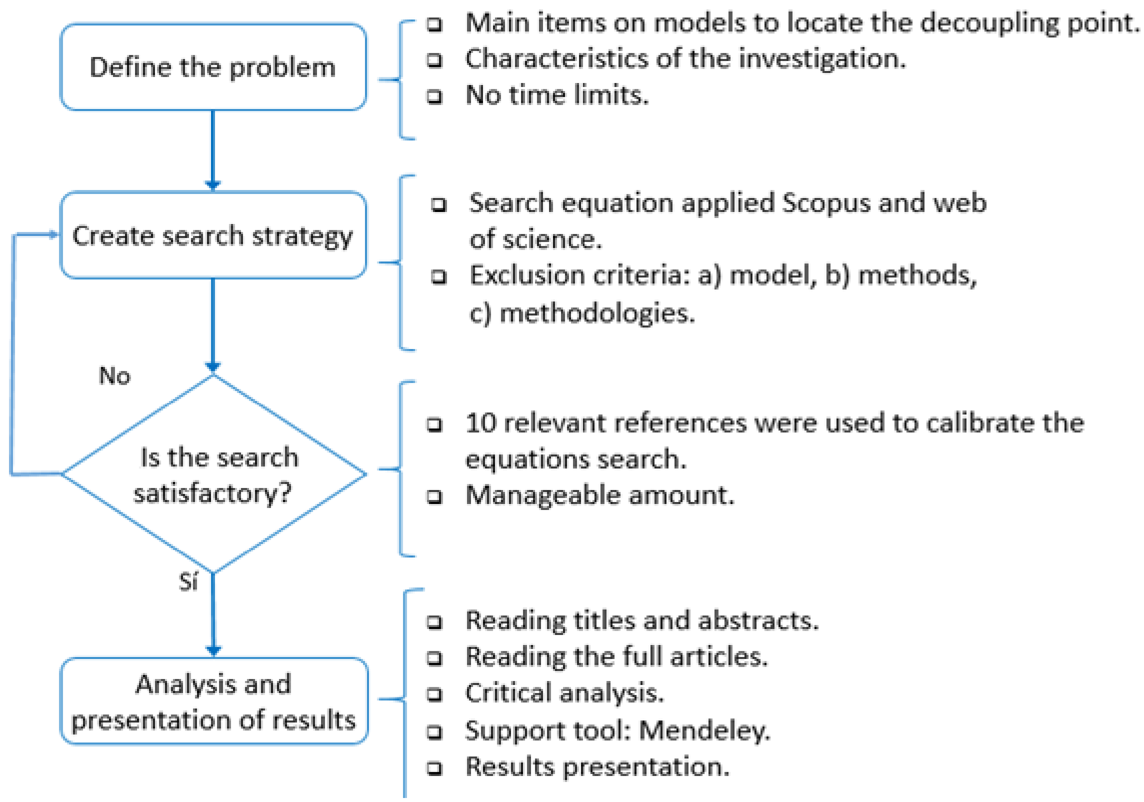
   These sustainability requirements are new sources of research which in this case may have a strong relationship with the decision of the decoupling point location. This point of view raises the possibility of research in the sustainable selection of a decoupling point and adapt the methodology effectively.

5. The literature highlights that despite multiple applications and theoretical developments addressed to the issue of postponement and mass customization, the development of methodologies for its application in companies is still lagging (Daaboul, Bernard, and Laroche 2012; Hoek 2001; Shidpour, Da Cunha, and Bernard 2014; Stojanova, Suzic, and Orcik 2012; Suzic, Anišic, and Forza 2014). The result of this document is only one of the links of the requirements for applying postponement. But it is a valuable starting point from which an investigative process can be started.

A. Annex: Description of the systematic literature review

Aiming to identify used models, techniques or methods for the DP location, and thus developing an analysis of the achieved progress in the field of research, a systematic review was performed, following the steps shown in Figure A-1. This methodology was used in order to meet the minimum conditions of effectiveness, clarity and replicability.

Figure A-1: Systematic search methodology.



Source: elaborated by (Vivares-Vergara 2014)

The main input for the systematic search is the search equation which should contain the basic information of interest, represented by keywords. For this reason, the research started from a narrative search that offered the opportunity to go deeper into the issue and therefore, allowed highlighting the most important words and create the search equation.

The general question that drove the search was as follows:

What models for the decoupling point location exist in specialized literature?

As mentioned above, everything began with a deepening process of the subject in order to make a proper selection of the necessary words to the development of the search equation. Having clarified this purpose, a narrative search was performed and resulted in the highlighted documents in Table A-1.

Table A-1: Found reference from the narrative search.

Article title	Authors	Year
A Leading Journal of Supply Chain Management A theoretical framework for postponement concept in a supply chain	(Ferreira, Tomas, and Alcântara 2015)	2014
CODP Position of leagile supply chain based on polychromatic sets theory	(Liu, Wang, and Fu 2009)	2009
Positioning of CODP Based on Entropy Technology and Ideal Point Principle	(Luo and Han 2008)	2008
Positioning multiple decoupling points in a supply network	(Sun et al. 2008)	2008
Multiple decoupling point paradigms in a global supply chain syndrome : a relational analysis	(Banerjee, Sarkar, and Mukhopadhyay 2012)	2012
Analysis of form postponement based on optimal positioning of the differentiation point and stocking decisions	(Wong, Wikner, and Naim 2009)	200

According to the readings of the different articles, a collection of words and acronyms used by the authors or highlighted by them to make reference to the decoupling point was generated (See Table A-2)

Table A-2: Referenced words.

Concept	Author
Customer order decoupling point	(Luo and Han 2008) (Banerjee, Sarkar, and Mukhopadhyay 2012)
Decoupling point	(Ferreira, Tomas, and Alcântara 2015) (Luo and Han 2008) (Sun et al. 2008) (Banerjee, Sarkar, and Mukhopadhyay 2012)
CODP (*customer order decoupling point*)	(Luo and Han 2008)
Order penetration point	(Banerjee, Sarkar, and Mukhopadhyay 2012)
OPP (*order penetration point*)	(Wong, Wikner, and Naim 2009)
DP (*decoupling point*)	(Sun et al. 2008)

From this point, the systematic search was developed in four stages:

In the first stage the search equation #1 was applied in the bibliographical tools Scopus and Web of Science (See Table A-3). These tools resulted in a total of 2350 and 938 references respectively. Later the reading of the abstracts and titles identified that the search equation was biased, which caused that some of the results were inconsistent with regard to the issue of interest. Through a segmented search equation analysis, it was identified that the origin of this difficulty was the use of acronyms; as these could have different interpretations in different research areas. From which the search equation #2 was performed (See Table A-4).

Table A-3: Search equation #1.

Search equation #!			
#	**Concept**	**#**	**Concept**
1	Customer order decoupling point	7	Location
2	Decoupling point	8	Decision
3	CODP		
4	Order penetration point		
5	OPP		
6	DP		

Related search equation

(“#1” OR “#2” OR “#3” OR” #4” OR “#5” OR “#6”) AND (“#7” OR “#8”)

Search fields: title, abstract and key words

Year ≤ 2015 to date (March 4 and 5)

Type: All

Table A-4: Search equation #2.

Search equation #2			
#	**Concept**	**#**	**Concept**
1	Customer order decoupling point	4	Location
2	Decoupling point	5	Decision
3	Order penetration point		

Related search equation

(“#1” OR “#2” OR “#3”) AND (“#4” OR “#5”)

Search fields: title, abstract and key words

Year ≤ 2015 to date (March 4 and 5)

Type: All

In the second stage, the search equation #2 was used, having as a result a total of 35 references for Web of Science and 66 for Scopus. With these reference the articles of interest were selected by reading the titles and abstracts. This process allowed refining the pertinence of the obtained results in a total of 29 references for Scopus and 21 references for Web of Science.

The third stage was focused on the reading of the first selected articles to validate the search equation and to anticipate any difficulties in the process. Thereby, it was possible to identify that the search equation did not include an important word “model”. This word allows direct searches of different models to select the decoupling point. Therefore, the search equation #3 was developed. (See Table A-5)

Table A-5: Search equation #3.

Search Equation #3			
#	**Concept**	**#**	**Concept**
1	Customer order decoupling point	4	Location
2	Decoupling point	5	Decision
3	Order penetration point	6	Model

Search equation related

(“#1” OR “#2” OR “#3”) AND (“#4” OR “#5” OR “#6”)

Search fields: title, abstract and key words

Year ≤ 2015 to date (March 15 to 20)

Type: All

From the previous search, a total of 146 references were found in Scopus and 68 references in Web of Science. After the cleaning process and search refinement, a total of 35 articles were obtained. The detailed reading of these articles allowed identifing 6 words which had not been considered, and are important for the search equation structuring. Therefore, a last search equation was structured (See Table A-6).

Table A-6: Search equation #4.

Search equation #4			
#	**Concept**	**#**	**Concept**
1	Customer order decoupling point	9	Location
2	Decoupling point	10	Decision
3	Order penetration point	11	Model
4	Customer order point	12	Placement
5	Postponement point		
6	Point of differentiation		
7	Delayed product differentiation		
8	Custoization point		

Search equation related

("#1" OR "#2" OR "#3") AND ("#4" OR "#5" OR "#6")

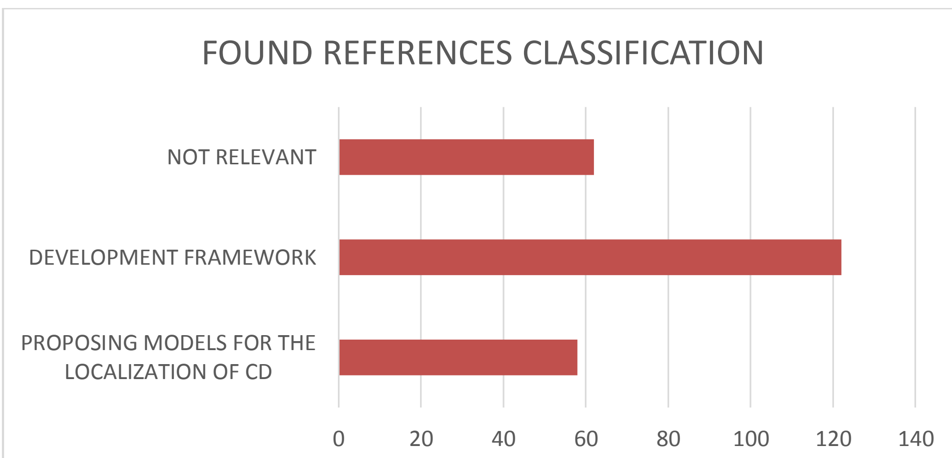
Search fields: title, abstract and key words

Year ≤ 2015 to date (October 14, 2015)

Type: All

From the final search, a total of 210 references were detected in the bibliographic tool Scopus and 112 references in Web of Science. The comparison between the obtained articles in the two bibliographic tools showed that 80 of them were repeated in both. As a result, a total of 242 articles was obtained. Among them, only 59 were closely related to the subject of interest because they displayed models, techniques or methods for the decoupling point location. Regarding the other references, 122 articles were related to the topic of decoupling point location, but they only developed theories of it without proposing any model or tool for its location. The remaining 61 articles were not related to the subject or the study area (See Figure A-2).

Figure A-2: Found references classification.



The systematic search methodology resulted in a total of 46 items (See Annex B). Among the 59 detected articles there were 13 articles which could not be accessed, 4 of them because they were written in one of the Altaic languages and 9 because they were not available.

B. Annex: Models for decoupling point location

Table B-1: Detected decoupling point location models.

#	REFERENCE	SO	MO	QT	MS	DM	GM	ES	ME	PST	AHP	FANP
1	(Ngniatedema, Fono, & Mbondo, 2015)	X										
2	(Yang & Wang, 2014)	X										
3	(Fahmy, Mohamed, & Abdelmaguid, 2014)					X						
4	(W. Liu, Mo, Yang, & Ye, 2014)	X										
5	(Shidpour, Da Cunha, & Bernard, 2014)		X									
6	(L. Zhou & Li, 2014)					X						
7	(W. Zhou, Huang, & Zhang, 2014)			X								
8	(Vanteddu & Chinnam, 2014)	X										
9	(W. Liu, Yang, et al., 2014)		X									
10	(W. Liu, Xu, Sun, Yang, & Mo, 2013)		X									
11	(Ebrahim Teimoury & Fathi, 2013)			X								
12	(Karrer, Alicke, & Günther, 2012)			X	X							
13	(E Teimoury, Modarres, Khondabi, & Fathi, 2012)			X								
14	(Huang, Wang, Ren, & Zhang, 2012)	X										
15	(Qin & Geng, 2011)			X	X							
16	(X. Xu & Liang, 2011)										X	
17	(Cirullies, Klingebiel, & Scarvarda, 2011)				X							
18	(Jeong, 2011)					X						
19	(Hamed Rafiei & Rabbani, 2011)											X
20	(Wang, 2011)							X				
21	(Velev, Andreev, & Panayotova, 2011)										X	
22	(Ji & Sun, 2011)	X										
23	(M. Zhang, Cheng, Zhang, & Guo, 2010)				X							
24	(Tang & Chen, 2009)	X										
25	(Hamed Rafiei & Rabbani, 2009)					X						
26	(J. G. J. Ge, Wei, Huang, & Gao, 2009)	X			X							
27	(H Rafiei & Rabbani, 2009)											X
28	(D. Liu, Wang, & Fu, 2009)									X		
29	(Jewkes & Alfa, 2009)			X								
30	(Ahmadi & Teimouri, 2008)					X						

#	REFERENCE	SO	MO	QT	MS	DM	GM	ES	ME	PST	AHP	FANP
30	(Ahmadi & Teimouri, 2008)					X						
31	(J. H. Ge, Huang, Xu, & Gao, 2008)	X			X							
32	(Wu, Ma, Yang, & Sun, 2008)			X								
33	(Sun, Ji, Sun, & Wang, 2008)	X										
34	(Luo & Han, 2008)								X			
35	(Gupta & Benjaafar, 2008)			X								
37	(Y.-B. Zhang & Chen, 2008)			X	X							
38	(Xuan G. Xu, 2007)						X					
39	(JI, Qi, & GU, 2007)	X										
40	(X.G Xu, Li, & Kong, 2007)							X				
41	(Chen, Kang, & Lee, 2006)					X						
42	(Ashayeri & Selen, 2005)							X				
43	(Hsu & Wang, 2004)					X						
44	(Viswanadham & Raghavan, 2000)			X								
45	(Raghavan & Viswanadham, 1999)			X								
46	(Lee & Tang, 1997)	X										
	Número total de artículos	12	3	11	7	7	1	4	1	1	2	2

C. Annex: Current market characterization

This Annex displays the obtained results from the narrative review of the literature destined to obtain information about the main features of today's markets. This required the development of a total of 19 articles and a doctoral thesis.

As a result, was obtained:

- According to the reviewed articles, 8 current market features were found:
    1. Technology evolution.
    2. Increase on competitiveness among companies.
    3. Globalization.
    4. The dynamic of the markets.
    5. Different localization of the markets.
    6. Decreased in the life cycle of products.
    7. The most demanding requirements and/or individualized.
    8. High levels control of information by customers.

- Among the detected features, those which had more authors in common were: decrease in the life cycles of products, increasingly stringent demands and/or individualized and Globalization.

Table C-1: Current market characteristics according to the literature.

Authors	Current market characteristics							
	1	2	3	4	5	6	7	8
(Hsuan Mikkola & Skjøtt-Larsen, 2004)	X			X	X	X	X	X
(Skipworth & Harrison, 2004)	X	X		X		X	X	
(Y. Yang et al., 2007)	X	X	X					
(Arroyo-Gutiérrez & Jiménez-Partearroyo, 2013)			X				X	
(Grabot et al., 2014)			X			X		
(Mapes, 2002)			X					
(Fan, 2012)			X					
(Koren et al., 1999)			X					
(Muriel et al., 2006)			X					
(P. Liu et al., 2011)						X		
(Di Pierri D, 2006)								X
(Hoek, 2001)				X		X	X	
(Jiao et al., 2003)	X			X			X	
(Yanhong Qin & Xiong, 2013)				X		X	X	
(Bernhardt, Liu, & Serfes, 2007)	X			X			X	
(Chuang & Su, 2011)	X					X	X	
(Swaminathan, 2003)			X			X	X	
(D. Mourtzis et al., 2012)					X	X	X	
(Luft & Besenfelder, 2014)	X		X	X			X	
(Silveira et al., 2001)	X	X				X	X	
Total numer of autores	8	3	9	7	2	10	12	2

D. Annex: Definitions of mass customizations according to the literature

Some found definitions of mass customizations are shown below:

Table D-1: Mass customization according to the literature.

Author	Definition
(Hart, 1995)	"It is the ability to offer to consumers everything they want, in a profitable way, wherever they want, whenever they want"
(Kotha, 1995)	"It is the process by which companies apply the technology and management methods to offer product variety and customization through flexibility and quick response"
(Silveira et al., 2001)	"It is the ability to offer products or services to consumers through flexible process with high volumes and low reasonable costs"
(Frutos & Borenstein, 2004)	"It is an emerging concept in the industry designed to offer products and services to consumers through flexible processes with high volumes and prices reasonably low"
(Wikner & Wong, 2007)	"It has been defined as the technology and systems that deliver products that get adapted to the individual needs of customers, with an efficiency close to mass production"
(Suh et al., 2011)	"It is the ability to produce customized products and services at a similar cost off mass production"
(Coletti & Aichner, 2011) P.29	"It is a strategy that creates value through the interaction between the company and the consumers in the design of the workstations in order to create customized products, following a hybrid strategy combining cost leadership and differentiation"
(Fogliatto et al., 2012)	"It is a production strategy focused on offering a wide range of customized products and services, mainly through the modularization of the designs of products and services, flexible processes, and the integration among the members of the supply chain."

(Xiong et al., 2012)	“It is the ability to offer to many costumers designs of individualized products and services through an agile, flexible and integrated process […]”
(Boër et al., 2013) P.1	“It can be defined as the capacity to produce customized goods, with the efficiency and costs close to mass production”
(Gutierrez et al., 2015)	“Mass customization is understood as the competitive and productive strategy that allows value creation, by offering products that meet individual preferences, with costs and efficiencies similar to mass production. The design of the individual product is made by co-design with the consumer, this product is located in a fixed space of solution, which delimitates the offer and defines the processes, the technologies and the productive system”
(Jianzhong Li, 2011)	“It is an strategic thinking based on the innovation of consumer’s value, it is also a portfolio of strategic competitiveness that integrates mass production with mass customization, it integrates the economies of scale with the economy of scope, it integrates the costs and the diversification of the products with speed”

E. Annex: Categories of postponement according to the literature

The different classifications of postponement found in the literature are shown on the following chart.

Table E-1: Categories of postponement according to the literature.

Author	Categories
- (Swaminathan, 2003) - (Cooper, 1998) - (Nahmens, 2007) - (Chuang & Su, 2011) - (Guericke et al., 2012) - (Fan, 2012) - (S. Dong, 2010)	• Labeling postponement • Packaging postponement • Assembly postponement • Manufacturing or Production postponement • Time postponement
- (B Yang & Burns, 2003) - (Y Qin, 2011) - (Kisperska-Moron & Swierczek, 2011) - (Heinung, 2011) - (Van Kampen & Van Donk, 2013)	• Time postponement • Place postponement • Form postponement
- (Su, Chang, & Ferguson, 2005) - (Yohanes, 2008) - (J.-H. Ji & Shao, 2008) - (Can, 2008) - (W. Zhou et al., 2013) - (Jørgensen & Hauschild, 2014) - (W. Zhou et al., 2014)	• Form postponement • Time postponement

- (B Yang et al., 2004a) - (Chaudhry & Hodge, 2012) - (Lu, Tsai, & Chen, 2012) - (B Yang & Burns, 2003)	• Product development postponement • Purchansing postponement • Manufacturing or Production postponement • Logistics postponement
- (W. Zhou et al., 2013)	• Demand postponement • Price postponement • Time/Pull postponement • Form postponement
- (S. (Sam) Saghiri & Hill, 2013)	• Production operation postponement • Purchansing postponement • Product design postponement

F. Annex: Approaches of the production system according to the localization of the decoupling point

Some classifications of the production approached according to the localization of the decoupling point is shown in the following table.

Table F-1: Approaches of the production system according to the localization of the decoupling point.

Autor	Clasificación del enfoque del sistema de producción
(Olhager, 2003),(Rudberg & Wikner, 2004),(Olhager, 2010),(Ahmed & Mohammed, 2010), (Heinung, 2011),(Y Qin, 2011),(Lin et al., 2012),(Kramarz & Kramarz, 2012)	• Engineer-to-order • Make-to-order • Assemble-to-order • Make-to-Stock
(Chuang & Su, 2011),(Can, 2008)	• Make to stock • Shipment ro order • Packaging/labeling to order • Assemblig to order • Make to order • Buy to order • Engineering to order

(Kramarz & Kramarz, 2012)	• Make to stock • Shipment to stock • Assembly to order • Production to order • Designing to order
(Modrak et al., 2015)	• Make to stock • Assemble to order • Make to order • Engineer to order • Develop to order

G. Annex: Consistency test calculation in the Enterprise application Herragro S.A

In the following part is shown the consistency test calculation.

Initial variables		
M	Experts	7
n	Criteria	8

Calculation of mean value of ranges (T):

$$T = \frac{M(\, n+1)}{2} = \frac{7(8+1)}{2} = \ 31.5$$

Calculation of deviation for each criterion (D^2).

$$D^2 = \sum_{j=1}^{n} (\sum_{k=1}^{M} (C_{jk}) - T)^2$$

Calculation of Kendall's index (W):

$$W = \frac{12\ \sum D^2}{M^2\ (n^3 - n)}$$

C_{jk}	T	$(\sum_{k=1}^{M}(C_{jk}) - T)$	$(\sum_{k=1}^{M}(C_{jk}) - T)^2$	W
47		15.5	240.25	
45		13.5	182.25	
41		9.5	90.25	
19.5	31.5	-12	144	0.695578231
28		-3.5	12.25	
10		-21.5	462.25	
44		12.5	156.25	
19.5		-12	144	
$D^2 = \sum_{j=1}^{n}(\sum_{k=1}^{M}(C_{jk}) - T)^2$			1431.5	

H. Annex: Subjective weighting II, in the enterprise application Herragro S.A

In the following tables is presented the pairwise comparison of the criteria assigned by each expert.

Table H-1: Paired comparison given by expert 1*, case Herragro S.A*

Criterion	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**Total Sum E_1**
C_1	1	0	0	1	1	1	0	1	5
C_2	1	1	1	1	1	1	0	1	7
C_3	1	0	1	1	1	1	0	1	6
C_4	0	0	0	1	1	1	0	1	4
C_5	0	0	0	0	1	0	0	0	1
C_6	0	0	0	0	1	1	0	1	3
C_7	1	1	1	1	1	1	1	1	8
C_8	0	0	0	0	1	0	0	1	2

Table H-2: Paired comparison given by expert 2, *case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_2
C_1	1	1	0	1	1	1	0	0	5
C_2	0	1	1	1	1	1	0	1	6
C_3	1	0	1	0	0	1	0	1	4
C_4	0	0	1	1	1	1	0	1	5
C_5	0	0	1	0	1	0	0	1	3
C_6	0	0	0	0	1	1	0	1	3
C_7	1	1	1	1	1	1	1	1	8
C_8	1	0	0	0	0	0	0	1	2

Table H-3: Paired comparison given by expert 3, *case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_3
C_1	1	0	1	1	1	1	1	0	6
C_2	1	1	1	1	1	1	1	1	8
C_3	0	0	1	1	1	1	0	0	4
C_4	0	0	0	1	1	1	1	0	4
C_5	0	0	0	0	1	1	1	0	3
C_6	0	0	0	0	0	1	0	0	1
C_7	0	0	1	0	0	1	1	0	3
C_8	1	0	1	1	1	1	1	1	7

Table H-4: Paired comparison given by expert 4*, case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_4
C_1	1	1	0	1	1	1	0	1	6
C_2	0	1	1	1	0	1	0	1	5
C_3	1	0	1	1	1	1	1	1	7
C_4	0	0	0	1	0	1	0	1	3
C_5	0	1	0	1	1	1	0	1	5
C_6	0	0	0	0	0	1	0	0	1
C_7	1	1	0	1	1	1	1	0	6
C_8	0	0	0	0	0	1	1	1	3

Table H-5: Paired comparison given by expert 5*, case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_5
C_1	1	0	1	1	0	0	0	1	4
C_2	1	1	1	0	1	1	0	1	6
C_3	0	0	1	1	0	0	0	1	3
C_4	0	1	0	1	1	1	0	1	5
C_5	1	0	1	0	1	1	0	1	5
C_6	1	0	1	0	0	1	0	0	3
C_7	1	1	1	1	1	1	1	1	8
C_8	0	0	0	0	0	1	0	1	2

Table H-6: Paired comparison given by expert 6*, case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_6
C_1	1	0	1	0	0	0	0	0	2
C_2	1	1	1	1	1	0	1	0	6
C_3	0	0	1	0	0	0	0	0	1
C_4	1	0	1	1	0	0	0	0	3
C_5	1	0	1	1	1	0	0	0	4
C_6	1	1	1	1	1	1	1	0	7
C_7	1	0	1	1	1	0	1	0	5
C_8	1	1	1	1	1	1	1	1	8

Table H-7: Paired comparison given by expert 7*, case Herragro S.A*

Criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_7
C_1	1	1	1	1	1	1	1	1	8
C_2	0	1	0	1	0	1	0	1	4
C_3	0	1	1	1	1	1	0	1	6
C_4	0	0	0	1	0	1	0	0	2
C_5	0	1	0	1	1	1	0	1	5
C_6	0	0	0	0	0	1	0	1	2
C_7	0	1	1	1	1	1	1	1	7
C_8	0	0	0	1	0	0	0	1	2

I. Annex: Qualitative criteria evaluation with AHP in the Enterprise application Herragro S.A

In this part is shown the results of the AHP application in the three qualitative criteria for each product mother. It is necessary understand that the comparison between just two criterial is consistent, therefore in this case is not shown the calculations.

1. Product Mother 1

Storage C_6

Logistics Manager

Table I-1: Evaluation of Logistics Manager for C_6 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1	1
Sharpen	1	1	1
Polish	1	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.33	0.33	0.33	0.33
Sharpen	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33

Table I-2: Consistency test

CI	0
RI	0.58
CR	0

Maintenance Manager

Table I-3: Evaluation of Maintenance Manager for C_6 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	5	5
Sharpen	1/5	1	1
Polish	1/5	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.71	0.71	0.71	0.71
Sharpen	0.14	0.14	0.14	0.14
Polish	0.14	0.14	0.14	0.14

Table I-4: Consistency test

CI	0.056
RI	0.580
CR	0.096

Production Manager

Table I-5: Evaluation of Production Manager for C_6 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1	1
Sharpen	1	1	1
Polish	1	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.33	0.33	0.33	0.33
Sharpen	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33

Table I-6: Consistency test

CI	0
RI	0.58
CR	0

Engineering Manager

Table I-7: Evaluation of Engineering Manager for C_6 of the product mother 1*, case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	3	7
Sharpen	1/3	1	3
Polish	1/7	1/3	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.68	0.69	0.64	0.67
Sharpen	0.23	0.23	0.27	0.24
Polish	0.10	0.08	0.09	0.09

Table I-8: Consistency test

CI	0.003
RI	0.58
CR	0.006

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-9: Qualitative Weight for ADP in C_6 *for the product mother 1, case Herragro S.A*

ADP	Logistics Manager	Maintenance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.33	0.71	0.33	0.67	0.51
Sharpen	0.33	0.14	0.33	0.24	0.26
Polish	0.33	0.14	0.33	0.09	0.22

Risk of product damage C_7

Quality Manager

Table I-10: Evaluation of Quality Manager for C_7 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	7	7
Sharpen	1/7	1	1
Polish	1/7	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.78	0.78	0.78	0.78
Sharpen	0.11	0.11	0.11	0.11
Polish	0.11	0.11	0.11	0.11

Table I-11: Consistency test

CI	0
RI	0.58
CR	0

Warehouse Manager

Table I-12: Evaluation of Warehouse Manager for C_7 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	3	5
Sharpen	1/3	1	4
Polish	1/5	1/4	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.65	0.71	0.50	0.62
Sharpen	0.22	0.24	0.40	0.28
Polish	0.13	0.06	0.10	0.10

Table I-13: Consistency test

CI	0.043
RI	0.58
CR	0.074

Production Manager

Table I-14: Evaluation of Production Manager for C_7 of the product mother 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1/4	5
Sharpen	4	1	9
Polish	1/5	1/9	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.19	0.18	0.33	0.24
Sharpen	0.77	0.73	0.60	0.70
Polish	0.04	0.08	0.07	0.06

Table I-15: Consistency test

CI	0.036
RI	0.58
CR	0.062

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-16: Qualitative Weight for ADP in C_7 *for the product mother 1, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.78	0.62	0.24	0.54
Sharpen	0.11	0.28	0.70	0.37
Polish	0.11	0.10	0.06	0.09

Ease for restarting the production process C_8

Production Manager

Table I-17: Evaluation of Production Manager for C_8 of the *product mother* 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1/4	1/9
Sharpen	4	1	1/5
Polish	9	5	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.07	0.04	0.08	0.07
Sharpen	0.29	0.16	0.15	0.20
Polish	0.64	0.80	0.76	0.74

Table I-18: Consistency test

CI	0.036
RI	0.58
CR	0.062

Logistics Manager

Table I-19: Evaluation of Logistics Manager for C_8 of the *product mother* 1, *case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1	1
Sharpen	1	1	1
Polish	1	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.33	0.33	0.33	0.33
Sharpen	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33

Table I-20: Consistency test

CI	0
RI	0.58
CR	0

Process Manager

Table I-21: Evaluation of Process Manager for C_8 of the *product mother* 1*, case Herragro S.A*

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	5	5
Sharpen	1/5	1	1
Polish	1/5	1	1

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.71	0.71	0.71	0.71
Sharpen	0.14	0.14	0.14	0.14
Polish	0.14	0.14	0.14	0.14

Table I-22: Consistency test

CI	0
RI	0.58
CR	0

FINAL EIGENVECTOR FOR THE CRITERION EASINNES TO RESTART THE PRODUCTION PROCESS

Table I-23: Qualitative Weight for ADP in C_8 *for the product mother 1, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.33	0.71	0.07	0.37
Sharpen	0.33	0.14	0.20	0.23
Polish	0.33	0.14	0.74	0.40

2. Product Mother 2

<u>Storage C_6</u>

Logisticts Manager

Table I-24: Evaluation of Logistics Manager for C_6 of the product mother 2*, case Herragro S.A*

ADP	Heat Treament	Paint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Label ing	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

Maintenance Manager

Table I-25: Evaluation of Maintenance Manager for C_6 of the product mother 2*, case Herragro S.A*

ADP	Heat Treatment	Paint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

Production Manager

Table I-26: Evaluation of Production Manager for C_6 of the product mother 2*, case Herragro S.A*

ADP	Heat Treatment	Paint and Labeling
Heat Treatment	1	1/9
Paint and Labeling	9	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.1	0.1	0.1
Paint and Labeling	0.9	0.9	0.9

Engineering Manager

Table I-27: Evaluation of Engineering Manager for C_6 of the product mother 2*, case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-28: Qualitative Weight for ADP in C_6 *for the product mother 2, case Herragro S.A*

ADP	Logistics Manager	Maintenance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.88	0.88	0.10	0.88	0.68
Paint and Labeling	0.13	0.13	0.90	0.13	0.32

Risk of product damage C_7

Quality Manager

Table I-29: Evaluation of Quality Manager for C_7 of the product mother 2*, case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	1
Paint and Labeling	1	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.5	0.5	0.5
Paint and Labeling	0.5	0.5	0.5

Warehouse Manager

Table I-30: Evaluation of Warehouse Manager for C_7 of the product mother 2, *case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

Production Manager

Table I-31: Evaluation of Production Manager for C_7 of the product mother 2, *case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	1/7
Paint and Labeling	7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.9	0.9	0.9
Paint and Labeling	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-32: Qualitative Weight for ADP in C_7 *for the product mother 2, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.50	0.88	0.13	0.50
Paint and Labeling	0.50	0.13	0.88	0.50

Ease for restarting the production process c_8

Logistics Manager

Table I-33: Evaluation of Logistics Manager for C_8 of the product mother 2, *case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

Process Manager

Table I-34: Evaluation of Process Manager for C_8 of the product mother 2, *case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	1
Paint and Labeling	1	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.5	0.5	0.5
Paint and Labeling	0.5	0.5	0.5

Production Manager

Table I-35: Evaluation of Production Manager for C_8 of the product mother 2, *case Herragro S.A*

ADP	Heat Treament	Pint and Labeling
Heat Treatment	1	7
Paint and Labeling	1/7	1

ADP	Heat Treatment	Paint and Labeling	Priority vector
Heat Treatment	0.88	0.88	0.88
Paint and Labeling	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-36: Qualitative Weight for ADP in C_8 *for the product mother 2, case Herragro S.A*

ADP	Gerente de Logística	Gerente de Procesos	Gerente de Producción	Final weighting (S_f)
Heat Treatment	0.88	0.50	0.88	0.75
Paint and Labeling	0.13	0.50	0.13	0.25

3. Product Mother 3

Storage C_6

Logistics Manager

Table I-37: Evaluation of Logistics Manager for C_6 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

Maintenance Manager

Table I-38: Evaluation of Maintenance Manager for C_6 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	5
Sharpen	1/5	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.83	0.83	0.83
Sharpen	0.17	0.17	0.17

Production Manager

Table I-39: Evaluation of Production Manager for C_6 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	9
Sharpen	1/9	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.9	0.9	0.9
Sharpen	0.1	0.1	0.1

Engineering Manager

Table I-40: Evaluation of Engineering Manager for C_6 of the product mother 3*, case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	3
Sharpen	1/3	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.75	0.75	0.75
Sharpen	0.25	0.25	0.25

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-41: Qualitative Weight for ADP in C6 *for the product mother 3, case Herragro S.A*

ADP	Logistics Manager	Maintenance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.88	0.83	0.90	0.75	0.84
Sharpen	0.13	0.17	0.10	0.25	0.16

Risk of product damage C_7

Quality Manager

Table I-41: Evaluation of Quality Manager for C_7 of the product mother 3*, case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

Warehouse Manager

Table I-42: Evaluation of Warehouse Manager for C_7 of the product mother 3*, case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	5
Sharpen	1/5	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.83	0.83	0.83
Sharpen	0.17	0.17	0.17

Production Manager

Table I-43: Evaluation of Production Manager for C_7 of the product mother 3*, case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	9
Sharpen	1/9	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.9	0.9	0.9
Sharpen	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT MANAGE

Table I-44: Qualitative Weight for ADP in C_7 *for the product mother 3, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.83	0.90	0.87
Sharpen	0.13	0.17	0.10	0.13

Ease for restarting the production process C_8

Logistics Manager

Table I-45: Evaluation of Logistics Manager for C_8 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

Process Manager

Table I-46: Evaluation of Process Manager for C_7 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	5
Sharpen	1/5	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.83	0.83	0.83
Sharpen	0.17	0.17	0.17

Production Manager

Table I-47: Evaluation of Production Manager for C_7 of the product mother 3, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	1/9
Sharpen	9	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.1	0.1	0.1
Sharpen	0.9	0.9	0.9

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-48: Qualitative Weight for ADP in C_8 *for the product mother 3, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.83	0.10	0.60
Sharpen	0.13	0.17	0.90	0.40

4. Product Mother 4

<u>Storage C_6</u>

Logistics Manager

Table I-49: Evaluation of Logistics Manager for C_6 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	8
Polish	1/8	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.89	0.89	0.89
Polish	0.11	0.11	0.11

Maintenance Manager

Table I-50: Evaluation of Maintenance Manager for C_6 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	5
Polish	1/5	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.83	0.83	0.83
Polish	0.17	0.17	0.17

Production Manager

Table I-51: Evaluation of Production Manager for C_6 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	9
Polish	1/9	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.9	0.9	0.9
Polish	0.1	0.1	0.1

Engineering Manager

Table I-52: Evaluation of Engineering Manager for C_6 of the product mother 4*, case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	5
Polish	1/5	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.83	0.83	0.83
Polish	0.17	0.17	0.17

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-53: Qualitative Weight for ADP in C_6 *for the product mother 4, case Herragro S.A*

ADP	Logistics Manager	Maintenance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.89	0.83	0.90	0.83	0.86
Polish	0.11	0.17	0.10	0.17	0.14

<u>Risk of product damage C_7</u>

Quality Manager

Table I-54: Evaluation of Quality Manager for C_7 of the product mother 4*, case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	7
Polish	1/7	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.88	0.88	0.88
Polish	0.13	0.13	0.13

Warehouse Manager

Table I-55: Evaluation of Warehouse Manager for C_7 of the product mother 4*, case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	5
Polish	1/5	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.83	0.83	0.83
Polish	0.17	0.17	0.17

Production Manager

Table I-56: Evaluation of Production Manager for C_7 of the product mother 4*, case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	9
Polish	1/9	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.9	0.9	0.9
Polish	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-57: Qualitative Weight for ADP in C_7 *for the product mother 4, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.83	0.90	0.87
Polish	0.13	0.17	0.10	0.13

Ease for restarting the production process C_8

Logistics Manager

Table I-58: Evaluation of Logistics Manager for C_8 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	8
Polish	1/8	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.89	0.89	0.89
Polish	0.11	0.11	0.11

Process Manager

Table I-59: Evaluation of Process Manager for C_8 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	7
Polish	1/7	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.13	0.13	0.13
Polish	0.88	0.88	0.88

Production Manager

Table I-60: Evaluation of Production Manager for C_8 of the product mother 4, *case Herragro S.A*

ADP	Heat Treatmen	Polish
Heat Treatment	1	1/9
Polish	9	1

ADP	Heat Treatmen	Polish	Priority vector
Heat Treatment	0.1	0.1	0.1
Polish	0.9	0.9	0.9

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-61: Qualitative Weight for ADP in C_8 *for the product mother 4, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.89	0.13	0.10	0.37
Polish	0.11	0.88	0.90	0.63

5. Product Mother 5

<u>Storage C6</u>

Production Manager

Table I-62: Evaluation of Production Manager for C_6 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

Maintenance Manager

Table I-63: Evaluation of Maintenance Manager for C_6 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	1
Sharpen	1	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.5	0.5	0.5
Sharpen	0.5	0.5	0.5

Production Manager

Table I-64: Evaluation of Production Manager for C_6 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	6
Sharpen	1/6	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.86	0.86	0.86
Sharpen	0.14	0.14	0.14

Engineering Manager

Table I-65: Evaluation of Engineering Manager for C_6 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	3
Sharpen	1/3	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.75	0.75	0.75
Sharpen	0.25	0.25	0.25

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-66: Qualitative Weight for ADP in C_6 *for the product mother 5, case Herragro S.A*

ADP	Logistics Manager	Maintanance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.88	0.50	0.86	0.75	0.75
Sharpen	0.13	0.50	0.14	0.25	0.25

Risk of product damage C_7

Quality Manager

Table I-67: Evaluation of Engineering Manager for C_7 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Tratamiento térmico	0.88	0.88	0.88
Afilar	0.13	0.13	0.13

Warehouse Manager

Table I-68: Evaluation of Warehouse Manager for C_7 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	6
Sharpen	1/6	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.86	0.86	0.86
Sharpen	0.14	0.14	0.14

Production Manager

Table I-69: Evaluation of Production Manager for C_7 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	7
Sharpen	1/7	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-70: Qualitative Weight for ADP in C_7 *for the product mother 5, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.86	0.88	0.87
Sharpen	0.13	0.14	0.13	0.13

Ease for restarting the production process C_8

Logistics Manager

Table I-71: Evaluation of Logistics Manager for C_8 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	8
Sharpen	1/8	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.89	0.89	0.89
Sharpen	0.11	0.11	0.11

Process Manager

Table I-72: Evaluation of Process Manager for C_8 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	5
Sharpen	1/5	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.83	0.83	0.83
Sharpen	0.17	0.17	0.17

Production Manager

Table I-73: Evaluation of Production Manager for C_8 of the product mother 5, *case Herragro S.A*

ADP	Heat Treatment	Sharpen
Heat Treatment	1	1/8
Sharpen	8	1

ADP	Heat Treatment	Sharpen	Priority vector
Heat Treatment	0.11	0.11	0.11
Sharpen	0.89	0.89	0.89

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-74: Qualitative Weight for ADP in C_8 *for the product mother 5, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production manager	Final weighting (S_f)
Heat Treatment	0.89	0.83	0.11	0.61
Sharpen	0.11	0.17	0.89	0.39

6. Product Mother 6

Storage C_6

Logistics Manager

Table I-75: Evaluation of Logistics Manager for C_6 of the product mother 6*, case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	8
Clean	1/8	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.89	0.89	0.89
Clean	0.11	0.11	0.11

Maintanance Manager

Table I-76: Evaluation of Maintenance Manager for C_6 of the product mother 6*, case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	1
Clean	1	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.5	0.5	0.5
Clean	0.5	0.5	0.5

Production Manager

Table I-77: Evaluation of Production Manager for C_6 of the product mother 6*, case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	1
Clean	1	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.5	0.5	0.5
Clean	0.5	0.5	0.5

Engeneering Manager

Table I-78: Evaluation of Engineering Manager for C_6 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	7
Clean	1/7	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.88	0.88	0.88
Clean	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-79: Qualitative Weight for ADP in C_6 *for the product mother 6, case Herragro S.A*

ADP	Logistics Manager	Maintanance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Punch and Mark	0.89	0.50	0.50	0.88	0.69
Clean	0.11	0.50	0.50	0.13	0.31

Risk of product damage C_7

Quality Manager

Table I-80: Evaluation of Quality Manager for C_7 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	5
Clean	1/5	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.83	0.83	0.83
Clean	0.17	0.17	0.17

Warehouse Manager

Table I-81: Evaluation of Warehouse Manager for C_7 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	1/5
Clean	5	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.17	0.17	0.17
Clean	0.83	0.83	0.83

Production Manager

Table I-82: Evaluation of Production Manager for C_7 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	7
Clean	1/7	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.88	0.88	0.88
Clean	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-83: Qualitative Weight for ADP in C_7 *for the product mother 6, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Punch and Mark	0.83	0.83	0.88	0.85
Clean	0.17	0.17	0.13	0.15

Ease for restarting the production process C_8

Logistics Manager

Table I-84: Evaluation of Logistics Manager for C_8 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	1/8
Clean	8	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.11	0.11	0.11
Clean	0.89	0.89	0.89

Process Manager

Table I-85: Evaluation of Process Manager for C_8 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	5
Clean	1/5	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.83	0.83	0.83
Clean	0.17	0.17	0.17

Production Manager

Table I-86: Evaluation of Production Manager for C_8 of the product mother 6, *case Herragro S.A*

ADP	Punch and Mark	Clean
Punch and Mark	1	1/5
Clean	5	1

ADP	Punch and Mark	Clean	Priority vector
Punch and Mark	0.17	0.17	0.17
Clean	0.83	0.83	0.83

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION MANAGER

Table I-87: Qualitative Weight for ADP in C8 *for the product mother 6, case Herragro S.A*

ADP	Logistics Manger	Process Manager	Production Manager	Final weighting (S_f)
Punch and Mark	0.11	0.83	0.17	0.37
Clean	0.89	0.17	0.83	0.63

7. Product Mother 7

<u>Storage C_7</u>

Logistics Manager

Table I-88: Evaluation of Logistics Manager for C_6 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	6
Sharpen	1/6	1

ADP	Weld	Sharpen	Priority vector
Weld	0.86	0.86	0.86
Sharpen	0.14	0.14	0.14

Maintanance Manager

Table I-89: Evaluation of Maintanace Manager for C_6 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1
Sharpen	1	1

ADP	Weld	Sharpen	Priority vector
Weld	0.5	0.5	0.5
Sharpen	0.5	0.5	0.5

Production Manager

Table I-90: Evaluation of Production Manager for C_6 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1
Sharpen	1	1

ADP	Weld	Sharpen	Priority vector
Weld	0.5	0.5	0.5
Sharpen	0.5	0.5	0.5

Engineering Manager

Table I-91: Evaluation of Engineering Manager for C_6 of the product mother 7*, case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1
Sharpen	1	1

ADP	Weld	Sharpen	Priority vector
Weld	0.5	0.5	0.5
Sharpen	0.5	0.5	0.5

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-92: Qualitative Weight for ADP in C_6 *for the product mother 7, case Herragro S.A*

ADP	Logistics Manager	Maintanance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Weld	0.86	0.50	0.50	0.50	0.59
Sharpen	0.14	0.50	0.50	0.50	0.41

Riks of product damage C_7

Quality Manager

Table I-93: Evaluation of Quality Manager for C_7 of the product mother 7*, case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	7
Sharpen	1/7	1

ADP	Weld	Sharpen	Priority vector
Weld	0.88	0.88	0.88
Sharpen	0.13	0.13	0.13

Warehouse Manager

Table I-94: Evaluation of Warehouse Manager for C_7 of the product mother 7*, case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1/5
Sharpen	5	1

ADP	Weld	Sharpen	Priority vector
Weld	0.17	0.17	0.17
Sharpen	0.83	0.83	0.83

Production Manager

Table I-95: Evaluation of Quality Manager for C_7 of the product mother 7*, case Herragro S.A*

ADP	Soldar	Afilar
Weld	1	1
Sharpen	1	1

ADP	Weld	Sharpen	Priority vector
Weld	0.5	0.5	0.5
Sharpen	0.5	0.5	0.5

FINAL EIGENVECTOR FOR THE CRITERION RIKS OF PRODUCT MANAGE

Table I-96: Qualitative Weight for ADP in C_7 *for the product mother 7, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Weld	0.88	0.83	0.50	0.74
Sharpen	0.13	0.17	0.50	0.26

<u>Ease for restarting the production process C_8</u>

Logistics Manager

Table I-97: Evaluation of Logistics Manager for C_8 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1/8
Sharpen	8	1

ADP	Weld	Sharpen	Priority vector
Weld	0.11	0.11	0.11
Sharpen	0.89	0.89	0.89

Process Manager

Table I-98: Evaluation of Process Manager for C_8 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1/3
Sharpen	3	1

ADP	Weld	Sharpen	Priority vector
Weld	0.25	0.25	0.25
Sharpen	0.75	0.75	0.75

Production Manager

Table I-99: Evaluation of Production Manager for C_8 of the product mother 7, *case Herragro S.A*

ADP	Weld	Sharpen
Weld	1	1/2
Sharpen	2	1

ADP	Weld	Sharpen	Priority vector
Weld	0.33	0.33	0.33
Sharpen	0.67	0.67	0.67

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-100: Qualitative Weight for ADP in C_8 *for the product mother 7, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production Manager	Final weighting (S_f)
Weld	0.11	0.25	0.33	0.23
Sharpen	0.89	0.75	0.67	0.77

8. Product Mother 8

Storage C_6

Logistics Manager

Table I-101: Evaluation of Logistics Manager for C_6 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	7
Straighten	1/7	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.88	0.88	0.88
Straighten	0.13	0.13	0.13

Maintanance Manager

Table I-102: Evaluation of Maintenance Manager for C_6 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1
Straighten	1	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.5	0.5	0.5
Straighten	0.5	0.5	0.5

Production Manager

Table I-103: Evaluation of Production Manager for C_6 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1
Straighten	1	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.5	0.5	0.5
Straighten	0.5	0.5	0.5

Engineering Manager

Table I-104: Evaluation of Engineering Manager for C_6 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1/7
Straighten	7	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.13	0.13	0.13
Straighten	0.88	0.88	0.88

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table I-105: Qualitative Weight for ADP in C_6 *for the product mother 8, case Herragro S.A*

ADP	Logistics Manager	Maintanance Manager	Production Manager	Engineering Manager	Final weighting (S_f)
Heat Treatment	0.88	0.50	0.50	0.13	0.50
Straighten	0.13	0.50	0.50	0.88	0.50

Risk of product manager C_7

Quality Manager

Table I-106: Evaluation of Quality Manager for C_7 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	7
Straighten	1/7	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.88	0.88	0.88
Straighten	0.13	0.13	0.13

Warehouse Manager

Table I-107: Evaluation of Warehouse Manager for C_7 of the product mother 8*, case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1/5
Straighten	5	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.17	0.17	0.17
Straighten	0.83	0.83	0.83

Production Manager

Table I-108: Evaluation of Production Manager for C_7 of the product mother 8*, case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	9
Straighten	1/9	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.9	0.9	0.9
Straighten	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table I-109: Qualitative Weight for ADP in C_7 *for the product mother 8, case Herragro S.A*

ADP	Quality Manager	Warehouse Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.17	0.90	0.65
Straighten	0.13	0.83	0.10	0.35

Ease for restarting the production process C_8

Logistics Manager

Table I-110: Evaluation of Logistics Manager for C_8 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	7
Straighten	1/7	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.88	0.88	0.88
Straighten	0.13	0.13	0.13

Process Manager

Table I-111: Evaluation of Process Manager for C_8 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1
Straighten	1	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.5	0.5	0.5
Straighten	0.5	0.5	0.5

Production Manager

Table I-112: Evaluation of Production Manager for C_8 of the product mother 8, *case Herragro S.A*

ADP	Heat Treatment	Straighten
Heat Treatment	1	1/8
Straighten	8	1

ADP	Heat Treatment	Straighten	Priority vector
Heat Treatment	0.11	0.11	0.11
Straighten	0.89	0.89	0.89

FINAL EIGENVECTOR FOR THE CRITERION EASE FOR RESTARTING THE PRODUCTION PROCESS

Table I-113: Qualitative Weight for ADP in C_8 *for the product mother 8, case Herragro S.A*

ADP	Logistics Manager	Process Manager	Production Manager	Final weighting (S_f)
Heat Treatment	0.88	0.50	0.11	0.50
Straighten	0.13	0.50	0.89	0.50

J. Annex: Test of the performance of the methodology from the product mother 9

In the step 1, section 1.3, in someproduct mother s, the experts agreed in the decoupling point selection. This implies that for these products, since this section is already selected the decoupling point. Taking advantage of this, the product mother product mother 9 was selected to test the performance of the methodology.

In this sense it should be understood beforehand that the ideal result is known. Therefore, it is expected that once the methodology is applied and the expected results are obtained, it is a fact that the process contributed to validate the methodology.

This process is part of the obtained results in steps 1, 2 and 3 as these are common results for the whole methodology. In this case, only the nine criteria for the product mother will be qualified and the results will be weighted in step 5 and 6. From which the obtained result for the experts will be compared to the results generated by the methodology.

STEP 4. EVALUATE THE CRITERIA

4.1 qualitative criteria

Storage C_6

Logistics manager

Table J-1: Evaluation of Logistics Manager for C_6 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	8	9
Polish	1/8	1	3
Abrasive Blasting	1/9	1/3	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.81	0.86	0.69	0.79
Polish	0.10	0.11	0.23	0.15
Abrasive Blasting	0.09	0.04	0.08	0.07

Table J-2: Consistency test

CI	0.056
RI	0.580
CR	0.096

Maintenance manager

Table J-3: Evaluation of Maintenance Manager for C_6 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	9	7
Polish	1/9	1	2
Abrasive Blasting	1/7	1/2	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.80	0.86	0.70	0.78
Polish	0.09	0.10	0.20	0.13
Abrasive Blasting	0.11	0.05	0.10	0.09

Table J-4: Consistency test

CI	0.051
RI	0.580
CR	0.089

Production Manager

Table J-5: Evaluation of Production Manager for C_6 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	1	1
Polish	1	1	1
Abrasive Blasting	1	1	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33
Abrasive Blasting	0.33	0.33	0.33	0.33

Table J-6: Consistency test

CI	0
RI	0.58
CR	0

Engineering Manager

Table J-7: Evaluation of Engineering Manager for C_6 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	1	1
Polish	1/8	1	1
Abrasive Blasting	1/9	1/3	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33
Abrasive Blasting	0.33	0.33	0.33	0.33

Table J-8: Consistency test

CI	0
RI	0.58
CR	0

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table J-9: Qualitative Weight for ADP in C_6 for the product mother 9, case Herragro S.A

ADP	Logistics manager	Maintenance manager	Production manager	Engineering manager	Final weight
Heat Treatment	0.79	0.78	0.33	0.33	0.56
Polish	0.15	0.13	0.33	0.33	0.24
Abrasive Blasting	0.07	0.09	0.33	0.33	0.21

Risk of product damage C_7

Quality Manager

Table J-10: Evaluation of Quality Manager for C_7 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Shotpeened
Heat Treatment	1	9	9
Polish	1/9	1	1
Abrasive Blasting	1/9	1	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.82	0.82	0.82	0.82
Polish	0.09	0.09	0.09	0.09
Abrasive Blasting	0.09	0.09	0.09	0.09

Table J-11: Consistency test

CI	0
RI	0.58
CR	0

Warehouse Manager

Table J-12: Evaluation of Warehouse Manager for C_7 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	9	9
Polish	1/9	1	1
Abrasive Blasting	1/9	1	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.82	0.82	0.82	0.82
Polish	0.09	0.09	0.09	0.09
Abrasive Blasting	0.09	0.09	0.09	0.09

Table J-13: Consistency test

CI	0
RI	0.58
CR	0

Production Manager

Table J-14: Evaluation of Production Manager for C_7 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	1	1
Polish	1/9	1	1
Abrasive Blasting	1/9	1	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33
Abrasive Blasting	0.33	0.33	0.33	0.33

Table J-15: Consistency test

CI	0
RI	0.58
CR	0

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table J-16: Qualitative Weight for ADP in C_7 for the product mother 9, case Herragro S.A

ADP	Quality manager	Warehouse manager	Production manager	Final Weight (S_f)
Heat Treatment	0.82	0.82	0.33	0.66
Polish	0.09	0.09	0.33	0.17
Abrasive Blasting	0.09	0.09	0.33	0.17

Ease for restarting the production process C_8

Logistics Manager

Table J-17: Evaluation of Logistics Manager for C_8 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	1	1
Polish	1	1	1
Abrasive Blasting	1	1	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.33	0.33	0.33	0.33
Polish	0.33	0.33	0.33	0.33
Abrasive Blasting	0.33	0.33	0.33	0.33

Table J-18: Consistency test

CI	0
RI	0.580
CR	0

Process Manager

Table J-19: Evaluation of Production Manager for C_8 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	7	9
Polish	1/7	1	3
Abrasive Blasting	1/9	1/3	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.80	0.84	0.69	0.78
Polish	0.11	0.12	0.23	0.15
Abrasive Blasting	0.09	0.04	0.08	0.07

Table J-20: Consistency test

CI	0.041
RI	0.580
CR	0.071

Production Manager

Table J-21: Evaluation of Process Manager for C_8 of the product mother 9, case Herragro S.A

ADP	Heat Treatment	Polish	Abrasive Blasting
Heat Treatment	1	8	6
Polish	1/7	1	2
Abrasive Blasting	1/9	1/3	1

ADP	Heat Treatment	Polish	Abrasive Blasting	Priority Vector
Heat Treatment	0.77	0.84	0.67	0.76
Polish	0.10	0.11	0.22	0.14
Abrasive Blasting	0.13	0.05	0.11	0.10

Table J-22: Consistency test

CI	0.041
RI	0.580
CR	0.071

FINAL EIGENVECTOR FOR THE CRITERION EASINNES TO RESTART THE PRODUCTION PROCESS

Table J-23: Qualitative Weight for ADP in C_8 for the product mother 9, case Herragro S.A

ADP	Logistics manager	Processes manager	Production manager	Final Weight (S_f)
Heat Treatment	0.33	0.78	0.76	0.62
Polish	0.33	0.15	0.14	0.21
Abrasive Blasting	0.33	0.07	0.10	0.17

Step 5. To evaluate the alternatives decoupling point

Table J-24: Final grade for the alternatives decoupling point in the product mother 9.

Product	ADP	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Final result Q_p
Mother product	Heat Treatment	0.30	0.30	0.34	0.27	0.30	0.56	0.66	0.62	40.8%
	Polish	0.32	0.35	0.33	0.32	0.33	0.24	0.17	0.21	28.8%
	Abrasive Blasting	0.38	0.35	0.33	0.41	0.37	0.21	0.17	0.17	30.4%

As can be seen in Table J-24, as well as in the selection made by the experts, by applying the methodology, the selected point was HEAT TREATMENT weighting 40.8%.

K. Annex: Consistency test calculation in the Enterprise application Muebles Marco Gomez

In the following part is shown the consistency test calculation.

Initial variables		
M	Experts	7
n	Criteria	8

Calculation of mean value of ranges (T):

$$T = \frac{M(\ n + 1)}{2} = \frac{7(8 + 1)}{2} = \ 31.5$$

Calculation of deviation for each criterion (D^2).

$$D^2 = \sum_{j=1}^{n} (\sum_{k=1}^{M} (C_{jk}) - T)^2$$

Calculation of Kendall's index (W):

$$W = \frac{12\ \sum D^2}{M^2\ (n^3 - n)}$$

C_{jk}	T	$(\sum_{k=1}^{M}(C_{jk}) - T)$	$(\sum_{k=1}^{M}(C_{jk}) - T)^2$	W
47	31.5	15.5	240.25	0.695578231
45		13.5	182.25	
41		9.5	90.25	
19.5		-12	144	
28		-3.5	12.25	
10		-21.5	462.25	
44		12.5	156.25	
19.5		-12	144	
$D^2 = \sum_{j=1}^{n}(\sum_{k=1}^{M}(C_{jk}) - T)^2$			1431.5	

L. Annex: Subjective weighting II, in the enterprise application Muebles Marco Gomez

In the following tables is presented the pairwise comparison of the criteria assigned by each expert.

Table L-1: Paired comparison given by expert 1*, case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_1
C_1	1	0	1	0	0	0	1	0	3
C_2	1	1	1	0	0	1	1	0	5
C_3	0	0	1	0	0	0	0	0	1
C_4	1	1	1	1	0	0	1	0	5
C_5	1	1	1	1	1	1	0	0	6
C_6	1	0	1	1	0	1	1	0	5
C_7	0	0	1	0	1	0	1	0	3
C_8	1	1	1	1	1	1	1	1	8

Table L-2: Paired comparison given by expert 2, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_2
C_1	1	1	1	0	0	0	0	0	3
C_2	0	1	1	0	0	0	0	0	2
C_3	0	0	1	0	0	0	0	1	2
C_4	1	1	1	1	0	0	0	0	4
C_5	1	1	1	1	1	0	0	1	6
C_6	1	1	1	1	1	1	0	0	6
C_7	1	1	1	1	1	1	1	0	7
C_8	1	1	0	1	0	1	1	1	6

Table L-3: Paired comparison given by expert 3, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_3
C_1	1	0	1	1	0	0	0	0	3
C_2	1	1	1	0	0	0	1	0	4
C_3	0	0	1	0	0	0	0	0	1
C_4	0	1	1	1	1	0	1	1	6
C_5	1	1	1	0	1	0	1	1	6
C_6	1	1	1	1	1	1	0	1	7
C_7	1	0	1	0	0	1	1	0	4
C_8	1	1	1	0	0	0	1	1	5

Table L-4: Paired comparison given by expert 4, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_4
C_1	1	0	0	0	0	0	0	0	1
C_2	1	1	1	0	0	0	1	0	4
C_3	1	0	1	0	0	0	0	0	2
C_4	1	1	1	1	0	0	1	0	5
C_5	1	1	1	1	1	1	1	1	8
C_6	1	1	1	1	0	1	1	0	6
C_7	1	0	1	0	0	0	1	0	3
C_8	1	1	1	1	0	1	1	1	7

Table L-5: Paired comparison given by expert 5, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_5
C_1	1	1	1	1	0	1	1	0	6
C_2	0	1	1	0	0	0	0	0	2
C_3	0	0	1	0	0	0	0	0	1
C_4	0	1	1	1	0	0	1	0	4
C_5	1	1	1	1	1	1	1	0	7
C_6	0	1	1	1	0	1	1	0	5
C_7	0	1	1	0	0	0	1	0	3
C_8	1	1	1	1	1	1	1	1	8

Table L-6: Paired comparison given by expert 6, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_6
C_1	1	1	1	0	0	1	1	0	5
C_2	0	1	1	0	0	1	1	0	4
C_3	0	0	1	0	0	0	0	0	1
C_4	1	1	1	1	0	1	1	0	6
C_5	1	1	1	1	1	1	1	1	8
C_6	0	0	1	0	0	1	1	0	3
C_7	0	0	1	0	0	0	1	0	2
C_8	1	1	1	1	0	1	1	1	7

Table L-7: Paired comparison given by expert 7, *case Muebles Marco Gomez*

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_7
C_1	1	1	0	0	0	0	1	0	3
C_2	0	1	0	1	0	1	1	0	4
C_3	1	1	1	1	0	1	1	0	6
C_4	1	0	0	1	0	1	1	0	4
C_5	1	1	1	1	1	1	1	1	8
C_6	1	0	0	0	0	1	1	0	3
C_7	0	0	0	0	0	0	1	0	1
C_8	1	1	1	1	0	1	1	1	7

Table L-8: Paired comparison given by expert 8*, case Muebles Marco Gomez*

Criteria	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**Total Sum E_8**
C_1	1	1	0	1	0	0	0	0	3
C_2	0	1	0	1	0	0	0	0	2
C_3	1	1	1	1	0	1	1	0	6
C_4	0	0	0	1	0	0	0	0	1
C_5	1	1	1	1	1	1	1	1	8
C_6	1	1	0	1	0	1	1	0	5
C_7	1	1	0	1	0	0	1	0	4
C_8	1	1	1	1	0	1	1	1	7

M. Annex: Qualitative criteria evaluation with AHP in the Enterprise application Muebles Marco Gomez

In this part is shown the results of the AHP application in the three qualitative criteria for each piece of the product mother. It is necessary understand that the comparison between just two criterial is consistent, therefore in this case is not shown the calculations.

1. Headboard of the floating bed

Storage C_3

Production Manager

Table M-1: Evaluation of Production Manager for C_3 of the product mother 1*, case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	3	9
Join	1/3	1	1	7
Sheathe	1/3	1	1	9
Patch	1/9	1/7	1/9	1

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.56	0.58	0.59	0.35	0.52
Join	0.19	0.19	0.20	0.27	0.21
Sheathe	0.19	0.19	0.20	0.35	0.23
Patch	0.06	0.03	0.02	0.04	0.04

Table M-2: Consistency test

CI	0.043
RI	0.890
CR	0.048

Administrative Secretary

Table M-3: Evaluation of Administrative Secretary for C_3 of the product mother 1, *case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	5	3	9
Join	1/5	1	1	7
Sheathe	1/3	1/1	1	9
Patch	1/9	1/7	1/9	1

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.40	0.40	0.42	0.29	0.38
Join	0.40	0.40	0.42	0.29	0.38
Sheathe	0.13	0.13	0.14	0.38	0.20
Patch	0.06	0.06	0.02	0.04	0.04

Table M-4: Consistency test

CI	0.073
RI	0.58
CR	0.082

Chief Joinery

Table M-5: Evaluation of Chief Joinery for C_3 of the product mother 1*, case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	3	7
Join	1/3	1	3	7
Sheathe	1/3	1/3	1	9
Patch	1/7	1/7	1/9	1

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.40	0.40	0.42	0.29	0.38
Join	0.40	0.40	0.42	0.29	0.38
Sheathe	0.13	0.13	0.14	0.38	0.20
Patch	0.06	0.06	0.02	0.04	0.04

Table M-6: Consistency test

CI	0.081
RI	0.580
CR	0.091

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table M-7: Qualitative Weight for ADP in C_3 *for the product mother 1, case Muebles Marco gomez*

ADP	Production Manager	Chief Joinery	Administrative Secretary	Final weighting (S_f)
Router	0.52	0.38	0.56	0.49
Join	0.21	0.38	0.18	0.26
Sheathe	0.23	0.20	0.22	0.22
Patch	0.04	0.04	0.04	0.04

Risk of Product Damage C_5

Production Manager

Table M-8: Evaluation of Production Manager for C_5 of the product mother 1, *case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	1	3
Join	1/3	1	1	1
Sheathe	1	1	1	5
Patch	1/3	1	1/5	1

ADP	Router	Join	Sheathe	Patch	Priority
Router	0.38	0.50	0.31	0.30	0.37
Join	0.13	0.17	0.31	0.10	0.18
Sheathe	0.38	0.17	0.31	0.50	0.34
Patch	0.13	0.17	0.06	0.10	0.11

Table M-9: Consistency test

CI	0.087
RI	0.58
CR	0.098

Chief Joinery

Table M-10: Evaluation of Chief Joinery for C_5 of the product mother 1, *case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	1	7
Join	1/3	1	1	7
Sheathe	1	1	1	9
Patch	1/7	1/7	1/9	1

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.40	0.58	0.32	0.29	0.40
Join	0.13	0.19	0.32	0.29	0.24
Sheathe	0.40	0.19	0.32	0.38	0.32
Patch	0.06	0.03	0.04	0.04	0.04

Table M-11: Consistency test

CI	0.053
RI	0.58
CR	0.060

Joinery Operator II

Table M-12: Evaluation of Joinery Operator II for C_5 of the product mother 1, *case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	1	9
Join	1/3	1	1	7
Sheathe	1	1	1	7
Patch	1/9	1/7	1/7	1

ADP	Router	Join	Sheathe	Patch	Priority
Router	0.41	0.58	0.32	0.38	0.42
Join	0.14	0.19	0.32	0.29	0.24
Sheathe	0.41	0.19	0.32	0.29	0.30
Patch	0.05	0.03	0.05	0.04	0.04

Table M-13: Consistency test

CI	0.042
RI	0.58
CR	0.047

FINAL EIGENVECTOR FOR THE CRITERION RRISK OF PRODUCT DAMAGE

Table M-14: Qualitative Weight for ADP in C_5 *for the product mother 1, case Muebles Marco gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Final weighting (S_f)
Router	0.37	0.40	0.42	0.40
Join	0.18	0.24	0.24	0.22
Sheathe	0.34	0.32	0.30	0.32
Patch	0.11	0.04	0.04	0.06

Production Planning C_6

Production Manager

Table M-15: Evaluation of Production Manager for C_6 of the product mother 1, *case Muebles Marco Gomez*

ADP	Router	Join	Sheathe	Patch
Router	1	3	3	7
Join	1/3	1	1	5
Sheathe	1	1	1	9
Patch	1/7	1/5	1/9	1

ADP	Router	Join	Sheathe	Patch	Priority vector
Router	0.55	0.58	0.59	0.32	0.51
Join	0.18	0.19	0.20	0.23	0.20
Sheathe	0.18	0.19	0.20	0.41	0.25
Patch	0.08	0.04	0.02	0.05	0.05

Table M-16: Consistency test

CI	0.060
RI	0.580
CR	0.067

Side Rail and Leg of the floating bed

<u>Storage C_3</u>

Production Manager

Table M-17: Evaluation of Production Manager for C_3 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	7
Polish	1/7	1

ADP	Patch	Polish	Priority vector
Patch	0.88	0.88	0.88
Polish	0.13	0.13	0.13

Chief Joinery

Table M-18: Evaluation of Chief Joinery for C_3 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	7
Polish	1/7	1

ADP	Patch	Polish	Priority vector
Patch	0.88	0.88	0.88
Polish	0.13	0.13	0.13

Administrative Secretary

Table M-19: Evaluation of Administrative Secretary for C_3 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	5
Polish	1/5	1

ADP	Patch	Polish	Priority vector
Patch	0.83	0.83	0.83
Polish	0.17	0.17	0.17

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table M-20: Qualitative Weight for ADP in C_3 *for the product mother 2, case Muebles c*

ADP	Production Manager	Chief Manager	Administrative Secretary	Ponderación final (S_f)
Patch	0.88	0.88	0.83	0.86
Polish	0.13	0.13	0.17	0.14

Risk of product damage C_5

Production Manager

Table M-21: Evaluation of Administrative Secretary for C_5 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	5
Polish	1/5	1

ADP	Patch	Polish	Priority vector
Patch	0.83	0.83	0.83
Polish	0.17	0.17	0.17

Chief Joinery

Table M-22: Evaluation of Chief Joinery for C_5 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	9
Polish	1/9	1

ADP	Patch	Polish	Priority vector
Patch	0.9	0.9	0.9
Polish	0.1	0.1	0.1

Joinery Operator II

Table M-23: Evaluation of Joinery Operator II for C_5 of the product mother 2, *case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	7
Polish	1/7	1

ADP	Patch	Polish	Priority vector
Patch	0.88	0.88	0.88
Polish	0.13	0.13	0.13

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table M-24: Qualitative Weight for ADP in C_5 *for the product mother 2, case Muebles Marco Gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Ponderación final (S_f)
Patch	0.83	0.90	0.88	0.87
Polish	0.17	0.10	0.13	0.13

Production Planning C_6

Production Manager

Table M-25: Evaluation of Production Manager for C_5 of the product mother 2*, case Muebles Marco Gomez*

ADP	Patch	Polish
Patch	1	7
Polish	1/7	1

ADP	Patch	Polish	Priority vector
Patch	0.88	0.88	0.88
Polish	0.13	0.13	0.13

The Headboard of the chair

Storage C_3

Production Manager

Table M-26: Evaluation of Production Manager for C_3 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	7	9	5
Router	1/9	1	3	1
Cut MDF	1/9	1/3	1	1
Patch	1/5	1	1	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.69	0.75	0.64	0.63	0.68
Router	0.10	0.11	0.21	0.13	0.14
Cut MDF	0.08	0.04	0.07	0.13	0.08
Patch	0.14	0.11	0.07	0.13	0.11

Table M-27: Consistency test

CI	0.051
RI	0.580
CR	0.058

Chief Manager

Table M-28: Evaluation of Chief Joinery for C_3 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	1	3	7
Router	1	1	5	9
Cut MDF	1/3	1/5	1	7
Patch	1/7	1/9	1/7	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.40	0.43	0.33	0.29	0.36
Router	0.40	0.43	0.55	0.38	0.44
Cut MDF	0.13	0.09	0.11	0.29	0.16
Patch	0.06	0.05	0.02	0.04	0.04

Table M-29: Consistency test

CI	0.075
RI	0.580
CR	0.084

Administrative Secretary

Table M-30: Evaluation of Administrative Secretary for C_3 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	1	3	7
Router	1	1	1	5
Cut MDF	1/3	1	1	7
Patch	1/7	1/5	1/7	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.40	0.31	0.58	0.35	0.41
Router	0.40	0.31	0.19	0.25	0.29
Cut MDF	0.13	0.31	0.19	0.35	0.25
Patch	0.06	0.06	0.03	0.05	0.05

Table M-31: Consistency test

CI	0.056
RI	0.580
CR	0.063

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table M-32: Qualitative Weight for ADP in C_3 *for the product mother 3, case Muebles Marco Gomez*

ADP	Production Manager	Chief Manager	Administrative Secretary	Ponderación final (S_f)
Sheathe	0.68	0.36	0.41	0.48
Router	0.14	0.44	0.29	0.29
Cut MDF	0.08	0.16	0.25	0.16
Patch	0.11	0.04	0.05	0.07

Risk of Product damage C_5

Production Manager

Table M-33: Evaluation of Production Manager for C_5 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	1	3	7
Router	1	1	3	7
Cut MDF	1/3	1/3	1	9
Patch	1/7	1/7	1/9	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.40	0.40	0.42	0.29	0.38
Router	0.40	0.40	0.42	0.29	0.38
Cut MDF	0.13	0.13	0.14	0.38	0.20
Patch	0.06	0.06	0.02	0.04	0.04

Table M-34: Consistency test

CI	0.081
RI	0.580
CR	0.091

Chief Joinery

Table M-35: Evaluation of Chief Joinery for C_5 of the product mother 3*, case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	3	1	5
Router	1	1	1	7
Cut MDF	1/3	1	1	9
Patch	1/5	1/7	1/9	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.39	0.58	0.32	0.23	0.38
Router	0.13	0.19	0.32	0.32	0.24
Cut MDF	0.39	0.19	0.32	0.41	0.33
Patch	0.08	0.03	0.04	0.05	0.05

Table M-36: Consistency test

CI	0.078
RI	0.580
CR	0.088

Joinery Operator II

Table M-37: Evaluation of Joinery Operator II for C_5 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	5	3	7
Router	1/5	1	1	3
Cut MDF	1/3	1	1	9
Patch	1/7	1/3	1/9	1

ADP	Sheathe	Router	Cut MDF	Patch	Priority vector
Sheathe	0.60	0.68	0.59	0.35	0.55
Router	0.12	0.14	0.20	0.15	0.15
Cut MDF	0.20	0.14	0.20	0.45	0.25
Patch	0.09	0.05	0.02	0.05	0.05

Table M-38: Consistency test

CI	0.084
RI	0.580
CR	0.095

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table M-39: Qualitative Weight for ADP in C_5 *for the product mother 3, case Muebles Marco Gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Ponderación final (S_f)
Sheathe	0.38	0.38	0.55	0.44
Router	0.38	0.24	0.15	0.26
Cut MDF	0.20	0.33	0.25	0.26
Patch	0.04	0.05	0.05	0.05

Production Planning C_6

Production manager

Table M-40: Evaluation of Production Manager for C_6 of the product mother 3, *case Muebles Marco Gomez*

ADP	Sheathe	Router	Cut MDF	Patch
Sheathe	1	1	1	7
Router	1	1	3	6
Cut MDF	1	1/3	1	9
Patch	1	1/5	1/9	1

ADP	Sheathe	Router	Cut	Patch	Priority
Sheathe	0.32	0.40	0.20	0.30	0.30
Router	0.32	0.40	0.59	0.26	0.39
Cut MDF	0.32	0.13	0.20	0.39	0.26
Patch	0.05	0.07	0.02	0.04	0.04

Table M-41: Consistency test

CI	0.076
RI	0.580
CR	0.086

The base of the dining tables square

<u>Storage C_3</u>

Production Manager

Table M-42: Evaluation of Production Manager for C_3 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Soldar	Afilar	Vector propio
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Chief Joinery

Table M-43: Evaluation of Chief Joinery for C_3 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Resanar	Ensamblar	Vector propio
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Administrative Secretary

Table M-44: Evaluation of Administrative Secretary for C_3 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	9
Join	1/9	1

ADP	Resanar	Ensamblar	Vector propio
Patch	0.9	0.9	0.9
Join	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table M-45: Qualitative Weight for ADP in C_3 *for the product mother 4, case Muebles Marco Gomez*

ADP	Production Manager	Chief Manager	Administrative Secretary	Ponderación final (S_f)
Resanar	0.88	0.88	0.90	0.88
Ensamblar	0.13	0.13	0.10	0.12

Risk of product damage C_5

Production Manger

Table M-46: Evaluation of Production Manager for C_5 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	5
Join	1/5	1

ADP	Patch	Join	Priority vector
Patch	0.83	0.83	0.83
Join	0.17	0.17	0.17

Chief Joinery

Table M-47: Evaluation of Chief Joinery for C_5 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Patch	Join	Priority vector
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Joinery Operator II

Table M-48: Evaluation of Joinery Operator II for C_5 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	3
Join	1/3	1

ADP	Patch	Join	Priority vector
Patch	0.75	0.75	0.75
Join	0.25	0.25	0.25

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table M-49: Qualitative Weight for ADP in C_5 *for the product mother 4, case Muebles Marco Gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Ponderación final (S_f)
Patch	0.83	0.88	0.75	0.82
Join	0.17	0.13	0.25	0.18

Production Planning C_6

Production Manager

Table M-50: Evaluation of Production Manager for C_6 of the product mother 4, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	5
Join	1/5	1

ADP	Patch	Join	Priority vector
Patch	0.83	0.83	0.83
Join	0.17	0.17	0.17

The base of the dining tables tear drop shaped

Storage C_3

Production Manager

Table M-51: Evaluation of Production Manager for C_3 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Patch	Join	Priority vector
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Chief Joinery

Table M-52: Evaluation of Chief Joinery for C_3 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Patch	Join	Priority vector
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Administrative Secretary

Table M-53: Evaluation of Administrative Secretary for C_3 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	9
Join	1/9	1

ADP	Patch	Join	Priority vector
Patch	0.9	0.9	0.9
Join	0.1	0.1	0.1

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table M-54: Qualitative Weight for ADP in C_3 *for the product mother 5, case Muebles Marco Gomez*

ADP	Production Manager	Chief Manager	Administrative Secretary	Ponderación final (S_f)
Patch	0.88	0.88	0.90	0.88
Join	0.13	0.13	0.10	0.13

Risk of product damage C_5

Production Manager

Table M-55: Evaluation of Production Manager for C_5 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	5
Join	1/5	1

ADP	Patch	Join	Priority vector
Patch	0.83	0.83	0.83
Join	0.17	0.17	0.17

Chief Joinery

Table M-56: Evaluation of Chief Joinery for C_5 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	7
Join	1/7	1

ADP	Patch	Join	Priority vector
Patch	0.88	0.88	0.88
Join	0.13	0.13	0.13

Joinery Operator II

Table M-57: Evaluation of Joinery Operator II for C_5 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	3
Join	1/3	1

ADP	Patch	Join	Priority vector
Patch	0.75	0.75	0.75
Join	0.25	0.25	0.25

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table M-58: Qualitative Weight for ADP in C_5 *for the product mother 5, case Muebles Marco Gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Ponderación final (S_f)
Patch	0.83	0.88	0.75	0.82
Join	0.17	0.13	0.25	0.18

<u>Production Planning C_6</u>

Production Manager

Table M-59: Evaluation of Production Manager for C_5 of the product mother 5, *case Muebles Marco Gomez*

ADP	Patch	Join
Patch	1	5
Join	1/5	1

ADP	Patch	Join	Priority vector
Patch	0.83	0.83	0.83
Join	0.17	0.17	0.17

N. Annex: Test of the performance of the methodology from the product mother Headboard and footboard bed base

In the step 1 section 1.3, in someproduct mother s, experts agreed in the selection of the decoupling point. This means that for these products, since this section, the decoupling point is already selected. Taking advantage of this, the pieces BED BASE and HEADBOARD were selected to test the performance of the methodology.

In this sense it should be understood beforehand that the ideal result is known. Therefore, it is expected that once the methodology is applied and the expected results are obtained, it is a fact that the process contributed to validate the methodology.

This process is part of the obtained results in steps 1, 2 and 3 as these are common results for the whole methodology. In this case, only the nine criteria for the product mother will be qualified and the results will be weighted in step 5 and 6. From which the obtained result for the experts will be compared to the results generated by the methodology.

SETEP 4. TO EVALUATE THE CRITERIA

Storage C_3

Production Manager

Table N-1: Evaluation of Production Manager for C_3 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	7	9
Patch	1/7	1	3
Apply dye	1/9	1/3	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.80	0.84	0.69	0.78
Patch	0.11	0.12	0.23	0.15
Apply dye	0.09	0.04	0.08	0.07

Table N-2: Consistency test.

CI	0.041
RI	0.580
CR	0.070

Chief Manager

Table N-3: Evaluation of Chief Joinery for C_3 of the product mother*, case Muebles Marco Gomez.*

ADP	Router	Patch	Apply dye
Router	1	7	7
Patch	1/7	1	1
Apply dye	1/7	1	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.78	0.78	0.78	0.78
Patch	0.11	0.11	0.11	0.11
Apply dye	0.11	0.11	0.11	0.11

Table N-4: Consistency test

CI	0
RI	0.580
CR	0

Administrative Secretary

Table N-5: Evaluation of Administrative Secretary for C_3 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	7	9
Patch	1/7	1	1
Apply dye	1/9	1	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.80	0.78	0.82	0.80
Patch	0.11	0.11	0.09	0.11
Apply dye	0.09	0.11	0.09	0.10

Table N-6: Consistency test

CI	0.003
RI	0.580
CR	0.006

FINAL EIGENVECTOR FOR THE CRITERION STORAGE

Table N-7: Qualitative Weight for ADP in C_3 *for the product mother, case Muebles Marco Gomez*

ADP	Production Manager	Chief Manager	Administrative Secretary	Final Weight (S_f)
Router	0.78	0.78	0.80	0.78
Patch	0.15	0.11	0.11	0.12
Apply dye	0.07	0.11	0.10	0.09

Risk of Product damage C_5

Production Manager

Table N-8: Evaluation of Production Manager for C_5 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	7	6
Patch	1/7	1	1
Apply dye	1/5	1	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.76	0.78	0.75	0.76
Patch	0.11	0.11	0.13	0.12
Apply dye	0.13	0.11	0.13	0.12

Table 20. Consistency test

CI	0.001
RI	0.580
CR	0.002

Chief Joinery

Table N-9: Evaluation of Chief Joinery for C_5 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	9	5
Patch	1/9	1	1
Apply dye	1/5	1	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.76	0.82	0.71	0.77
Patch	0.08	0.09	0.14	0.11
Apply dye	0.15	0.09	0.14	0.13

Table N-10: Consistency test

CI	0.019
RI	0.580
CR	0.033

Joinery Operator II

Table N-11: Evaluation of Joinery Operator II for C_5 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	1	3
Patch	1	1	5
Apply dye	1/3	1/5	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.43	0.45	0.33	0.41
Patch	0.43	0.45	0.56	0.48
Apply dye	0.14	0.09	0.11	0.11

Table N-12: Consistency test

CI	0.014
RI	0.580
CR	0.025

FINAL EIGENVECTOR FOR THE CRITERION RISK OF PRODUCT DAMAGE

Table N-13: Qualitative Weight for ADP in C_5 *for the product mother, case Muebles Marco Gomez*

ADP	Production Manager	Chief Joinery	Joinery Operator II	Final Weight (S_f)
Router	0.76	0.77	0.41	0.64
Patch	0.12	0.11	0.48	0.23
Apply dye	0.12	0.13	0.11	0.12

Production Planning C_6

Production manager

Table N-14: Evaluation of Production Manager for C_6 of the product mother, *case Muebles Marco Gomez*

ADP	Router	Patch	Apply dye
Router	1	7	9
Patch	1/7	1	3
Apply dye	1/9	1/3	1

ADP	Router	Patch	Apply dye	Priority vector
Router	0.80	0.84	0.69	0.78
Patch	0.11	0.12	0.23	0.15
Apply dye	0.09	0.04	0.08	0.07

Table N-15: Consistency test

CI	0.041
RI	0.580
CR	0.070

STEP 5. To evaluate the alternative decoupling points

Table N-16: Final grade for the alternatives decoupling point in the product mother 9.

Product	ADP	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_9	Final Result Q_p
BED BASE. HEADBOARD	**Router**	0.23	0.33	0.78	0.31	0.64	0.78	0.33	0.33	46.4%
	Patch	0.57	0.33	0.12	0.20	0.23	0.15	0.28	0.33	29.3%
	Apply dye	0.19	0.33	0.09	0.49	0.12	0.07	0.39	0.33	24.2%

As can be seen in Table N-16, as well as in the selection made by the experts, by applying the methodology, the selected point was Router weighting 46.4%.

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