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MANUFACTURING TECHNOLOGY SELECTION IN THE SUPPLY CHAIN CONTEXT BY MEANS OF FUZZY-AHP: A CASE IN THE HIGH PERFORMANCE TEXTILE INDUSTRY

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ABSTRACT

The selection of a manufacturing technology may have major implication on the business performance and the whole supply chain. In particular for innovative sector dealing with no standardised materials and technologies, technology selection is a main issue. Moreover, selecting a manufacturing technology may not depend only on its technical merit, but on supply chain-related factors such as availability of raw materials, capacity, suppliers, workers among others. This paper explores the factors affecting manufacturing technology selection with respect to the supply chain using the Fuzzy Analytical Hierarchy Process, which has proven to be a powerful tool when dealing with problems affected by uncertainty. This work uses a case study involving a leading enterprise in the high performance textile industry to select between two different lamination technologies taking into account 12 factors. Results show the validity of the used procedure in understanding which factors are the most important when it comes to selecting a manufacturing technology with respect to the supply chain. Factors such as service level/on time deliveries and supply chain performance proven to be the most import factors for the company studied, followed by return on investment, hire/train staff with new skills and environmental impact.

Keywords: technology selection, supply chain management, fuzzy-AHP, textile industry, innovative industries.

INTRODUCTION

Around the world organisations involved in the development of new products and applications based on technological innovations are facing numerous challenges. One of the great challenges is about responding to uncertainty because of highly volatile demand [1] which consequently affects the management of supply chains. A review of the traditional definition of supply chain management remind us about the creation of value by reaching beyond the traditional borders of a firm including suppliers, customers and other stakeholders [2]. In a climate characterized for uncertainty companies in manufacturing need to collaborate with suppliers and customers to achieve seamless integration of manufacturing and supply chains [3].

The selection of the right technology plays a fundamental role in enabling seamless integration of manufacturing and supply chains. Several recent cases on technology selection can be found in the literature with a wide scope that covers from the selection and deployment of certain types of technologies and evaluation techniques such as RFID in retail operations using real options analysis [4], the use of fuzzy multiple objective programming to control inventory problems associated to the technological advances of transistor-liquid crystal technology [5] and the use of analytical hierarchy process (AHP) combined with strategic model for the selection of manufacturing technologies to promote manufacturing and supply chain collaboration and coordination [3].

Many technologically innovative industries are usually under pressure to be responsive and resilient to changes in the marketplace. The supply chain of technologically innovative industries can be highly fragmented where the introduction of a change at any one place results on logistical impacts and constraints across the supply chain. Furthermore, in technologically innovative industries some of the biggest challenges are represented by the lack of standard manufacturing processes and the lack of standardized selection of materials with defined or proscribed properties.

One technologically innovative industry subject to a myriad of pressures is the textile industry, in particular high performance textiles which has experienced significant growth in recent years. High performance textiles represent one of the most dynamic sectors of the international textile and clothing industry [6]. High performance textiles undergo specialised surface treatments for applications including protective clothing; heat and fire protection; medical textiles; wound care textiles; geotextiles; fibres and textiles for civil engineering applications; fibre-reinforced composites for sustainable energy applications and leisure and sport [6].

This paper addresses the challenges faced by technologically innovative companies when it comes to technology selection with respect of their supply chains.

Using an industry case this work addresses the particularities of the high performance textiles industry and the challenges it faces when it comes to making a selection between two competing technologies, in this case full lamination/solvent type and dot lamination/solvent free. According to the Textile Centre of Excellence [7] laminated fabrics are widely used in high performance apparel where fabrics are required to be waterproof yet breathable, a laminate membrane laminates often consist of a non-textile membrane sandwiched between two textiles, for example in the case of the micro-pourous membranes such as Gore Tex.

Fuzzy Analytical Hierarchy Process (Fuzzy-AHP) has been used to explore the importance of different factors in selecting a manufacturing technology because of its ability in dealing with uncertainty and vagueness. The next section shows a review of the literature involving decision support systems. The next section shows a review of the literature involving decision support systems. The literature review section is followed by the presentation of the case study methodology which is used to investigate 12 key factors related to technology selection with respect to the supply chain in the high performance textile industry.

LITERATURE REVIEW

Technology selection plays a fundamental role in the operations of today's supply chains as there can be multiple benefits that can be achieved. Technologies and strategies affecting manufacturing operations result in better competitiveness and improvement programmes. Technology selection has a fundamental role in the configuration of the supply chain, as opportunities and threats are normally associated with a technology alternative in the supply chain context [3]. Technology represents a key variable for identifying competitive policies, production strategy, innovations, and creativity and commercialisation activities among others [8].

The rating of technology-related factors is important as new technologies and new technological developments continue to affect the performance of the supply chain. Cegielski *et al*. [9] highlights that as an emerging technology, cloud computing is changing the form and function of information technology infrastructures and spreading within the supply chain.

Technology selection can have multiple ramifications and it can be assessed in various ways. Farooq and O'Brien [3] state that technology is mostly assessed in terms of financial benefits; however, these models have been subjected to criticism over time.

Technology selection has close links to supplier selection because of its strategic implications for design/planning in the supply chain. Wu and Barnes [10] reviewed the literature on supply partner selection decision-making published between 2001 and 2011 using a classification framework developed by Luo *et al*. [11] and based on De Boer et al. [12]. Wu and Barnes [10] recognize that the use of De Boer's *et al.* [12] formulation of criteria, qualification, final selection and application feedback allows for an effective means of solving highly complex problems.

The use of Analytical Hierarchy Process (AHP) is a well-known decision support methodology that has gained acceptance in supply chain management especially when it comes to process selection. The work by Korpela *et al*. [13] used AHP for supporting supply chain development processes. The authors used AHP to approach supply chain development from a business process re-engineering point of view focusing on the logistics process. Palma-Mendoza [14] addressed supply-chain re-design by using the Supply Chain Operations Reference (SCOR) model to identify relevant processes and SCOR model performance attributes and metrics as evaluation criteria to conduct an Analytical Hierarchy Process (AHP) analysis for target process selection. According to the author AHP can aid in deciding which supply chain processes are better candidates to re-design in light of predefined criteria. The proposed model was tested through application in an Airline MRO supply chain, for the purpose of identifying relevant supply chain processes and the selection of a target for re-design.

The analytic hierarchy process (AHP) is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution [13]. AHP is a problem-solving framework and a systematic procedure for representing the elements of any problem [15]. AHP is based on the following three principles: decomposition, comparative judgements, and the synthesis of priorities. AHP starts by decomposing a complex, multi-criteria problem into a hierarchy where each level consists of a few manageable elements which are then decomposed into another set of elements [15]. AHP is introduced for choosing the most suitable alternative, which fulfils entire set of objectives in multi-attribute decision-making problems.

Although AHP has the merit to be a simple and powerful tool for multi-criteria decision-making, the crisp scale used in the judgment process might not be sufficient to take into account the uncertainty associated with the human judgment [16]. The linguistic assessment of human feelings and judgements are vague and it is not reasonable to represent it in terms of precise numbers. It feels more confident to give interval judgements than fixed value judgements. For this purpose, Fuzzy set theory [17] has been integrated to address uncertainty in AHP decision-making process [18]. In the context of supply chain management, Fuzzy Analytical Hierarchy Process has been widely used to solve problems such as supplier selection and supply chain design/planning [19, 20].

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FUZZY-AHP

AHP is a multi-criteria decision-making method proposed by Saaty [15]. The conventional AHP is based on the pairwise comparison using a crisp nine-point scale reflecting the human preferences. In order to take into account the uncertainty due to the human judgment, it has been proven the benefit in using an intervals scale [16].

Fuzzy set theory has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. In the Fuzzy Analytical Hierarchy Process (FAHP) each point of the Saaty's scale has been replaced by a numerical interval characterised by a membership function, which assigns to each object a grade of membership ranging between 0 and 1 [17]. The most simple and commonly used membership function has a triangular shape. In this case the fuzzy number is a triplet of values such as (a1, a2, a3) which represent the smallest possible value, the most promising value and the largest value. Triangular fuzzy membership functions corresponding to Saaty's nine points scale are shown in Figure-1. The linguistic scale, its corresponding crisp values (1 to 8) and fuzzy numbers are indicated in Table-1.

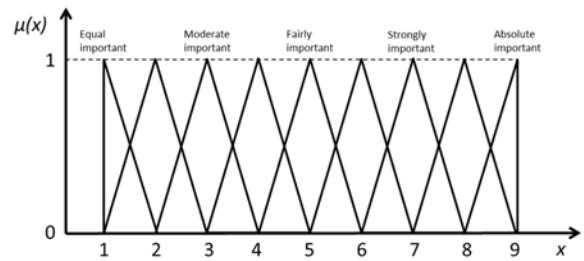

Figure-1. Saaty's nine point scale.

Table-1. Judgement scale's Fuzzy numbers.

Linguistic judgement scale	Crisp scale	Fuzzy triangular scale (a_1,a_2,a_3)	Reciprocal fuzzy triangular scale (1/a_3,1/a_2,1/a_1)
Just equal	1	(1,1,1)	(1,1,1)
Equal important	1	(1,1,2)	(1/2,1,1)
Equal-moderate important	2	(1,2,3)	(1/3,1/2,1)
Moderate important	3	(2,3,4)	(1/4,1/3,1/2)
Moderate-fairly important	4	(3,4,5)	(1/5,1/4,1/3)
Fairly important	5	(4,5,6)	(1/6,1/5,1/4)
Fairly-strongly important	6	(5,6,7)	(1/7,1/6,1/5)
Strongly important	7	(6,7,8)	(1/8,1/7,1/6)
Strongly-absolute important	8	(7,8,9)	(1/9,1/8,1/7)
Absolute important	9	(8,9,9)	(1/9,1/9,1/8)

In this paper FAHP has been applied to select the right manufacturing technology for a textile lamination process, and 12 key criteria have been taken into account according to [3]. In Table-2, the 12 key criteria considered are listed. The first stage of the FAHP consists of filling a 12x12 pairwise comparison matrix shown, in order to express the relative importance of one criterion over another. After that, Consistency Index (CI) are calculated according to the procedure described in [16] and then priority weights for each criterion are calculated from the comparison matrix according to the procedure described in [18].

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Table-2. Considered factors affecting technology selection.

	Factor
C1	Technology used by our suppliers
C2	Technology used by our customers
C3	Automation
C4	Rapid manufacturing/prototyping
C5	Capacity sizing and high volumes manufacturing
C6	Reduce supply chain cycle time
C7	Low cost manufacturing
C8	Return on investment
C9	Supply chain performance
C10	On-time deliveries/service level to customer
C11	Hire/train staff with new skills
C12	Reduce environmental impact

Once the criteria have been ranked, during the second stage of the FAHP 12 pairwise comparison matrixes, one for each criterion, are filled in order to express the importance of each manufacturing technology alternative over another with respect to each criterion as. The weight vector of each alternative with respect to the corresponding criterion are determined similarly to the previous phase. Finally the priority weights of each manufacturing technology can be calculated by weights per technology multiplied by weights of the corresponding criterion. The highest score of the manufacturing technology gives the idea about the best option to select for the manufacturing process.

CASE STUDY

This research aims to understand how a leading enterprise in the high performance textiles industry gets to select one out of two competing technologies that can affect the configuration of its supply chain. For this purpose, a case study involving a company who is leader in the high performance textile industry was conducted during 2014. The case study methodology has been thoroughly explained by Yin [21]. To justify the use of the case study methodology Buganza *et al.* [22] highlight that the case study methodology approach allows a holistic and contextualized analysis and it is properly suited for the initial phases of the exploratory nature of research work as is the case of the textile industry. It is important to indicate that quantitative methods such as surveys do not provide the depth for investigating the phenomenon closely and identify the mechanisms by which the variables interrelate [21].

The company selected to participate in the case study is a leader in the high performance textiles sector. Its high performance textiles covers applications such as winter sport jackets, rainwear, casual wear, golf wear, hunting wear and luxury casual wear. The company director and sales assistant were interviewed to participate in this research. The study started during the autumn of 2014 and concluded in the spring of 2015. Lamination for this company is an important process that involves selection between two competing technologies shown in Figure 2. In lamination the adhesive is required to bond the fabric and component layers together [23]. Creating a strong bond, which will not deteriorate through conditions experienced in use such as movement and laundering, is not the biggest challenged faced. Adhesives are often associated with making the fabric too rigid and thus affecting the handle, which is often a negative characteristic, particularly for applications in performance clothing where comfort is a requirement [23]. Environmental consideration has led towards more interest in hot melt adhesives, rather than solvent based adhesive, or the use of flame adhesion [23].

The gathering of data for this research comprises the factors identified by Farooq and O'Brien C [3] where a technology selection framework integrates manufacturing within a supply chain. The company director and sales assistant companies were asked to fill the pairwise comparison matrixes for the 12 factors and 2 lamination technology options. Totally, 20 matrixes were filled. Before calculating the priority vectors, CI was calculated for all the matrixes showing values lower than 0.10 which means the judgements was consistent.

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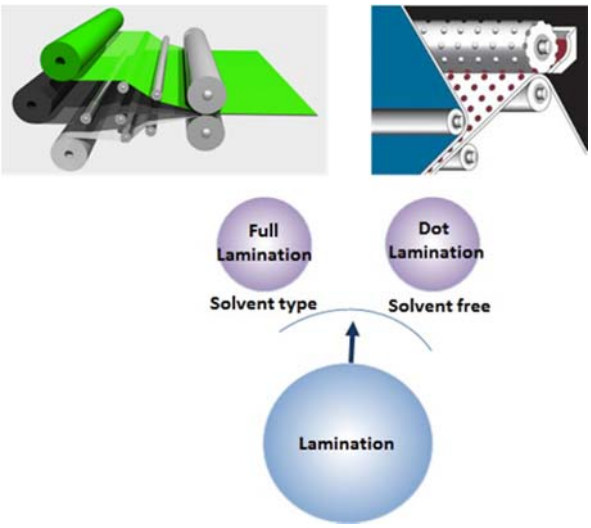

Figure-2. Two competing lamination technologies.

Figure-3 shows the top rated factors. The most important factors for the company in selecting a manufacturing technology are: On-time deliveries/service level to customer, Supply chain performance, Return on investment, Hire/train staff with new skills and finally reduce environmental impact. This outcome shows how supply chain-related factors are crucial when it comes to the selection of a manufacturing technology. Also the availability of staff with the right skills and the environmental impact are important factor. Furthermore, combining the factors' weights with the technology options' weights for each factor, the final weights for each technology have been obtained. Full lamination/solvent type option has received a highest final weight compared to Dot lamination/solvent free (See Table-3).

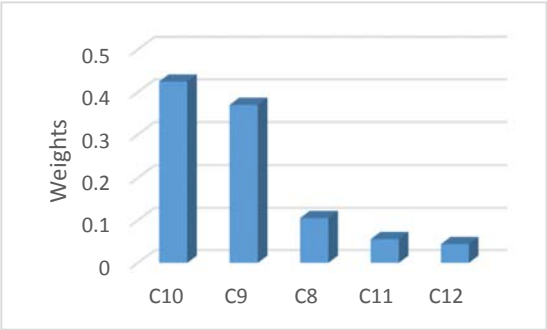

Figure-3. Weight for each factor.

Fuzzy AHP outcomes confirmed the company's preferences regarding the factors and the technology option. As a matter of fact, factors directly related to the technical merit of the technology such as low cost manufacturing or automation, are not priorities for the company since they already reached high levels. On the contrary, the company is now focused on improving supply chain-related aspects such as supply chain performance and service level, although economic and environmental issues still represent a priority.

Table-3. Technology options' final ranking.

Technology option	Weight
Full lamination/solvent type	0.72
Dot lamination/solvent free	0.28

CONCLUSIONS

This paper has investigated the importance of the factors affecting the selection of a manufacturing technology in the supply chain context. A case study regarding a high performance textile company has been conducted in order to select a lamination technology among two competing options. Fuzzy-AHP methodology has been employed as a tool to carry out the analysis because of its strength in capturing the vagueness of human judgment and its simplicity and ability in solving multi-criteria decision making problems.

Results have shown that service level and supply chain performance is the most important factors for the company when it comes to the selection of a manufacturing technology. Also return on investment, hire/train people with new skills and environmental impact have shown to be important factors for the high performance textile company. Moreover, full lamination/solvent type turned out to be the suggested technology option for high performance textile manufacturing. Finally, Fuzzy AHP proven to be a fast, simple and valid decision-making support tool for technology selection.

For high-tech industries facing challenges in terms of standardisation of processes and materials the identification of factors affecting technology selection with respect to their supply chains is important because of its implications in the configuration of robust, resilient and fast supply chains that are also capable of mitigating the effects of uncertainty due to technology selection and ultimately achieve best practices.

Uncertainty associated to manufacturing technology selection with respect to the supply chain becomes more significant if an industry is actively seeking to introduce new manufacturing processes and new materials for the development of innovative products. High-tech industries such as the high performance textile face a high degree of uncertainty; hence the rating of factors affecting technology selection has the potential to

lead to best practices that can benefit the entire high performance textile industry.

It is recognized that this research has limitations, which are also opportunities for further research. A wider investigation involving a large pool of companies in innovative high tech industrial sectors may be required in order to extend the findings. An industry survey could be conducted in order to grasp to a high level of detail the views of the high performance textile industry regarding the factors presented in this paper and how that affects the supply chain.

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