International Journal of Industrial Engineering & Production Research

International Journal of Industrial Engineering & Production Research

pISSN: 2008-4889

March 2015, Volume 26, Number 2
pp. 147-162

http://IJIEPR.iust.ac.ir/

Supply Chain Liability Using an Integrated AHP-Fuzzy-QFD Approach

Mahnaz Zarei’ , Yahia Zare Mehrjerdi *

Mahnaz Zarei Department of Industrial Engineering, Islamic Azad University, Shiraz Branch, Iran, delbina.2008@gmail.com
Yahia Zare Mehrjerdi Department of Industrial Engineering, Yazd University, Yazd, Iran, yazm2000@yahoo.com

KEYWORDS

Supply chain management,
Liability,
Analytic Hierarchy Process,
Fuzzy logic,
Quality Function Deployment.

ABSTRACT

Nowadays supply chain management has become one of the powerful business concepts for organizations to gain a competitive advantage in global market. This is the reason that now competition between the firms has been replaced by competitiveness among the supply chains. Moreover, the popular literature dealing with supply chain is replete with discussions of leanness and agility. Agile manufacturing is adopted where demand is volatile while lean manufacturing is used in stable demands. However, in some situations it is advisable to utilize a different paradigm, called leagility, to enable a total supply chain strategy. Although, various generic hybrids have been defined to clarify means of satisfying the conflicting requirements of low cost and fast response, little research is available to provide approaches to enhance supply chain leagility.By linking Leagile Attributes and Leagile Enablers (LAs and LEs), this paper, based upon Quality Function Deployment (QFD), strives to identify viable LEs to achieve a defined set of LAs. Due to its wide applicability, AHP is deployed to prioritize LAs. Also, fuzzy logic is used to deal with linguistics judgments expressing relationships and correlations required in QFD. To illustrate the usefulness and ease of application of the approach, the approach was exemplified with the help of a case study in chemical industry.

1- Introduction

The combined effect of system-induced and marketplace uncertainty typically leads to the type of bullwhip effect supply chain dynamics (Fisher, 1997); Furthermore, the need to distinguish between stable functional products competing on price and volatile fashion or innovative products dependent on fast response, is now widely accepted (Fisher, 1997). The popular literature dealing with manufacturing practices is replete with discussions of leanness and agility. The lean approach operates best when there is high volume, predictable demand with supply certainty, so that functional products can be created. In low volume, highly volatile supply chains, where customer requirements are often unpredictable and supplier capabilities and innovations are difficult to control, a more responsive or agile approach, based on innovative products, is appropriate operationally (Cox and Chicksand, 2005). There can never be any one single best way

* **Corresponding** author: **Yahia Zare Mehrjerdi**
***Email:*yazm2000@yahoo.com**

(lean or agile) of managing business strategy and supply chain (Cox and Chicksand, 2005). Indeed, sometimes "agilean" approaches may be necessary because there are decoupling points in supply chains that require a lean approach at one point and a more agile approach at another (Naylor et al., 1999).

The proposed paper tries to develop an integrated approach to obtain supply chain leagility. Furthermore, we attempt to introduce a practical tool that could be easily adopted to implement leagile strategies. By linking Leagile Attributes and Enablers (LAs and LEs) our proposed approach, which is based upon the House of Quality (HOQ) of Quality Function Deployment (QFD) methodology, aims at identifying the most appropriate leagile enablers to be implemented by supply chain management. Leagile Attributes (LAs) represent company's requirements, and appear as "whats" in the HOQ, while Leagile Enablers (LEs) are listed as "hows", since they are considered as practical tools the company can implement to achieve leagility. First, the priority weights of LAs are computed by Analytic Hierarchy Process (AHP). Then, LEs are ranked through the application of fuzzy-QFD. Fuzzy logic is used to deal with linguistics judgments expressing relationships and correlations required in the HOQ.

The remainder of the paper is organized as follows. In the second section, we have the literature review of lean, agile and leagile supply chain. Then, traditional QFD, fuzzy logic, and AHP frameworks are presented as are commonly discussed in literature. In the third section, based on the findings from the literature, Leagile Attributes and Enablers (LAs and LEs) are identified, and our AHP-fuzzy-QFD approach to enhance supply chain leagility is detailed. A case study is presented, in section four, to illustrate the usefulness and ease of application of the model. Finally, the last section contains the concluding remarks and future research directions.

2. Review of the Literature

We begin by providing a brief overview of the tools and paradigms used in this work.

2-1. Lean Supply Chain

The term "lean production" was first used by Krafcik (1988b), and subsequently, Womack et al. (1990) used this term to contrast Toyota with the western "mass production" system in his book of "The Machine That Changed the World". Lean production, originating from the Toyota Production System is one of the initiatives that many major businesses all around the world have been trying to adopt in order to remain competitive in the increasingly global market (Pe´rez and Sa´nchez, 2000; Schonberger, 2007; Womack, et al., 1990). The focus of this multi-dimensional approach is on cost reduction by eliminating non-value added activities, and using tools such as JIT, cellular manufacturing, total productive maintenance, production smoothing, setup reduction and others to eliminate the waste (Abdulmalek and Rajgopal, 2007; Monden, 1998; Nahmias, 2001), extending not only within the organization but also along the company's supply chain network (Scherrer-Rathje, et al., 2009). A key feature of the "Machine" book was that it did not only discuss manufacturing operations, but also supply chain (Holweg, 2007). The core thrust of lean production is that the mentioned tools can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Crute et al., 2003; Shah and Ward, 2003). Lean promises significant benefits in terms of increased organizational and supply chain communication and integration (Scherrer-Rathje, et al., 2009).

The adoption of lean principles, which put more emphasis on levelizing the production schedule (Naylor et al., 1999), lead to a positive outcome with stable and/or increasing profitability (Cox and Chicksand, 2005). Furthermore, managing the supply chain and working closely with suppliers is facilitated by rationalizing the supplier base and focusing on suppliers committed to the ideals of lean production (Kannan and Tan, 2005).

While aspects of lean thinking may be appropriate internally for all participants in supply chains, the ability to extend this way of thinking beyond the boundaries of the firm into the extended supply chain is problematic to some extent; so, lean supply is of limited utility for many participants in supply chains. This is primarily because the leverage resources sometimes do not exist to allow a lean SCM approach to be adopted throughout the chain (Cox and Chicksand, 2005).

2-2. Agile Supply Chain

Among proposals of how to deal with an uncertain and unpredictable environment, agility is one of the most predominant and popular ones (Kettunen, 2009; Sherehiy et al., 2007) emerged in the beginning of the 1990s. The creators of "agility'' concept at the Iacocca Institute of Lehigh University (USA) (1991) defined it as: ''A manufacturing system with capabilities (hard and soft technologies, human resources, educated management, and information) to meet the rapidly changing needs of the marketplace''. Gunasekaran (1999) defined agility as the ability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-defined products and services. An agile system puts more emphasis on rapid reconfiguration and robustness (Naylor et al., 1999). Sharifi and Zhang (1999) mentioned that responding to change in proper ways and taking advantages of changes are the main factors of agility. Despite the differences, all definitions of ''agility'' emphasize the speed and flexibility as the primary attributes of an agile organization (Gunasekaran, 1999; Sharifi and Zhang, 1999; Sherehiy et al., 2007; Yusuf et al., 1999). An equally important attribute of agility is the effective response to change and uncertainty (Goldman et al., 1995; Kidd, 1994; Sharifi and Zhang, 2001; Va´zquez-Bustelo and Avella, 2006).

One of the challenges the new millennium has brought about for supply chain managers is the commonality of turbulence and volatility in markets (Lancioni, 2000). As Christopher (1999) pointed out, nowadays agility is an important factor in the design of supply chains. This refers to the ability of the supply chain to respond quickly to changes in customer and competitive demands. Agility in a supply chain, according to Ismail and Sharifi (2005), is the ability of the supply chain as a whole and its members to rapidly align the network and its operations to dynamic and turbulent requirements of the customers. The foundation of the agile supply chain lies in the integration of customer sensitivity, organization, processes, networks and information systems (Lin et al., 2006). In her study, Bottani (2009) proposed an original approach to show the applicability of the Quality Function Deployment (QFD) methodology, and particularly of the House of Quality (HOQ), to enhance agility of enterprises. She suggested that future studies can address the development of a similar integrated approach to enhance the leanness of companies. This sound suggestion is the impetus behind the present study.

Agility, encompassing both companies and the supply chain as a whole (Ren et al., 2001), is recognized as fundamental for survival in turbulent and volatile markets and to help companies to deliver the right product at the right time to the customers (Agarwal et al., 2007; Gunasekaran et al., 2002; Lin et al. 2006; Yusuf et al., 1999; Yusuf et al., 2004).

2-3. Leagility to cope with supply chain uncertainty and different product types

SCM improvement strives to match supply and demand which requires the reduction of uncertainty within the supply chain to facilitate a more predictable upstream demand. Sometimes, however, uncertainty is impossible to remove from the supply chain due to the type of product involved (Bhavnagar and Shoal , 2005). If a product is highly fashionable its demand will be unpredictable. Thus, the supply chains are faced with uncertainty but need to develop a strategy that enables them still to match supply and demand. Towill and McCullen (1999) believe that many of the detrimental effects of uncertainty can be alleviated by working hard to reduce the system-induced effects. This leaves the supply chain to develop a strategy that needs to deal with marketplace uncertainty. The combined effect of system-induced and marketplace uncertainty typically leads to the type of "bullwhip effect" supply chain dynamics (Fisher, 1997; Towill et al., 2003) that is the resultant behavior due to a system-imposed uncertainty resulting from a supplier discount scheme operating in a retail supply chain (Mason-Jones et al., 2000).

On the other hand, product features influence supply chain configuration and management choices. As mentioned before, a well-established classification is the one proposed by Fisher (1997): "innovative and functional products"; innovative and fashion sensitive ones match with a market-responsive strategy, while functional products match with a physically efficient supply chain management strategy (Aitken et al., 2003; Stratton and Warburton, 2003). The terms lean and agile supply have emerged to reflect the distinction between function products and fashion ones. Various generic hybrids have been defined to clarify means of satisfying the conflicting requirements of low cost and fast response (Christopher and Towill, 2000; Mason-Jones et al., 2000). The driving force for delivering fashion products is to develop a strategy to improve the match between supply and demand, while the challenge faced by a supply chain for basic and functional product is cost reduction (Fisher, 1997).

The lean approach operates best when there is predictable demand with supply certainty, so that functional products can be created. In highly volatile supply chains, where customer requirements are often unpredictable and supplier capabilities are difficult to control, a more responsive or agile approach, based on innovative products, is appropriate operationally (Cox and Chicksand, 2005).

Lean manufacturing and agile manufacturing are distinct, yet overlapping paradigms (Narasimhan, 2006). In fact, Naylor et al. (1999), van Hoek (2000) and others have coined the word ''leagility'' to mention to the overlap in content of both paradigms. Naylor et al. (1999) argued that while both lean and agile systems emphasize supply integration, waste reduction, and lead time compression, they differ most importantly in their emphasis on flexibility for market responsiveness. They suggested that a lean system is best applied upstream from the decoupling point in a supply chain while an agile system should be applied downstream from this point. The leagile supply chain which has a carefully selected material flow decoupling point, usually are based on product configuration considerations (Naylor et al., 1999). Decoupling point is the point that indicates how deeply the customer order penetrates into the goods (Hoekstra and Romme, 1992). It is also defined as the stocking point which separates activities that respond directly to customer orders from activities that are driven by forecasts and demand planning. Upstream of the decoupling point, orders conform to the level scheduling mode and are therefore smoothed. Downstream of the decoupling point, i.e. nearer the marketplace, orders conform directly to end customer requirements and are volatile (Christopher and Towill, 2002; Towill et al., 2003).

In their paper, Mason-Jones et al. (2000) resulted that classifying supply chain design and operations according to the Lean, Agile and Leagile paradigms enables us to match the supply chain type according to marketplace need. They presented real-world case studies in the mechanical precision products (lean), carpet making (agile), and electronic products (leagile) market sectors to demonstrate the approach to matching supply chain design to the actual needs of the marketplace. Moreover, a framework was presented by Agarwal et al.(2007), which encapsulated the market sensitiveness, process integration, information driver and flexibility measures of supply chain performance on the three types of supply chains: lean, agile and leagile.

2-4. Fuzzy-Quality Function Deployment

As mentioned previously, our integrated approach grounds on the House of Quality (HOQ) of the QFD methodology widely used as an able tool in prosperous companies all around the world (Akao, 1990), originally implemented and developed in Japan at the Kobe Shipyards of Mitsubishi Heavy Industries in 1972 (Hauser and Clausing, 1988). It is a widely used customer-driven design and manufacturing tool (Gunasekaran et al., 2002; Wang et al., 2010), commonly used in new product development field to translate customer requirements (whats) into appropriate products engineering characteristics (hows). The success of QFD applications may be the result of some of its benefits, such as higher customer satisfaction, greater customer focus, shorter lead time, and knowledge preservation (Liu, 2009). The crucial and essential activity in the application of QFD is to construct the HOQ accurately, which includes determining the importance weights of customer requirements, the relationship matrix between customer requirements and engineering characteristics, and the correlation matrix among engineering characteristics. For HOQ modeling approach, see (Bottani and Rizzi, 2006; Chan and Wue, 2002; Chan and Wue, 2005; Fung et al., 2003; Temponi et al., 1999; Vairaktarakis, 1999). In the proposed approach, QFD and HOQ principles are translated from the new products development field to the leagility context. HOQ represents a practical tool, which allows directly assessing the impact of leagile enablers on leagile attributes, through the relationships matrices. It also allows identifying possible correlations between enablers.

On the other hand, leagility assessment is often deal with through fuzzy logic, due to the imprecise definition of leagility indicators. Owning to vagueness frequently represented in decision data, the crisp values are inadequate to model real life situations. Considering the typical vagueness or imprecision of functional relationships between LAs and LEs, it is difficult to identify them. Fuzzy logic allows taking into account the different meaning that we may give to the same linguistic expression. Thus, the major contribution of fuzzy set theory is its capability of representing vague data (Zadeh, 1965). As a matter of fact, this is why the fuzzy approach has been so widely adopted in different research fields, as witnessed by the massive literature on the subject (Bottani and Rizzi, 2006). A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between 0 and 1 (Kahraman and Ertay, 2006; Zadeh, 1965). By the adoption of fuzzy logic we will have the opportunity to express ill-defined judgments, such as the impact of a leagile enabler on a leagile attribute (Bottani and Rizzi, 2006).

Sohn and Choi (2001) applied fuzzy-QFD to the supply chain and developed a fuzzy MCDM method to select a design with an optimal combination of reliability and customer satisfaction (Sohn and Choi, 2001). Chan and Wue (2005) paid special attention to the various subjective assessments in the HOQ process, and symmetrical triangular fuzzy numbers (STFNs) were suggested for use to capture the vagueness in people's linguistic assessments. Bottani and Rizzi (2006) proposed a fuzzy-QFD approach and addressed the issue of how to deploy HOQ to efficiently and effectively improve logistic process. Moreover, in the context of agility, a detailed comparison between three different methodologies for agility assessment, both under crisp and fuzzy environments, was performed by Bottani (2008), which the reader is referred to for additional details.

2-4-1. Triangular Fuzzy Number (TFN)

If a,b and c, respectively, denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event, then the triangular fuzzy number (TFN) can be denoted as a triplet (a,b,c) where, $a \le b \le c$. When $a = b = c$, it is a non-fuzzy number by convention. The membership function can be defined as (Chamodrakas et al., 2009; Zimmermann, 1991):

$$\mu_N(x) : \begin{cases} (x-a)/(b-a), & x \in [a,b] \\ (c-x)/(c-b), & x \in [b,c] \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

If $M = (a_1, b_1, c_1)$ and $N = (a_2, b_2, c_2)$ represents two TFN, then required fuzzy calculations are performed as below:

Fuzzy addition: $M \oplus N = (a_1+a_2, b_1+b_2, c_1+c_2)$. (2)

Fuzzy multiplication: $M \otimes N = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2)$. (3)

$M \otimes 1 / N = (a_1/c_2, b_1/b_2, c_1/a_2)$ (4)

Fuzzy and a natural number multiplication: $r \otimes M = (r.a , r.b , r.c)$. (5)

2-5. Analytic hierarchy process (AHP)

Due to its wide applicability and ease of use, the Analytic Hierarchy Process (AHP), developed by Saaty (1980), has been studied extensively for the last 20 years. It has been widely used to address multi-criterion decision making problems. Fundamentally, AHP works by developing priorities for goals in order to value different alternatives (Ban˜uls and Salmeron, 2008). The AHP consists of three main operations, including hierarchy construction, priority analysis, and consistency verification (Ho, 2008). The hierarchy of the decision variables is the subject of a pairwise comparison of the AHP. The pairwise comparison is established using a nine-point scale which converts the human preferences between available alternatives as equally, moderately, strongly, very strongly or extremely preferred. This discrete scale of AHP has the advantage of simplicity and ease of use (Chan and Kumar, 2007). Ho (2008) reviewed the literature of the applications of integrated AHPs. The results showed that the focus has been confined to the applications of the integrated AHPs rather than the stand-alone AHP. He also concluded that QFD is one of the five tools that commonly combined with the AHP (Ho, 2008). In the paper proposed, AHP is deployed to prioritize LAs; the output of this prioritization, represented as W_i, is the input of Fuzzy-QFD part of the model.

3. An Integrated Approach to Enhance Supply Chain Legality

The framework to achieve supply chain legality (SCL) by AHP-fuzzy-QFD comprises four main parts. It has a stepwise description as presented below:

3-1. Identify LAs and LEs of the supply chain

To be truly leagile, a supply chain must possess a number of distinguishing attributes and enablers. By discussing agile and lean attributes and enablers available in literature, we strive to provide practitioners with the required fundamentals to apply the methodology developed to real cases. Leagile attributes (LAs), hereafter defined as the elements which constitute the underlying structure of a leagile organization, are originally conceived as core concepts of leagile manufacturing. Accordingly, leagile enablers (LEs) are enabling tools, technologies, and methods critical to successfully accomplish leagile supply chain management.

LAs enhancing supply chain leagility and LEs to be exploited in order to achieve the required LAs, accepted by several authors, were identified. Based on a review of the normative literature (Brown and Bessant, 2003; de Treville and Antonakis, 2006; Hopp and Spearman, 2004; McLachlin, 1997; Narasimhan et al., 2006; Prince and Kay, 2003; Shah and Ward, 2003; Sharifi and Zhang, 2001) many LAs and LEs were defined for leagile supply chain, as shown in Fig. 4, which is the complete AHP-Fuzzy-HOQ presented in our proposed paper. Furthermore, suggestions to identify viable sets of lean and agile attributes and enablers can be found in literature, and different or additional LAs/LEs could be listed in the HOQ. As can be seen in Fig. 1, the leagile attributes consist of lean, agile and the joint or shared attribues between lean and agile ones. Similarly, the leagile eneblers consist of lean, agile and the joint ones.

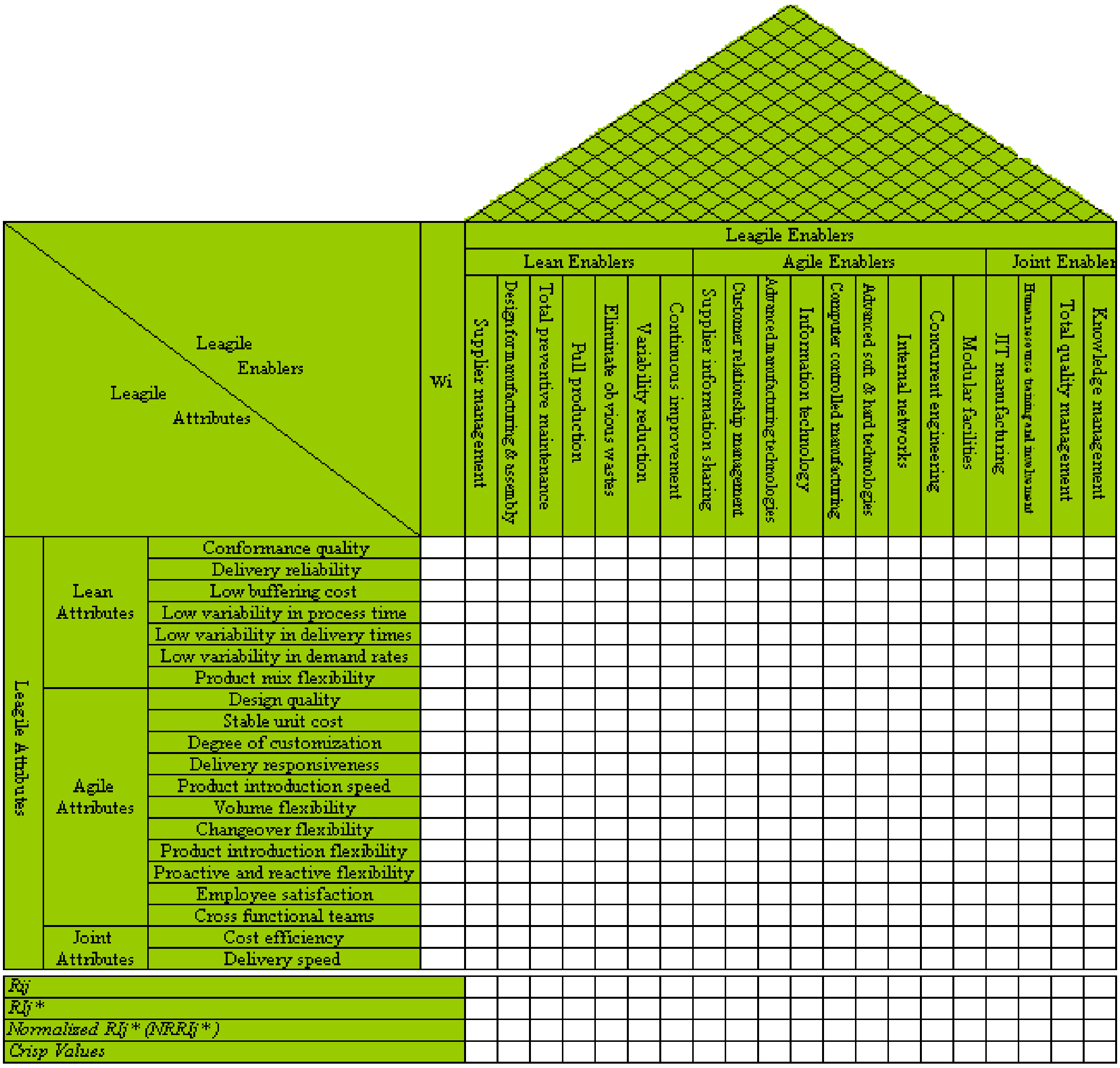


Fig. 1. LAs and LEs listed in AHP-Fuzzy-HOQ achieved from the literature survey

3-2. Prioritize LAs by AHP to obtain LAs' priority weights (W_i)

After defining LAs, their priority weights are computed by using Expert Choice 9.5; for this purpose, first the pair-wise assessment matrices are prepared to evaluate the alternatives (LAs) with respect to criteria. Then, the criteria are evaluated with respect to the goal. After evaluating the related literature, 7 criteria were identified including speed, flexibility, cost, responsiveness, competency, quality, and innovation (Giachetti et al., 2003; Sharifi and Zhang (1999); Yusuf et al., 1999; Yusuf and Adeleye, 2002) Furthermore, as mentioned before, the hierarchy consists of 9 alternatives that are LAs; Thus, the output of this hierarchy, which indicates LAs' priority weights, represented as W_i, is the inputs of Fuzzy-QFD part of the proposed model.

3-3. Determine the relationships between LAs and LEs (R_{ij}), and the correlation between LEs (T_{kj})

Due to the qualitative and ambiguous attributes linked to leagility implementation, most measures are described subjectively using linguistic terms cannot be handled effectively using conventional approaches. However, fuzzy logic provides an effective means of dealing with problems involving imprecise and vague phenomena (Lin et al., 2006). It is exploited to translate linguistics judgments required for relationships and correlations matrices into numerical values. In this step, the degree of relationship between LAs and LEs is stated by the corresponding fuzzy numbers and puts in the matrix of HOQ. Moreover, the degree of correlation between LEs would be then expressed by fuzzy numbers in the fuzzy HOQ. Both mentioned correspondences are shown in Tables 1 and 2.

Tab. 1. Degree of relationships, and corresponding fuzzy numbers (Bottani and Rizzi, 2006).

Degree of **relationship**	Fuzzy number
Strong (S)	(0.7; 1; 1)
Medium (M)	(0.3; 0.5; 0.7)
Weak (W)	(0; 0; 0.3)

Tab. 2. Degree of correlations, and corresponding fuzzy numbers (Bottani and Rizzi, 2006).

Degree of **correlation**	Fuzzy number
Strong positive (SP)	(0.7; 1; 1)
Positive (P)	(0.5; 0.7; 1)
Negative (N)	(0; 0.3; 0.5)
Strong negative (SN)	(0; 0; 0.3)

3-4. Calculate the relative importance (RI_j) and priority weights of LEs (RI_j^*) to identify the most appropriate LEs

The aim of computing these two parameters is to determine which LE has the most effect on supply chain leagility. RI_j is computed by fuzzy multiplication of W_i, LAs' priority weights, to R_{ij}, the fuzzy number expressing the relationship between the *i-th* LA and the *j-th* LE in relationship matrix of HOQ.

$$RI_j = \sum_{i=1}^{n} W_i \otimes R_{ij} \quad j = 1,\dots,m \qquad (6)$$

$$RI_j^* = RI_j \oplus \sum_{k=j} T_{kj} \otimes RI_k \quad j = 1,\dots,m \qquad (7)$$

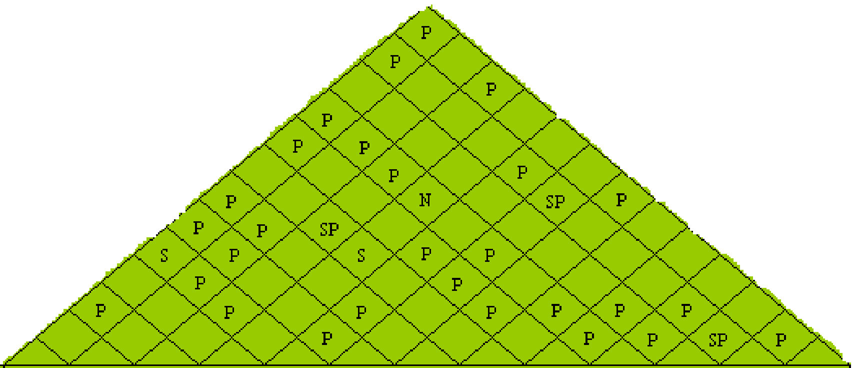
RI_k is the relative importance of the *k-th* LE and T_{kj} indicates the degree of correlation between the *k-th* and the *j-th* LE shown in the roof part of HOQ. Furthermore, normalization is performed by dividing each RI_j^* by the highest one according to the fuzzy sets algebra. Then, in order to rank LE*s*, the normalized scores of RI_j^* should be de-fuzzified. Suppose M (a,b,c) is a TFN, then the defuzzified value is computed as:

$$(a + 4b + c)/6 \qquad (8)$$

Leagile enablers with high crisp values indicate that they can be usefully exploited to enhance relevant leagile attributes; thus, such enablers should be selected for implementation.

4. Case study

The proposed approach was implemented in a case study to illustrate the usefulness and ease of application of the method, as well as considering practical implications of the methodology proposed. The case is presented in a company operating in chemical industry producing detergents. Focusing on the methodological point of view, in this study we do not deal with the definition of a specific set of LAs and LEs to be adopted in applying the approach; they should be identified according to the special characteristics of the company in exam. In this way, first a QFD team were organizaed headed by academics and including the firm's executives and the main business functions involved in the supply chain of the mentioned company. Then, 9 LAs, presented in Fig. 2, were chosen by the team from the 20 LAs listed in the HOQ of Fig. 1.



Leagile Attributes \ Leagile Enablers			Wi	Leagile Enablers												
				Lean Enablers				Agile Enablers					Joint Enablers			
				LE1	LE2	LE3	LE4	LE5	LE6	LE7	LE8	LE9	LE10	LE11	LE12	LE13
				Supplier management	Pull production	Eliminate obvious wastes	Variability reduction	Supplier information sharing	Customer relationship management	Information technology	Advanced soft & hard technologies	Internal networks	JIT manufacturing	Human resource training & involvement	Total quality management	Knowledge management
Leagile Attributes: Lean Attributes	LA1	Delivery reliability	0.065	M									M	W		
	LA2	Low buffering cost	0.049		M	M	W						W			
Agile Attributes	LA3	Stable unit cost	0.05					W		W	M					
	LA4	Degree of customization	0.18						M		S	W		M		M
	LA5	Delivery responsiveness	0.138						W		M	W		M		
	LA6	Volume flexibility	0.107								W		M			
	LA7	Employee satisfaction	0.195											S		S
Joint Attributes	LA8	Cost efficiency	0.127	W				M	M				M	W	W	W
	LA9	Delivery speed	0.088	M				W	M			M	S	W	W	
Rij				(0.046; 0.077; 0.145)	(0.014; 0.025; 0.034)	(0.014; 0.025; 0.034)	(0;0; 0.014)	(0.038; 0.063; 0.167)	(0.092; 0.153; 0.282)	(0;0; 0.015)	(0.128; 0.274; 0.344)	(0.026; 0.044; 0.156)	(0.151; 0.237; 0.312)	(0.231; 0.355; 0.500)	(0;0; 0.064)	(0.19; 0.285; 0.359)
*Rij**				(0.308; 0.660; 1.534)	(0.154; 0.342; 0.810)	(0.316; 0.763; 1.361)	(0; 0.071; 0.273)	(0.143; 0.311; 0.897)	(0.229; 0.469; 1.476)	(0.127; 0.342; 1.004)	(0.214; 0.465; 0.694)	(0.267; 0.644; 1.577)	(0.427; 0.896; 1.873)	(0.320; 0.552; 1.032)	(0.440; 0.971; 1.829)	(0.220; 0.352; 0.617)
Normalized Rij (NRRij*)*				(0.168; 0.680; 3.486)	(0.084; 0.352; 1.841)	(0.172; 0.785; 3.093)	(0; 0.073; 0.620)	(0.078; 0.320; 2.038)	(0.125; 0.483; 3.354)	(0.069; 0.352; 2.281)	(0.117; 0.478; 1.577)	(0.146; 0.661; 3.583)	(0.233; 0.922; 4.256)	(0.175; 0.568; 2.345)	(0.241; 1.000; 4.157)	(0.120; 0.363; 1.402)
Crisp Values				1.063	0.555	1.067	0.152	0.566	0.901	0.626	0.601	1.062	1.362	0.798	1.399	0.496

Fig. 2. AHP-Fuzzy-HOQ of the case study

AHP was deployed to rank LAs by using Expert Choice 9.5 in its distributed mode. So, the hierarchy of the goal, criteria and alternatives were structured as shown in Fig. 3. As seen in Fig. 3, in the mentioned hierarchy, the goal is to enhance the Supply Chain Leagility; moreover, 7 criteria mentioned before, with the 9 alternatives, i.e. LAs of the HOQ of Fig. 2 were considered. First the pair-wise assessment matrices were prepared by QFD team to evaluate the alternatives with respect to the criteria. Then, the team evaluated the criteria with respect to the goal. All can be seen in Tables 3-10.

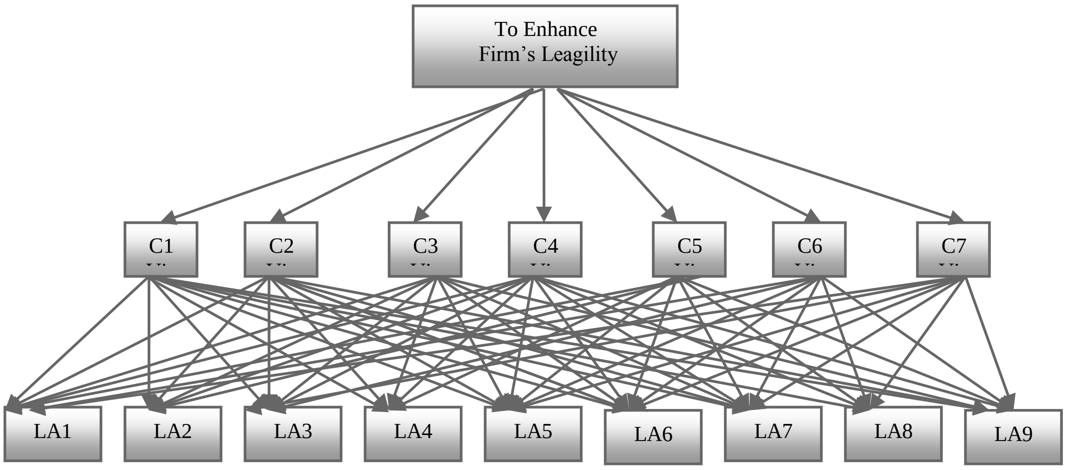


Fig. 3. Hierarchy for the firm's leagility; C1: Speed; C2: Flexibility; C3: Cost; C4: Responsiveness; C5: Competency; C6:Quality; C7:Innovation.

Then, the degree of relationship between LAs and LEs, i.e. R_{ij} was identified. Besides, the correlation between LEs, i.e. T_{kj} was determined. As mentioned before, the assessment of the relationships and correlations in HOQ, mainly rely on human judgments. Thus, in our approach, we proposed to exploit fuzzy logic as an effective mean to deal with them; in this way, both R_{ij} and T_{kj} were expressed by fuzzy numbers and inserted in Fig. 3. By using equations (6) and (7), RI_j and RI_j^* were computed, and RI_j^* was normalized by dividing each RI_j^* by the highest one, i.e. RI_{TQM}^* (Total quality management). Then the normalized scores were de-fuzzified by equation (8). All computation results are inserted in Fig. 3.

Tab. 3. The Pair Wise Assessment for Criteria With Respect to the Goal

Goal	C_1	C_2	C_3	C_4	C_5	C_6	C_7	W_G
C_1	1	1/2	3	1/2	1/3	1/2	3	0.144
C_2	2	1	3	1	1	2	2	0.165
C_3	1/3	1/3	1	1/2	1/2	1/2	1/3	0.060
C_4	2	1	2	1	1/2	2	3	0.182
C_5	3	1	2	2	1	1/2	3	0.205
C_6	2	1/2	2	1/2	2	1	2	0.168
C_7	1/3	1/2	3	1/3	1/3	1/2	1	0.077

Inconsistency ratio = 0.08

Tab. 4. The Pair Wise Assessment for the Alternatives With Respect to C_1

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_1
A_1	1	3	4	3	2	1/2	1/3	1/3	1/4	0.094
A_2	1/3	1	2	2	1/3	1/2	1/3	1/3	1/5	0.048
A_3	1/4	1/2	1	1/2	1/3	1/2	1/4	1/2	1/5	0.034
A_4	1/3	1/2	2	1	1/3	2	1/4	1/2	1/4	0.051
A_5	1/2	3	3	3	1	2	1/3	2	1/4	0.102
A_6	2	2	2	1/2	1/2	1	1/5	1/2	1/6	0.063
A_7	3	3	4	4	3	5	1	4	1	0.230
A_8	3	3	2	2	1/2	2	1/4	1	1/5	0.099
A_9	4	5	5	4	4	6	1	5	1	0.279

Inconsistency ratio = 0.08

Tab. 5. The pair wise assessment for the alternatives with respect to C_{2+}

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_2
A_1	1	1	2	1/6	3	1/4	1/4	1/3	1/2	0.053
A_2	1	1	1	1/6	1/3	1/4	1/5	1/4	1/2	0.033
A_3	1/2	1	1	1/4	1/2	1/5	1/5	1/3	1/3	0.032
A_4	6	6	4	1	3	2	3	4	4	0.270
A_5	1/3	3	2	1/3	1	1/5	1/2	1/2	1	0.057
A_6	4	4	5	1/2	5	1	3	4	5	0.236
A_7	4	5	5	1/3	2	1/3	1	4	3	0.158
A_8	3	4	3	1/4	2	1/4	1/4	1	4	0.102
A_9	2	2	3	1/4	1	1/5	1/3	1/4	1	0.058

Inconsistency ratio = 0.07

Tab. 6. The pair wise assessment for the alternatives with respect to C

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_3
A_1	1	1/7	1/6	2	1/2	1/2	1/5	1/6	1	0.033
A_2	7	1	3	4	6	6	3	1/4	6	0.210
A_3	6	1/3	1	5	6	6	3	1/4	5	0.162
A_4	1/2	1/4	1/5	1	2	3	1/5	1/5	3	0.050
A_5	2	1/6	1/6	1/2	1	2	1/3	1/6	1	0.037
A_6	2	1/6	1/6	1/3	1/2	1	1/5	1/7	1/4	0.026
A_7	5	1/3	1/3	5	3	5	1	1/5	3	0.105
A_8	6	4	4	5	6	7	5	1	6	0.338
A_9	1	1/6	1/5	1/3	1	4	1/3	1/6	1	0.038

Inconsistency ratio = 0.1

Tab. 7. The pair wise assessment for the alternatives with respect to C_4

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_4
A_1	1	3	2	1/3	1/6	1/4	1/5	1/3	1/3	0.038
A_2	1/3	1	2	1/5	1/7	1/5	1/5	1/3	1/3	0.026
A_3	1/2	1/2	1	1/6	1/6	1/4	1/5	1/3	1/4	0.024
A_4	3	5	6	1	1/2	3	4	4	4	0.216
A_5	6	7	6	2	1	4	5	5	6	0.313
A_6	4	5	4	1/3	1/4	1	1/3	3	4	0.109
A_7	5	5	5	1/4	1/5	3	1	4	5	0.155
A_8	3	3	3	1/4	1/5	1/3	1/4	1	3	0.067
A_9	3	3	4	1/4	1/6	1/4	1/5	1/3	1	0.052

Inconsistency ratio = 0.1

Tab. 8. The pair wise assessment for the alternatives with respect to C_5

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_5
A_1	1	3	2	1/2	1/3	1/2	1/2	1/4	2	0.080
A_2	1/3	1	1/3	1/3	1/2	1/2	1/3	1/3	1/3	0.040
A_3	1/2	3	1	1/3	1/4	1/3	1/2	1/2	1/3	0.055
A_4	2	3	3	1	1/2	2	1/2	1	2	0.128
A_5	3	2	4	2	1	2	1/2	1/2	2	0.150
A_6	2	2	3	1/2	1/2	1	1/2	1/2	1/2	0.087
A_7	2	3	2	2	2	2	1	3	2	0.203
A_8	4	3	2	1	2	2	1/3	1	3	0.167
A_9	1/2	3	3	1/2	1/2	2	1/2	1/3	1	0.089

Inconsistency ratio = 0.08

Tab. 9. The pair wise assessment for the alternatives with respect to C_6

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_6
A_1	1	3	2	1/4	1/2	2	1/5	1/3	1	0.073
A_2	1/3	1	2	1/4	1/2	1/2	1/3	1/3	1/2	0.049
A_3	1/2	1/2	1	1/4	1/3	1	1/3	1/2	2	0.054
A_4	4	4	4	1	4	2	1/2	3	4	0.222
A_5	2	2	3	1/4	1	2	1/3	1/2	2	0.097
A_6	1/2	2	1	1/2	1/2	1	1/3	1/2	1	0.063
A_7	5	3	3	2	3	3	1	4	4	0.265
A_8	3	3	2	1/3	2	2	1/4	1	2	0.120
A_9	1	2	1/2	1/4	1/2	1	1/4	1/2	1	0.056

Inconsistency ratio = 0.06

Tab. 10. The pair wise assessment for the alternatives with respect to C_7

C_1	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	Wc_7
A_1	1	2	1/2	1/3	1/2	3	1/3	1/2	2	0.081
A_2	1/2	1	1/2	1/3	1/2	1/2	1/4	1/2	1/2	0.045
A_3	2	2	1	1/3	1/2	2	1/3	1/2	1/2	0.077
A_4	3	3	3	1	3	2	1	2	4	0.211
A_5	2	2	2	1/3	1	2	1/3	2	2	0.120
A_6	1/3	2	1/2	1/2	1/2	1	1/3	1/2	1/2	0.056
A_7	3	4	3	1	3	3	1	3	3	0.225
A_8	2	2	2	1/2	1/2	2	1/3	1	3	0.113
A_9	1/2	2	2	1/4	1/2	2	1/3	1/3	1	0.072

Inconsistency ratio = 0.05

5. Discussions

In our proposed case study, AHP implication in computing LAs' priority weights showed that LA7 (Employee satisfaction) got the first rank of LAs, followed by LA5 (Delivery responsiveness) and LA8 (Cost efficiency). Thus, in the mentioned case, having satisfied employees would result in getting a more leagile supply chain mainly because of the high involvement rate of employees in achieving a leaner and agiler supply chain.

Moreover, Leagile enablers with high crisp values indicate that they can be usefully exploited to enhance relevant leagile attributes; thus, such enablers should be selected for implementation. Results in Fig. 3 indicate that LE12 (TQM) got the highest crisp value, followed by LE10 (JIT manufacturing). Although TQM's relationships with LAs are not so significant, its highest crisp value is mainly due to the wide number of correlations that can be identified between TQM and other important LEs, i.e. Strong Positive (SP) correlations with LE6 (CRM) and LE11 (HRM), and Positive (P) correlations with LE1 (Supplier management), LE5 (Supplier information sharing), and LE10 (JIT) that all have significant relationships with LAs. Furthermore, LE3 (Eliminate obvious waste), and LE1 (Supplier management) placed in the third and forth rank of implementation.

6. Conclusion and Suggestions

Lean manufacturing and agile manufacturing are distinct, yet overlapping paradigms (Narasimhan, 2006). Quite apart from the general driving out of waste using lean thinking principles (Womack and Jones, 1996), there has been tremendous pressure to increase the speed of response of the delivery process. It is clear that supply chains cannot be managed using only lean techniques because they have very unique demand and supply characteristics that require very different operational ways of working both internally and externally. Moreover, in supply chain it is essential to remove the system-induced uncertainty, as typified by the "Bullwhip" effect that is the resultant behavior due to a system-imposed uncertainty resulting from a supplier discount scheme operating in a retail supply chain (Mason Jones et al., 2000). However, whether to develop an agile capability or a lean manufacturing structure will be dependent upon where in the supply chain the members are located. Therefore, a total supply chain perspective is essential and companies should be striving for leagility that is carefully combining both lean and agile paradigms (Naylor,1999).

In this paper, an integrated AHP-QFD approach was proposed to enhance the leagility of supply chain. The approach shows the applicability of the QFD methodology, and especially of the HOQ, to identify viable leagile enablers to be practically implemented to achieve a defined set of leagile attributes. We benefited from AHP to prioritize leagile attributes; Besides, to well cope with vagueness of linguistics judgments required in building the HOQs, relationships, as well as correlations, relative importance (RI_j) and priority weights (RI_j^*) of LEs were all defined with fuzzy triangular numbers. Also, a case study was presented to illustrate the ease of application of the approach. Leagile supply chains already exist in the real world; what is important is to recognize when it is the best way for a particular supply chain so that it may be appropriately engineered from the outset (Mason Jones et al., 2000).

As mentioned before, the significant matter in developing a lean and/or agile capability is to consider where in the supply chain the members are located; thus, the focus of attention of future researches can be on this subject. Future researches can also consider utilizing other ranking methods instead of AHP, such as TOPSIS, to prioritize the leagile attributes and compute their priority weights (W_i); moreover, W_i s obtained from different ranking methods, can be compared. In the proposed paper a case study of a company in the supply chain of chemical industry was presented; it is suggested to provide more case studies in the supply chains of other fields.

References

[1] Abdulmalek, F.A., Rajgopal, J., 2007. Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. International Journal of Production Economics 107, 223–236.

[2] Agarwal, A., Shankar, R., Tiwari, M.K., 2006. Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach . European Journal of Operational Research 173 (1), 211-225.

[3] Agarwal, A., Shankar, R., Tiwari, M.K., 2007. Modeling agility of supply chain. Industrial Marketing Management 36 (4), 443-457.

[4] Aitken, J., Childerhouse, P., Towill, D.R., 2003. The impact of product life cycle on supply chain strategy. International Journal of Production Economics 85, 127–140.

[5] Akao, 1990.Quality Function Deployment: Integrating Customer Requirements into Product Design, Cambridge, MA. Productivity Press.

[6] Ban˜ uls, V.A., Salmeron, J.L., 2008. Foresighting key areas in the Information Technology industry. Technovation 28, 103–111.

[7] Bhatnagar, R., Sohal, A.S., 2005. Supply chain competitiveness: measuring the impact of location factors, uncertainty and manufacturing practices. Technovation 25, 443–456.

[8] Bottani, E., 2008. On the assessment of enterprise agility: issues from two case studies. International Journal of Logistics: Research and Applications doi: 10.1080/13675560802395160.

[9] Bottani, E., 2009. A fuzzy QFD approach to achieve agility. International Journal of Production Economics 119 (2), 380-391.

[10] Bottani, E, Rizzi, A., 2006. A fuzzy-QFD approach in strategic management of logistics service. International Journal of Production Economics 103 (2), 585-599.

[11] Brown, S., Bessant, J., 2003. The manufacturing strategy-capabilities links in mass customization and agile manufacturing-an exploratory study. International Journal of Operations and Production Management 23 (7), 707–730.

[12] Chamodrakas, I., Alexopoulou, N., Martakos, D., 2009. Customer evaluation for order acceptance using a novel class of fuzzy methods based on TOPSIS. Expert Systems with Applications 36, 7409–7415.

[13] Chan, F.T.S., Kumar, N., 2007. Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega, International Journal of Management Science 35, 417-431.

[14] Chan, L. K., Wue, M.L., 2002. Quality function deployment: A literature review. European Journal of Operational Research 143 (3), 463-497.

[15] Chan, L. K., Wue, M.L., 2005. A systematic approach to quality function deployment with a full illustrative example. Omega, International Journal of Management Science 33, 119-139.

[16] Christopher, M., 1999. The Agile Supply Chain: Competing in Volatile Markets. Industrial Marketing Management 29, 37–44.

[17] Christopher, M., Towill, D., 2000. Supply chain migration from lean and functional to agile and customized. Supply Chain Management: an International Journal 5(4), 206-213.

[18] Cox, A., Chicksand, D., 2005. The limits of lean management thinking. European Management Journal 23(6), 648–662.

[19] Crute, V., Ward, Y., Brown, S., Graves, A., 2003. Implementing Lean in aerospace- challenging the assumptions and understanding the challenges. Technovation 23 (2003) 917–928.

[20] de Treville, S.,, Antonakis, J., 2006. Could lean production job design be

intrinsically motivating? Contextual, configurational, and levels-of-analysis issues. Journal of Operations Management 24(2), 99-123.

[21] Fisher, M. L., 1997. The right supply chain for your product. Harvard Business Review March-April, 105-116.

[22] Fung , R.Y.K, Tang , J., Tu, P.Y., Chen, Y., 2003. Modeling of Quality Function Deployment planning with resource allocation. Research Engineering Design 14, 247-255.

[23] Giachetti, R.E., Martinez, L.D.., Saenz, O.A.., Chen, C.S., 2003. Analysis of the structural measures of flexibility and agility using a measurement theoretical framework. International Journal of Production Economics 86(1) 47-62.

[24] Goldman, S.L., Nagel, R.N., Preiss, K., 1995. Agile competitors and virtual organizations: strategies for Enriching the Customer, Van Nostrand Reinhold. New York.

[25] Gunasekaran, A., 1999. Agile manufacturing: a framework for research and development. International Journal of Production Economics 62(1-2), 87-105.

[26] Gunasekaran , A., Tirtiroglu, E., Wolstencroft, V., 2002. An investigation into the application of agile manufacturing in an aerospace company. Technovation 22, 405–415.

[27] Hauser, J.R., Clausing, D., 1998. The House of Quality. Harvard Business Review May-June, 63-73.

[28] Ho, W., 2008. Integrated analytic hierarchy process and its applications- A literature review. European Journal of Operational Research 186, 211-228.

[29] Hoekstra, S., Romme, J., 1992. Integral Logistic Structures: Developing Customer-oriented Goods Flow (Eds.), McGraw-Hill, London.

[30] Holweg , M., 2007. The genealogy of lean production. Journal of Operations Management 25, 420–437.

[31] Hopp, W.J., Spearman, M.L., 2004. To pull or not to pull: what is the question?. Manufacturing & Service Operations Management 6(2), 133-138.

[32] A balanced approach to building agile supply chain. In: Andersin H.E, Niemi R, Hirvonen V (Eds.), Proceedings of the International Conference on Agility—ICAM 2005. Helsinki: Finland, Helsinki University of Technology; 2005. p. 187–193.

[33] Kahraman, C., Ertay, T., Büyüközkan, G., 2006. A fuzzy optimization model or for QFD planning process using analytic network process. European Journal of Operational Research 171, 390-411.

[34] Kannan, V.R., Tan, K.C., 2005. Just in time, total quality management and supply chain management: understanding their linkages and impact on business performance. Omega, International Journal of Management Science 33, 153 -162.

[35] Kettunen, P., 2009. Adopting keylessonsfromagilemanufacturingtoagi lesoftware product development-Acomparativestudy. Technovation29, 408–422.

[36] Kidd, P.T., 1994. Agile manufacturing-forging new frontiers. Addison-Wesley. Wokingham.

[37] Krafcik, J.F., 1988. Triumph of the Lean Production System. Sloan Management Review, Fall.

[38] Lancioni, R.A., 2000. New Developments in Supply Chain Management for the Millennium Industrial Marketing Management 29(1), 1-6.

[39] Lin, C.T., Chiu, H., Tseng, Y.H., 2006. Agility evaluation using fuzzy logic. International Journal of Production Economics 101(2), 353-368.

[40] Liu, H. T., 2009. The extension of fuzzy QFD: From product planning to part deployment. Expert Systems with Applications 36, 11131–11144.

[41] Mason-Jones, R., Naylor, B., Towill, D., 2000. Lean, agile or leagile? Matching your supply chain to the marketplace. International Journal of Production Research 38(17), 4061-4070.

[42] McLachlin, R., 1997. Management initiatives and just-in-time manufacturing. Journal of Operations Management 15; 271–292.

[43] Monden, Y., 1998. Toyota Production System-An integrated approach to just-in-time, third ed. Engineering and Management Press. Norcross, Georgia.

[44] Nahmias, S., 2001. Production and Operations Analysis, fourth ed. McGraw Hill, New York.

[45] Narasimhan, R., Swink, M., Kim, S.W., 2006. Disentangling leanness and agility: an empirical investigation. Journal of Operations Management 24, 440-457.

[46] Naylor, J.B., Naim, M.M., Berry, D., 1999. Leagility: integrating the lean and agile manufacturing paradigm in the total supply chain. International Journal of Production Economics 62, 107–118.

[47] Pe´rez , M.P., Sa´nchez, A.M., 2000. Lean production and supplier relations: a survey of practices in the Aragonese automotive industry. Technovation 20, 665–676.

[48] Prince, J., Kay, J.M., 2003. Combining lean and agile characteristics: creation of virtual groups by enhanced production flow analysis. International Journal of Production Economics 85, 305–318.

[49] Ren, J., Yusuf, Y.Y., Burns, D., 2001. Organizational competitiveness: Identifying the critical agile attributes using principal component analysis. Proceedings of the 16th International Conference on Production Research, 29 July 3–August 2001, Prague, Czech Republic.

[50] Saaty, T.L., 1980. The Analytic Hierarchy Process. New York: McGraw-Hill.

[51] Scherrer-Rathje, M., Boyle, T.A., Deflorin, P., 2009. Lean, take two! Reflections from the second attempt at lean implementation. Business Horizons 52, 79-88.

[52] Schonbergerm, R.J., 2007. Japanese production management: An evolution with mixed success. Journal of Operations Management 25, 403–419.

[53] Shah, R., Ward, P.T., 2003. Lean manufacturing: context, practice bundles, and performance. Journal of Operations Management 21, 129–149.

[54] Sharifi, H., Zhang, Z., 1999. A methodology for achieving agility in manufacturing organizations: an introduction. International Journal of Production Economics 62(1-2), 7-22.

[55] Sharifi, H., Zhang, Z., 2001. Agile manufacturing in practice: application of a methodology. International Journal of Operations and Production Management 21(5-6), 772–794.

[56] Sherehiy, B., Karwowski, W, Layer, J.K., 2007. A review of enterprise agility: Concepts, frameworks, and attributes. International Journal of Industrial Ergonomics 37, 445–460.

[57] Sohn, S.Y., Choi, I.S., 2001. Fuzzy QFD for supply chain management with reliability consideration. Reliability engineering and system safety 72, 327-334.

[58] Stratton, R, Warburton, R.D.H., 2003.The strategic integration of agile and lean supply. International Journal of Production Economics 85; 183–198.

[59] Temponi, C., Yen, J., Tiao, W.A., 1999. House of quality: A fuzzy logic-based requirements analysis. European Journal of Operational Research 117 (2), 340-354.

[60] Towill ,D.R., Lambrecht, M.R., Disney, S.M., Dejonckheere, J., 2003. Explicit filters and supply chain design. Journal of Purchasing and Supply Management 9, 73–81.

[61] Towill, D.R., McCullen, P., 1999. The impact of an agile manufacturing program on supply chain dynamics. International Journal of Logistics Management 10(1), 83–96.

[62] Vairaktarakis, G.L., 1999. Optimization tools for design and marketing of new/improved products using HOQ. Journal of Operations Management 17, 645-663.

[63] van Hoek, R.I., 2000. The thesis of leagility revisited. International Journal of Agile Management Systems 2(3), 196-201.

[64] Va´zquez-Bustelo, D., Avella, L., 2006. Agile manufacturing: Industrial case studies in Spain. Technovation 26, 147–1161.

[65] Wang, J., Lin, W., Huang, Y.H., 2010. A performance-oriented risk management framework for innovative R&D projects. Technovation, Article In Press

[66] Womack, J.P., Jones, D.T., Ross, D., 1990. The machine that changed the world. Macmillan Publishing Company, Canada.

[67] Yusuf ,Y.Y., Adeleye, E.O., 2002. A comparative study of lean and agile manufacturing with related survey of current practices in the UK. International Journal of Production Research 40(17), 4545–4562.

[68] Yusuf, Y.Y., Gunasekaran, A., Adeleye, E.O., Sivayoganathan, K., 2004. Agile supply chain capabilities: Determinants of competitive objectives. European Journal of Operational Research 159(2), 379-392.

[69] Yusuf, Y.Y., Sarhadi, M., Gunasekaran, A. , 1999.Agile manufacturing: The drivers, concepts and attributes. International Journal of Production Economics 62, 33–43.

[70] Zadeh, L.A., 1965. Fuzzy Sets. Information and Control 8, 338-353.

[71] Zimmermann, H.J., 1991. Fuzzy set theory and its Applications, (Second ed.). Boston.: Kluwer Academic Publishers.