Measuring Organizational Leanness Using Fuzzy Approach

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Abstract

To develop a methodology for measuring leanness degree in manufacturing companies using fuzzy logic.
Design/methodology/approach- evaluation methods based on human perceptions; make this kind of measuring unreliable. Considering the deficiency, this research develop an approach based on linguistic variables and fuzzy numbers for measuring organizational leanness, and finally use the method for measuring a manufacturing organization`s leanness. The method developed is usable simply by practitioners and make more precise approximate for leanness and then better improvement path for them. Using this method help practitioners to evaluate leanness more precise than other methods presented by now and develop applied solutions to move toward organizational leanness effectively. This is a new method based on fuzzy logic for measuring organizational leanness using human perceptions.

Keywords
Lean production, Lean indexes, Measuring, Fuzzy logic.

1. Introduction
One of the widest spread assertions about production is ending period of mass production era and substitution of novel forms like flexible allocation instead. Waste management or lean production is a new phase of production, take mass and craft production benefits altogether. This method is based on multi-skill workers as well as automatic and flexible machines. In this method we try to reduce production space, investment on tools, engineering work time, and stagnant inventory to half and make our attention to zero defects and zero inventory. In the lean production method, producers desire in reducing resource consumption. In this method, work force, capital invested in machinery purchasing and installation, space required for production, in progress products, materials, and products' inventories and engineering and design personnel are reduced to half. Therefore, designing and building preiod as well as distribution and selling of a product would be halved, and this is just the main goal of lean production (Womack et al. 1990). After lean production introduction in 1970s, many books and articles have been published regarding various aspects of leanness which show the effect of this paradigm on the world of production and operations. orienting management research toward lean concepts, lot of attempts devoted to development of a tool to measure organizational leanness, since in order to have any kind of analysis, planning and then control (that from main elements of management), having a well-founded and structured style for evaluation of concepts is inevitable (Sink and Tuttle, 1989). In this regard, various styles are proposed by researchers for measuring organizational leanness, like methods according to logical concept of hierarchal process which are developed for organizations' comparison from view point of leanness (Agarwal et al., 2006). In this process, Pairwise comparisons are used to assess organizations' leanness capability. However, most researches use integrated index for measuring organizational leanness, that is sum of simple or weighted items' scores (Kojima and Kaplinsky, 2004; Rivera and Chen, 2007; Shah and Ward, 2007).

Cited methods are simple and comprehensible, but since occasionally some of the lean indexes are ambiguous and have unclear definition, and in some cases there is no enough evidence for assessment, or even experts do not have enough ability to assess the indexes meaningfully, ambiguity and vagueness is hidden in the essence of lean assessment methods. Therefore, using indexes to score lean capabilities has two limitations:

1. These techniques do not take in to account ambiguity and multiple probabilities related to the one person`s perception and judgment about a number.
2. Estimator`s choice, preferences and Subjective judgments have prominent effect on these methods.

Therefore, using fuzzy logic and linguistic variables, may render a more exact assessment about the degree of organizations' leanness (Karwowski and Mital, 1986). Many of lean scales, when encounter with ambiguities and multiple probabilities, are explained subjectively by linguistic variables. By using fuzzy concepts, estimators can use linguistic variables as common lexical words and in order to assess the indexes and then link each linguistic variables to a fuzzy membership function. Since fuzzy logic do not impose any assumptions about independence, integrity, or monopoly of evidences, it makes it possible to use ambiguous boundaries in the definitions (Machacha and

Bhattacharya, 2000) and moreover it make possible to use qualitative data in measuring and assessment studies appropriately using this approach, in this paper a model based on fuzzy logic has been developed, to prepare a proper tool for measuring an organization's leanness. In this approach, performance and preference weights of various lean capabilities have been evaluated and expressed as linguistic variables by the experts. Then, appropriate fuzzy numbers for expression of linguistic variables are defined and by performing fuzzy calculation operations, "fuzzy leanness index" (FLI) is attained. Finally, FLI is matched to a proper linguistic variable and therefore lean level is expressed as linguistic variables. The paper is organized as follows: In part 2 fuzzy logic and lean production literature are reviewed in details. Part 3 is dedicated to the research algorithm and methodology. In part 4, developed method in the previous stages is employed to assess an organization's leanness as a case study, and finally the last part covers the discussion and conclusion.

2. Literature Review

2.1. Lean production

Two revolutions occurred in the production arena in 20th century. The first revolution was set by Henry Ford and Alfred Sloan after World War I which led to termination of craft production era the advent of mass production. The second revolution was set by Taiichi Ohno at Toyota Company which caused creation of lean production method. In 1945, Eiji Toyoda, founder of Toyota Company, in accompany with Kiichiro Toyoda and TaiiChi Ohno started to study Ford production system. They inspire from Ford mass production system in order to modify it to Toyota and Japan's needs that led to design and accomplishment of Toyota's production system named as "Just in time Production" (Wada, 2004). In 1988, the word "lean" was firstly used by Krafcik to describe Toyota production system (Krafcik, 1988). However, the wide-spread use of this word postponed until 1990 when a book entitled as "The machine that changed the world" was published (Womack et al., 1990). The book was compiled by Womack, Jones and Roos from MIT University through research. They introduced lean production as a combination of Ford traditional production model and social control model at Japanese production environment.

From the year 2000 up to now, a lot of experimental papers (Shah and Ward, 2003) and books with different orientations are being written about lean production. Although, these researches enriched the literature of production system, did not provide a unique and adaptive definition for lean production (Hopp and Spearman, 2004; De Treville and Antonakis, 2006). In continuation, appropriate scales are defined through investigation of leanness conceptual and operational definitions and used methods for measuring the lean scale at the literature. Shah and Ward (2007) pointed out that three main problems exist in defining lean measures: The first problem is that some concepts are changing through passing of time. For example preventive maintenance regarded as one of the important dimensions of Just in time production (Sakakibara et al., 1993) but now is considered as an independent construct (McKone and Weiss, 1999). The second problem is that similar items are used to operationalize highly different concepts and finally, the third problem is opposite to the second one, in such a manner that different items are used to operationalize a single concept.
Measures for evaluating concepts are derived from definitions of those concepts in literature. Therefore, we first try to investigate the discussed definition for leanness and present an appropriate definition for it. According to different researchers, definition of lean production is trapped in a halo of ambiguity. Existing two approaches about lean production caused this ambiguity to be exacerbated. The first approach is a philosophical one in relation to the guidelines and lean goals (Womack and Jones, 1996; Spear and Bowen, 1999); the second approach, however, is a executive and experimental one comprised of a collection of managerial practices, tools or techniques which might be seen directly (Shah and Ward, 2003; Li et al., 2005). Such a difference may not necessarily cause inconformity; however, it affects conceptual transparency of this domain.

Through a comprehensive study of presented researches and by mixing the mentioned elements in these definitions, Shah and Ward (2007) give the following comprehensive definition for leanness: "Lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability". Wacker (2004) suggests that a conceptual definition should show evidence of clarity, communicability, consistency, parsimony, differentiability, inclusivity, and exclusivity. This definition meets these criteria and can be used as a lean definition in the present research. Different researchers, consider various dimensions and parts for presented concepts in lean production's definition. Simons and Zokaie (2005) consider lean production philosophy based on waste elimination and searching for perfection and Kaizen; moreover they define lean production strategy as lean stock, smooth production flow, workers training, encourage workers to participate and giving suggestion, quality circles, long range relations with suppliers, preventive maintenance policy, and commitment to continuous improvement. Kojima and Kaplinsky (2004) believe that lean production is measurable in three parts: flexibility, continuous improvement, and quality. Sancheze and Perez (2000) measured leanness on the base of following criteria: inventory turnover, lead time, and percentage of productive procedures documented in the organization. However, three general parts, Just in Time production, total quality management, and total productivity management are referred by many researchers (Cua et al., 2001; Katayama and Bennett, 1996; Sakakibara et al., 1997). Many of researchers consider another important category as “human resources management” (Flynn and Sakakibara, 1995; Forza, 1996; Lowe, 1997; MacDuffie, 1995; Smith et al., 2003; Shah and Ward, 2003).

By deep examination of the literature, Shah and Ward (2007) presented researches related to operational tools used to measure lean production elements as table (1). The table shows that there are a lot of overlapping and confusion in this regard. In this table, operational scales are in fact questions of survey questionnaires regarded as lean practices and tools and are presented as manifest variables/items in the researches. These variables are settled in latent variables using factor analysis and data reduction. These latent variables may be first hand (whenever the items are the base of their exploitation) or second hand or more (whenever the latent variables themselves are under data reduction and factor analysis). These scales show visible items of lean production. Totally, there are only three studies that specifically measured lean production (Shah and Ward, 2003; Li et al., 2005; Shah and Ward, 2007). Shah and Ward (2003) developed some criteria for lean production and made them operational as a set of practices related to total quality management, total preventive maintenance, and human resources management. At the other hand, Li and his Colleagues (2005) measured lean production with only 5 items including set up time, small lot size, and pull production.

Table 1: Lean production—charting the measurement instruments (Shah and Ward, 2003)

Scale/individual measure [a,b,c]	1	2	3 [d]	4 [e]	5 [d]	6	7 [f]	8	9	10	11	12
Just in time (JIT) principles						TQM[b]						
Quality management (QM)			Infrastructure[c]		JIT					TQM[a]		
Workforce management		Infrastructure[c]	Infrastructure[c]									
Setup time reduction	JIT system[b]	JIT[c]	JIT[c]	TBC[b]	JIT			JIT[b,c]	JIT[b]	JIT[a]	Lean[a]	X
Small lot size (reduction)	Flow[b]	JIT[c]								JIT[a]		X
Pull system (support)	Flow[b]											
Kanban/pull production	Flow[b]	JIT[c]	JIT[c]	TBC[b]	JIT			JIT[b,c]	JIT[b]	JIT[a]	Lean[a]	X
Equipment layout	Flow[b]		JIT[c]					JIT[b,c]	JIT[b]			X
(Continuous) flow										JIT[a]		X
Daily schedule adherence	JIT system[b]	JIT[c]	JIT[c]			TPM[b]		JIT[b,c]	JIT[b]			
Cellular manufacturing				TBC[b]	JIT					JIT[a]		X
Continuous improvement				TBC[b]						TQM[a]	Lean[a]	X
Statistical process control		TQM[c]	Quality anagement[c]						TQM[b]	TQM[a]		X
Group problem solving	JIT system[b]		Workforce management[c]									X
Training	JIT system[b]					TQM[b]	TPM[b]	Common[b,c]	HRM[b]	HRM[b]		X
Cross functional teams						TQM[b]	TPM[b]		HRM[b]	HRM[b]		X
Employee involvement				TBC[b,1]				Common[b,c]				X
Workforce commitment												
Preventive maintenance	JIT system[b]		JIT[c]	TBC[b]	JIT					TPM[a]		X
Product design (simplicity)	Flow[b]	TQM[c]	Infrastructure[c]					TQM[b,c]	JIT[b]			
JIT delivery by suppliers	Supplier management[b]		JIT[c]					JIT[b,c]				X
Supplier (quality) level	Supplier management[b]	Infrastructure[c]	Quality management[c]					TQM[b,c]				
Supplier relationship/involvement		Infrastructure[c]		TBC[b]		TQM[b]			TQM[b]		Lean[a]	X
Customer focus/involvement		TQM[c]				TQM[b]		TQM[b,c]	TQM[b]			X
JIT links with customers									JIT[b]			X

(1) Sakakibara et al. (1993); (2) Flynn et al. (1995); (3) Sakakibara et al. (1997); (4) Koufteros et al. (1998); (5) Koufteros and Vonderembse (1998); (6) Dow et al. (1999); (7) McKone andWeiss (1999); (8) Cua et al. (2001); (9) Ahmad et al. (2003); (10) Shah and Ward (2003); (11) Li et al. (2005); (12) Shah and Ward, 2007).

[a] Used as an item to measure a first order construct.

[b] Used as first order construct to measure a second order construct.

[c] Reduced the first order construct to a single score.

[d] Measurement items are not included in the study.

[e] TBC: time based competition.

[f] TPM: total preventive maintenance; 1-not included by Nahm et al. (2003) in their measures of TBC.

In their recent research, Shah and Ward (2007) with an comprehensive look and with regarding to all internal and external dimensions of lean production tried to define and test appropriate scales for organizational leanness measuring. In this study, at first, a list of lean items in the literature was extracted. Then,10 practitioners were interviewed in a structured manner for examining context validity and next the scales were tested by some of practitioners and academics. The result list was comprised of 48 items. Explanatory factor analysis and reliability test then was done using data from 63 organizations. After necessary corrections, 280 organizations' data (unless those organizations investigated at the pilot stage) were gathered and analyzed using new list. Authentic statistical tests in addition to an exact method to validate lean items' list, brought about a high reliability for identified items, groups and latent variables extracted in this research. Moreover, with respect to acute change of lean dimensions and elements presented at the literature over the time (Shah and Ward, 2007), it seems that comprehensiveness of items, the power of research method used and its time approximation with the present study, would justify the use of shah and ward`s lean items list in the current study.

2-2. Fuzzy logic

The criteria for measuring subjects and phenomena are different base on organizational behavior and research requirements. Nevertheless, what that would be fix forever, is the process and method of measuring. In this process, person or persons who enjoy enough expertise on the research question domain would change qualitative data to differentiable values. However, care must be applied that such a methods, neglect ambiguity related to individuals judgment and their value changes during transformation to numbers (Chakraborty, 1975). Fuzzy logic was first introduced by Professor Zadeh (1965), in order to answer such a challenge. He believes that human's logic can take advantage of concepts and knowledge that do not have well-defined borders (Yen and Langari, 1999). Fuzzy logic comprise a wide spectrum of theories and techniques mainly constructed upon four concepts: fuzzy sets, linguistic variables, probability distribution (membership function), and fuzzy if-then rules (Yen and Langari, 1999). Fuzzy sets and linguistic variables are widely used as the two fundamental concepts in qualitative assessments. Fuzzy set is a set in which members' certainty of membership is rejected and every member belong to the set with its own specific membership degree (μ).

At the other hand, in a situation that required data are quantitative, expressing them in terms of numerical amounts are allowed; however, when the research is in a qualitative environment and knowledge therein suffer from ambiguity and vagueness, data may not be expressed as exact numbers, as if in the most researches it is claimed that the most of managers cannot express an exact number in order to present their opinion and therefore linguistic assessment is used instead of specific numerical values (Beach et al., 2000; Gerwin, 1993; Herrera and Herrera-Viedma, 2000; Kacprzyk, 1986; Vokurka and O_Leary-Kelly, 2000). In these cases right values are fuzzy values (eg. true, highly true, more or less true, false, probably false, and …), therefore such values are expressible as linguistic variables and present more exact assessment (Zadeh, 1975,1987). Regularly, a proper linguistic variable is set up for explanation of ambiguity and vagueness base on the problem domain. Then, expressions' concept would be determined using fuzzy numbers, which are defined through space [1,0] and membership function. Since linguistic assessment is approximate, triangular and trapezoidal membership functions seem to be appropriate for responding ambiguity of these assessments (Delgado et al., 1993). Several researchers have shown that fuzzy membership function can reflect in mind the relative importance of linguistic words (Dyer and Sarin, 1979). Therefore, we can apply fuzzy membership function approach for transforming linguistic beliefs to numbers in interval scale (Hsiao, Article in Press, 2008). As if nowadays, the applicability of such an approach is more and more visible in the following fields: information retrieval (Bordogna and Pasi, 1993), medical (Degani and Bortolan, 1988), education (Law, 1996), suppliers' selection (Herrera et al., 1999) and decision making (Tong and Bonissone, 1980; Delgado et al., 1993; Yager, 1995; Herrera et al., 1995; Chen, 2000).

1- Research algorithm

The main goal of the paper is to render a method compatible to inexact human assessments for measuring organizations' leanness. This method stages are as follows:

1- Defining lean attributes: defining the lean attributes (enablers) is the first step in this algorithm. In this stage a proper set of lean scales with high validity and reliability would be defined by a deep study of literature and investigation of organizational lean assessment methods in the researchers' surveys.

2- Defining proper linguistic variables: As mentioned, ambiguity existed in human assessment about items, make using crisp methods unreliable. Fuzzy logic considering ambiguity and uncertainty, maintain an appropriate tool for encountering with ambiguity in human assessments. Linguistic variables and relevant membership functions have been extensively used by researchers in operations management. A variety of famous linguistic variables and related membership functions are proposed for linguistic assessments (Karwowski and Mital, 1986; Chen and Hwang, 1992). For convenience, we may directly use past studies or modify them according to the research needs and respondent conditions, in order to define appropriate linguistic variables and their related membership functions. However, as a general recommendation, the number of linguistic variables' levels should not exceed 9 levels which is recognized as human recognition limit (Lin et al., 2006).

3- Measuring performance and importance weight of lean enablers using linguistic variables: For proper accomplishment of this stage it is necessary to identify experts who are familiar to industry conditions and operations concepts especially lean production. To achieve higher validity and reliability, we should build a common viewpoint about concepts (lean enablers) between researcher and experts. For this we may use descriptions at the beginning of the questionnaire or take advantage of interview.

4- Integrating fuzzy importance Weights and performance of lean fuzzy enablers to achieve fuzzy lean index: A variety of methods like arithmetic mean, median, or mode might be used to integrating decision makers assessments. Since mean operator is used extensively in the researches, in this study it is used also in order to collect experts' opinions.

Assume that a committee of m evaluators, i.e., E_t ,t = 1,2,...,m conducts the leanness evaluation. Let F_j, j = 1,2,...,n; be factors for measuring leanness (enablers); let $R_{tj} = (a_{jt}, b_{jt}, c_{jt})$ be the fuzzy numbers approximating the linguistic ratings given to F_t by assessor E_t. And let $W_{tj} = (x_{jt}, y_{jt}, z_{jt})$ be the fuzzy numbers approximating the linguistic importance weights assigned to F_t by assessor E_t. using the average fuzzy rating R_j and average fuzzy importance weight W_j, the aggregation of the opinions of experts then are calculated as

$$R_j = (a_j, b_j, c_j) = (Rj1 (+) Rj2 (+)...(+) Rjm / m. \quad (1)$$

$$Wj = (x j, y j, z j) = (Wj1 (+) Wj2 (+)...(+) Wjm / m. \quad (2)$$

Fuzzy leanness index (FLI) is an information fusion, which consolidates the fuzzy ratings and fuzzy importance weights of all of the factors (enablers) that influence leanness. FLI represents overall organizational leanness. Organizational leanness increases with increasing FLI thus, the membership function of FLI is used to determine the leanness level. Let R_j and Wj , $j = 1,2,...,n$; respectively, denote the average fuzzy rating and average fuzzy importance weight given to factor j by the evaluation committee. The fuzzy leanness index, FLI, then is defined as

$$FAI = \sum_{j=1}^{n} \left(W_j (\cdot) R_j \right) / \sum_{i=1}^{n} W_j \quad (3)$$

The membership function of FLI can be calculated using the fuzzy weighted average operation; the calculation can be found in Kao and Liu (Kao and Liu, 2001).

5- Match the fuzzy Leanness index with an appropriate linguistic level: Once the FLI is obtained, to identify the leanness level, the FLI can be further matched with the linguistic label, the membership function which is the same as (or closest to) the membership function of the FLI from the membership function of the natural-language expression set of Leanness label (LL). Several methods have been proposed for matching the membership function with linguistic terms, of which include (1) Euclidean distance,(2)successive approximation, and (3) piecewise decomposition. This study recommends utilizing the Euclidean distance method since it is the most intuitive method for humans to use in perceiving proximity (Guesgen and Albrecht, 2000).

6- Assuming the natural-language leanness level expression set is LL, then U_{FLI} and U_{LLi} represent the membership functions of the FLI and natural-language leanness i, respectively. The distance between U_{FLI} and U_{LLi} then can be calculated as:

$$d(FLI, LL_i) = \left\{ \sum_{x \varepsilon p} (U_{FLI}(x) - U_{LL_i}(x))^2 \right\}^{1/2} \quad (4)$$

where $p = \{x_{00}, x_1, ..., x_{m0}\} \subset [o,1]$ *so that* $0 = x_0 < x_1 < ....x_m = 1.0.$ *To simplify let*

$$p = \{0, 0.05, 0.1, 0.15, 0.2 \ 0.25 \ 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1\}$$

The distance from the FLI to natural-language leanness i can then be calculated, and the closest natural expression with the smallest distance UFLI to ULLi can be identified.

4. Leanness Assessment using Fuzzy Logic Approach (Case Study)

In this section, the above proposed method is used for measuring leanness level of a tile and ceramic producing company. The steps are as follows:

Step 1: defining of lean enablers

The first step in successful measuring and analyzing an organization's leanness is to define leanness enablers. In this respect, the research team studied leanness and it`s enablers literature deeply and defined leanness scales on the basis of enablers. These scales were then modified using industry executive experts' opinions. The final list is compiled according to Figure 1. The graph shows that there are 3 dimensions, 10 subdimensions and 48 items.

Step 2: Preparing assessors for assessing leanness items in the organization
The estimating team was chosen among tile and ceramic industry experts who have academic education in production and operations related fields. To improve survey validity and build a common understanding for concepts, concepts of organizational leanness, its history, and definitions of leanness items were described for estimators firstly. Then leanness items were estimated using common agreement method.

Step 3: Designing linguistic variables for estimating leanness items
Using non general linguistic variables and related membership functions is always criticized in fuzzy logic (Lin et al., 2006). In addition many linguistic variables and membership functions are proposed for linguistic assessments (Chen and Hwang, 1992; Karwowski and Mital, 1986). Therefore, for convenience, we decided to use linguistic variables and related membership functions from previous studies and adjust them to research needs. Therefore, On the basis of the original data of the study conducted by Yang and Li (2002) and considering the human way of perceiving differences, the linguistic variables{Excellent [E], Very Good [VG], Good [G], Fair [F], Poor [P], Very Poor [VP], Worst [W]}, are selected to assess the performance rating of the leanness capabilities. Matching the above mentioned linguistic variables with fuzzy numbers is being done according to a similar study accomplished by Lin et al (Lin et al., 2006). These researchers proposed appropriate fuzzy numbers for these expressions (table 2) base on individual understanding from the meaning of linguistic variables.

Stage 4: Assessment of leanness capabilities using linguistic variables and approximating them by fuzzy numbers
Assessment committee evaluated the organization’s performance and importance weight in every leanness items using real data and their experience based on linguistic variables. The results are shown in the tables 3 and 4.

Stage 5: Calculation of fuzzy leanness index (FLI) using performance and importance weight of leanness items
Eq. 1 and 2 are being used for fuzzy score calculation of each items using their performance and importance. These calculations are presented in table (4). Sum of items` fuzzy scores related to each dimension, make fuzzy scores of sub dimensions` performance. These scores, also with a similar method, multiplying to the importance weights of sub dimensions, totally build fuzzy scores of dimensions’ performance. Finally, the resulted scores multiplying to importance of these dimensions would build fuzzy leanness index.

Table 2: Fuzzy numbers for approximating linguistic variable values

Performance-rating		Importance-weighting	
Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Worst (W)	(0, 0.5, 1.5)	Very Low (VL)	(0, 0.05, 0.15)
Very Poor (VP)	(1, 2 ,3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(2 ,3.5, 5)	Fairly Low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(3, 5, 7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(5, 6.5, 8)	Fairly High (FH)	(0.5, 0.65, 0.8)
Very Good (VG)	(7, 8 , 9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(8.5, 9.5, 10)	Very High (VH)	(0.85, 0.95, 1)

$$\begin{bmatrix} F\_Lean = [(3.29,4.71,6.14)\times(0.85,0.95,1)+(4.18,5.88,7.59)\times(0.5,0.65,0.8)+(4.85,6.33,7.82)\times(0.7,0.8,0.9)]/ \\ [(0.85,0.95,1)+(0.5,0.65,0.8)+(0.7,0.8,0.9)]=(4.04,5.57,7.13) \end{bmatrix}$$

Stage 6: Match the FLI with an appropriate Leanness level: Once the FLI has been obtained, to identify the level of leanness, the FLI can be further matched with the linguistic label whose membership function is the same as (or closest to) the membership function of the FLI from the natural-language expression set of leanness label (LL). Figure 2 shows the method using Lin research (Lin et al., 2006). In order to determine linguistic variables fit to leanness fuzzy score, it is necessary to calculate distance between this score and each of linguistic variables cited in figure 2. calculating distances, the linguistic variable with the least distance would show organization`s leanness degree. In order to calculate distance between the two fuzzy numbers following equation would be used. Suppose that A and B are two triangular fuzzy numbers like $A=(a_1,b_1,c_1)$ and $B=(a_2,b_2,c_2)$, then distance between A and B is calculated as:

$$D(A,B)=\sqrt{\frac{1}{3}\left[(a_2-a_1)^2+(b_2-b_1)^2+(c_2-c_1)^2\right]} \qquad (5)$$

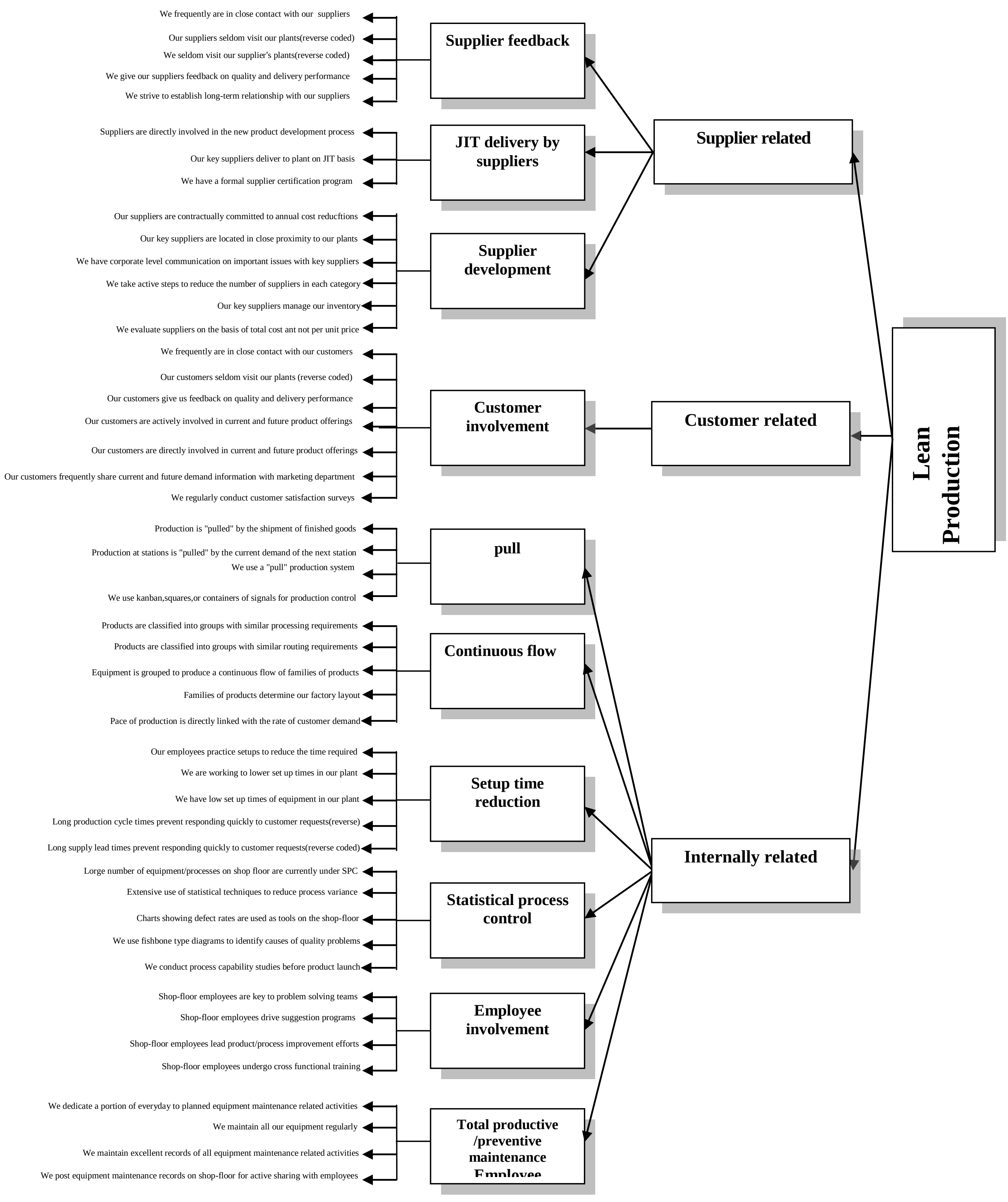

Figure 1: Leanness enablers

Table 3: Aggregated performance rating and aggregated importance weight of leanness capabilities

LMI_i	LMI_{ij}	importance weights	performance rate	LMI_i	LMI_{ij}	importance weights	performance rate
LMI_1				LMI_6			
	LMI_{11}	FL	G		LMI_{61}	M	W
	LMI_{12}	L	VP		LMI_{62}	M	W
	LMI_{13}	VL	F		LMI_{63}	M	W
	LMI_{14}	FL	F		LMI_{64}	M	W
	LMI_{15}	FH	G		LMI_{65}	FL	G
LMI_2				LMI_7			
	LMI_{21}	FL	P		LMI_{71}	L	F
	LMI_{22}	M	F		LMI_{72}	M	VG
	LMI_{23}	M	VP		LMI_{73}	FL	VP
					LMI_{74}	M	F
LMI_3					LMI_{75}	M	F
	LMI_{31}	L	VP				
	LMI_{32}	M	VG	LMI_8			
	LMI_{33}	L	VP		LMI_{81}	L	VP
	LMI_{34}	FH	F		LMI_{82}	L	VP
	LMI_{35}	M	W		LMI_{83}	FL	W
	LMI_{36}	L	P		LMI_{84}	M	VG
					LMI_{85}	VL	VG
LMI_4							
	LMI_{41}	L	P	LMI_9			
	LMI_{42}	L	P		LMI_{91}	VL	P
	LMI_{43}	L	P		LMI_{92}	FL	P
	LMI_{44}	VL	G		LMI_{93}	M	VP
	LMI_{45}	VL	G		LMI_{94}	M	G
	LMI_{46}	L	P				
	LMI_{47}	VL	W	LMI_{10}			
					$LMI_{10,1}$	M	G
LMI_5					$LMI_{10,2}$	M	VG
	LMI_{51}	M	VP		$LMI_{10,3}$	M	P
	LMI_{52}	H	G		$LMI_{10,4}$	FL	P
	LMI_{53}	FL	W				
	LMI_{54}	VL	W				

Table 4: Linguistic terms approximated by fuzzy numbers

Weights of 3 dimensions’	Weights of 10 subdimensions’	importance weights (Wij)	performance rates(Rij)	Weighted performance rates (Wij*Rij)
(0.85 ,0.95 ,1)	(0.7 ,0.8 ,0.9)	(0.85 ,0.95 ,1)	(3 ,5 ,7)	(2.55 ,4.75 ,7)
		(0.85 ,0.95 ,1)	(2 ,3.5 ,5)	(1.7 ,3.325 ,5)
		(0.85 ,0.95 ,1)	(3 ,5 ,7)	(2.55 ,4.75 ,7)
		(0.7 ,0.8 ,0.9)	(3 ,5 ,7)	(2.1 ,4 ,6.3)
		(0.7 ,0.8 ,0.9)	(2 ,3.5 ,5)	(1.4 ,2.8 ,4.5)
	(0.85 ,0.95 ,1)	(0.5 ,0.65 ,0.8)	(1 ,2 ,3)	(0.5 ,1.3 ,2.4)
		(0.85 ,0.95 ,1)	(1 ,2 ,3)	(0.85 ,1.9 ,3)
		(0.3 ,0.5 ,0.7)	(2 ,3.5 ,5)	(0.6 ,1.75 ,3.5)
	(0.85 ,0.95 ,1)	(0.85 ,0.95 ,1)	(1 ,2 ,3)	(0.85 ,1.9 ,3)
		(0.7 ,0.8 ,0.9)	(1 ,2 ,3)	(0.7 ,1.6 ,2.7)
		(0.7 ,0.8 ,0.9)	(3 ,5 ,7)	(2.1 ,4 ,6.3)
		(0.7 ,0.8 ,0.9)	(2 ,3.5 ,5)	(1.4 ,2.8 ,4.5)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
	(0.7 ,0.8 ,0.9)	(0.85 ,0.95 ,1)	(3 ,5 ,7)	(2.55 ,4.75 ,7)
		(0.5 ,0.65 ,0.8)	(5 ,6.5 ,8)	(2.5 ,4.225 ,6.4)
		(0.7 ,0.8 ,0.9)	(2 ,3.5 ,5)	(1.4 ,2.8 ,4.5)
		(0.7 ,0.8 ,0.9)	(2 ,3.5 ,5)	(1.4 ,2.8 ,4.5)
		(0.5 ,0.65 ,0.8)	(1 ,2 ,3)	(0.5 ,1.3 ,2.4)
		(0.85 ,0.95 ,1)	(2 ,3.5 ,5)	(1.7 ,3.325 ,5)
		(0.7 ,0.8 ,0.9)	(1 ,2 ,3)	(0.7 ,1.6 ,2.7)
	(0.85 ,0.95 ,1)	(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
	(0.7 ,0.8 ,0.9)	(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.85 ,0.95 ,1)	(5 ,6.5 ,8)	(4.25 ,6.175 ,8)
(0.5 ,0.65 ,0.8)	(0.5 ,0.65 ,0.8)	(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(3 ,5 ,7)	(2.1 ,4 ,6.3)
		(0.85 ,0.95 ,1)	(5 ,6.5 ,8)	(4.25 ,6.175 ,8)
		(0.85 ,0.95 ,1)	(3 ,5 ,7)	(2.55 ,4.75 ,7)
(0.7 ,0.8 ,0.9)	(0.7 ,0.8 ,0.9)	(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)
		(0.7 ,0.8 ,0.9)	(3 ,5 ,7)	(2.1 ,4 ,6.3)
	(0.85 ,0.95 ,1)	(0.5 ,0.65 ,0.8)	(5 ,6.5 ,8)	(2.5 ,4.225 ,6.4)
		(0.5 ,0.65 ,0.8)	(5 ,6.5 ,8)	(2.5 ,4.225 ,6.4)
		(0.5 ,0.65 ,0.8)	(3 ,5 ,7)	(1.5 ,3.25 ,5.6)
		(0.3 ,0.5 ,0.7)	(2 ,3.5 ,5)	(0.6 ,1.75 ,3.5)
	(0.5 ,0.65 ,0.8)	(0.7 ,0.8 ,0.9)	(7 ,8 ,9)	(4.9 ,6.4 ,8.1)
		(0.5 ,0.65 ,0.8)	(7 ,8 ,9)	(3.5 ,5.2 ,7.2)
		(0.3 ,0.5 ,0.7)	(7 ,8 ,9)	(2.1 ,4 ,6.3)
		(0.5 ,0.65 ,0.8)	(3 ,5 ,7)	(1.5 ,3.25 ,5.6)

Table 5: Weighted performance for leanness dimensions

Weights of 3 dimensions'	Weights of 10 subdimensions' (Wj)	performance of 10 subdimensions' (Ri)	Rj* Wj	performance of 3 dimensions' (Ri*Wj)
(0.85 ,0.95 ,1)	(0.7 ,0.8 ,0.9)	(2.60 ,4.41 ,6.20)	(1.82 ,3.52	(3..29, 4.71. 6.14)
	(0.85 ,0.95 ,1)	(2.16 ,3.72 ,5.26)	(1.84 ,3.53	
	(0.85 ,0.95 ,1)	(3.6 ,5 ,6.4)	(3.06 ,4.75 ,6.4)	
	(0.7 ,0.8 ,0.9)	(1.65 ,2.95 ,4.24)	(1.15 ,2.36	
	(0.85 ,0.95 ,1)	(3.37 ,4.69 ,6.02)	(2.86 ,4.46	
	(0.7 ,0.8 ,0.9)	(6.53 ,7.65 ,8.78)	(4.57 ,6.12	
(0.5 ,0.65 ,0.8)	(0.5 ,0.65 ,0.8)	(4.18 ,5.88 ,7.59)	(2.09 ,3.82	(4.18, 5.88, 7.59)
(0.7 ,0.8 ,0.9)	(0.7 ,0.8 ,0.9)	(5 ,6.5 ,8)	(3.5 ,5.2 ,7.2)	(4.85, 6.33, 7.82)
	(0.85 ,0.95 ,1)	(4.64 ,6.11 ,7.61)	(3.94 ,5.81	
	(5 ,6.5 ,8)	(5.01 ,6.44 ,7.87)	(2.50 ,4.18	

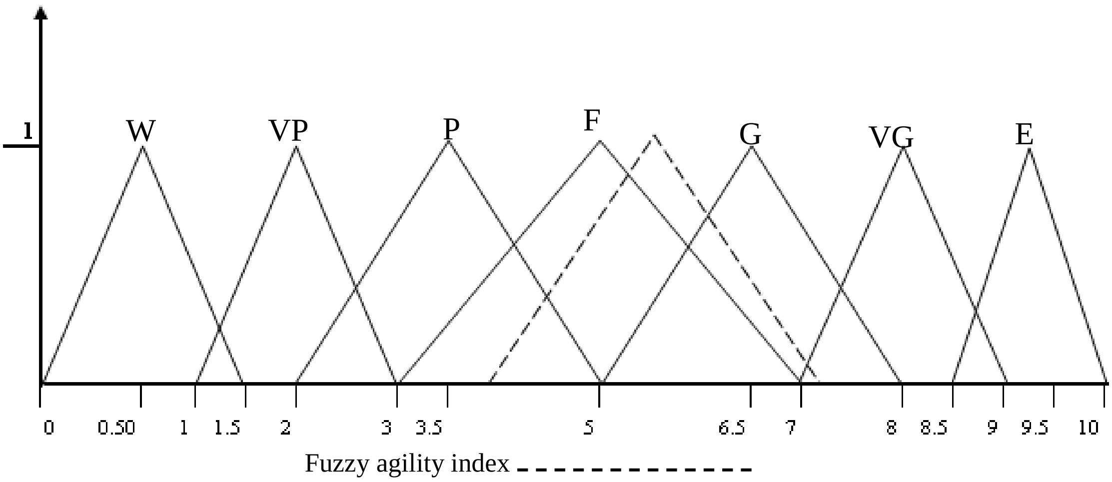

Figure 2: Linguistic levels to match fuzzy-agility-index

With respect to the above equation, distance between leanness fuzzy score with each of leanness linguistic variables is as follow:

D (FLI, very low) = 4.96 D (FLI, low) = 3.61
D (FLI, relatively low) = 2.08 D (FLI, medium) = 0.69
D (FLI, relatively high) = 0.92 D (FLI, high) = 2.54
D (FLI, very high) = 3.80

Thus, by matching a linguistic label with the minimum D, the leanness index level of the company can be identified as ‘‘medium lean’, as shown in Fig. 1.

5. Conclusion

Nevertheless developing lean production in recent years, there are some steps to it`s maturity. In fact there are some questions about leanness requirements: to what extent a company should be lean? What index should be used to measure organization leanness? How could organization leanness be measured? Answering this question is vital for leanness specialists and for developing lean theory. Then this research goal is answering some of these questions by special attention on leanness measuring. At the first step, we defined leanness concepts, dimensions and measures using a deep study of literature. Considering vagueness and uncertainty in human evaluation, At the second step, we developed a fuzzy method to measure organizational leanness. The fuzzy method include three stages: at the first, each measure's performance and importance weight and each subdimensions and dimensions` importance weight were measured in linguistic variables. At the second step, subdimensions and dimensions performance were calculated using performances and importance weights were asked in the last stage. At the end of this step fuzzy leanness index was calculated using dimensions performance and weights and finally third step dedicated to converting fuzzy leanness index to a linguistic variable. At the end, developed method was used for measuring an organization leanness and results showed the power and accuracy of this method.

References

1. Agarwal, A., Shankar, R. and Tiwari, M.K. (2006), "Modeling the metrics of lean, agile and legible supply chain: An ANP-based approach", European Journal of Operational Research, Vol. 173, No.1, pp. 211-225.

2. Ahmad, S., Schroeder, R.G., Sinha, K.K., 2003. The role of infrastructure practices in the effectiveness of JIT practices: implication for plant competitiveness. J. Engineering Tech. Management 20 (3), 161–191.
3. Beach, R., Muhlemann, A.P., Price, D.H.R., Paterson, A. and Sharp, J.A. (2000), "A review of manufacturing flexibility", European Journal of Operational Research, Vol. 122, pp. 41–57.
4. Bordogna, G. and Pasi, G. (1993), "A fuzzy linguistic approach generalising boolean information retrieval: a model and its evaluation", Information Systems, Vol. 44, pp. 70–82.
5. Chakraborty, D., Optimization in impressive and uncertain environment, Ph.D. Thesis, Dept. of Mathematics, IIT Kharagpur, 1975.
6. Chen, C.-T. (2000), "Extensions oft he TOPSIS for group decision-making under fuzzy environment", Fuzzy Sets and Systems, Vol. 114, pp. 1–9.
7. Chen, S.J. and Hwang, C.L. (1992), Fuzzy Multiple Attribute Decision Making Methods and Application. Springer, Berlin, Heidelberg.
8. Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001), "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", J. Operations Management, Vol. 19 No. 2, pp. 675–694.
9. De Treville, S. and Antonakis, J. (2006), "Could lean production job design be intrinsically motivating? Contextual, configurational and levels-of-analysis issue", J. Oper. Management, Vol. 24. No. 2, pp. 99–123.
10. Degani, R. and Bortolan, G. (1988), "The problem of linguistic approximation in clinical decision making", Int. J. Approx.Reasoning, Vol. 2, pp. 143–162.
11. Delgado, M., Verdegay, J.L. and Vila, v, (1993), "Linguistic decision making models", Int. J. Intel. Systems, Vol. 7, pp. 479–492.
12. Dow, D., Samson, D., Ford, S., 1999. Exploding the myth: do all quality management practices contribute to superior quality performance? Production and Operations Management 8 (1),1–27.
13. Dyer, J. S. and Sarin, R. K. (1979), "Measurable multiattribute value functions" Operations Research, Vol. 39, pp. 810–822.
14. Flynn, B.B. and Sakakibara, S. (1995), "Relationship between JIT and TQM: practices and performance", Academy of Management Journal, Vol. 38 No. 5, p. 1325.
15. Flynn, B.B., Sakakibara, S. and Schroeder, R.G. (1995), "Relationship between JIT and TQM: practices and performance", Academy of Management Journal, Vol. 38 No. 5, pp. 1325–1360.
16. Forza, C. (1996), "Work organization in lean production and traditional plants – what are the differences", International Journal of Operations & Production Management, Vol. 16 No. 2, p. 42.
17. Gerwin, D. (1993), "Manufacturing flexibility: A strategic perspective", Management Science, Vol. 39, No. 4, pp. 395–410.
18. Guesgen, H.W. and Albrecht, J. (2000), "Imprecise reasoning in geographic information systems", Fuzzy Sets and Systems, Vol. 113, pp. 121–131.
19. Herrera, F. and Herrera-Viedma, E. (2000), "Linguistic decision analysis: Steps for solving decision problems under linguistic information", Fuzzy Sets and Systems, Vol. 115, pp. 67–82.
20. Herrera, F., Herrera-Viedma, E. and Verdegay, J.L. (1995), "A sequential selection process in group decision making with linguistic assessment", Inform. Sci. Vol.85, pp. 223–239.
21. Herrera, F., Lopez, E., Menda˜na, C. and Rodriguez, M. (1999), "A linguistic decision model to suppliers selection in international purchasing", in: L.A. Zadeh, J. Kacprzyk (Eds.), Computing with words in information=intelligent systems 2. Applications, Physica-Verlag, Schursberg, pp. 500–524.
22. Hopp, W.J. and Spearman, M.L. (2004), "To pull or not to pull: what is the question?", Manufacturing and Service Operations Management, Vol. 6 No. 2, pp. 133–148.
23. Hsiao, W.F., Lin, H.H. and Chang, T.M. (2008), "Fuzzy consensus measure on verbal opinions", Expert Systems with Applications xxx, xxx–xxx
24. Kacprzyk, J. (1986), "Group decision making with a fuzzy linguistic majority", Fuzzy Sets and Systems, VOL. 18, PP. 105–118.
25. Kao,C. and Liu, S.T. (2001), "Fractional programming approach to fuzzy weighted average", Fuzzy Sets and Systems, Vol. 120, pp. 435–444.
26. Karwowski, W. and Mital, A.(1986), Applications of approximate reasoning in risk analysis. In: Karwowski, W. and Mital, A.(Eds.), Applications of Fuzzy Set Theory in Human Factors, Netherlands.
27. Katayama, H. and Bennett, D. (1996), "Lean production in a changing competitive world: a Japanese perspective", International Journal of Operations & Production Management, Vol. 16 No. 2, pp. 8-23.
28. Kojima, S. and Kaplinsky, R. (2004), "The use of a lean production index in explaining the transition to global competitiveness: the auto components sector in South Africa", Technovation, Vol. 24, pp. 199–206.
29. Koufteros, X.A., Vonderembse, M.A., Doll, W.J., 1998. Developing measures of time based manufacturing. Journal of Operations Management 16 (1), 21–41.
30. Koufteros, X.A., Vonderembse, M.A., 1998. The impact of organizational structure on the level of JIT attainment. International Journal of Production Research 36 (10), 2863–2878.

31. Krafcik, J.F. (1988) "Triumph of the lean production system", Sloan Management Review, Vol. 30 No. 1, pp. 41–52.
32. Law, C.K. (1996), "Using fuzzy numbers in educational grading system", Fuzzy Sets and Systems, Vol. 83, pp. 311–323.
33. Li, S., Subba Rao, S., Ragu-Nathan, T.S. and Ragu-Nathan, B. (2005), "Development and validation of a measurement instrument for studying supply chain management practices", Journal of Operations Management, Vol. 23, No. 6, pp. 618–641.
34. Lin, C.T, Chiu, H. and Tseng, Y. H. (2006), "Agility evaluation using fuzzy logic", Int. J. Production Economics, Vol. 101 No. 2, pp. 353-368.
35. Lowe, J., Delbridge, R. and Oliver, N. (1997), "High-performance manufacturing – evidence from the automotive components industry", Organization Studies, Vol. 18 No. 5, pp. 783-98.
36. MacDuffie, J.P. (1995), "Human resource bundles and manufacturing performance: organizational logic and flexible production systems in the world auto industry", Industrial and Labour Relations Review, Vol. 48 No. 2, p. 197.
37. Machacha, L.L. and Bhattacharya, P. (2000), "A fuzzy logic-based approach to project selection", IEEE Transactions on Engineering Management, Vol. 47 No 1, pp. 65–73.
38. McKone, K.E. and Weiss, E.N. (1999), "Total productive maintenance: bridging the gap between practice and research", Production and Operations Management, Vol. 7, No. 4, pp. 335–351.
39. Rivera, A. and Chen, F.F. (2007), "Measuring the impact of Lean tools on the cost–time investment of a product using cost–time profiles", Robotics and Comp.-Int. Manufacturing, Vol. 23 No. 6, pp. 684-689.
40. Sakakibara, S., Flynn, B.B. and Schroeder, R.G. (1993), "A framework and measurement instrument for just-in-time manufacturing", Production and Operations Management, Vol. 2, No. 3, pp. 177–194.
41. Sakakibara, S., Flynn, B.B., Schroeder, R.G. and Morris,W.T. (1997), The impact of just-in-time manufacturing and its infrastructure on manufacturing performance" Management Science, Vol. 43 No. 9, pp. 1246–1257.
42. Sanchez, A. and Perez, M. (2000), "Lean indicators and manufacturing strategies", International Journal of Operations & Production Management, Vol. 21 No. 11, pp. 1-13.
43. Shah, R. and Ward, P.T. (2003), "Lean manufacturing: context, practice bundles, and performance", Journal of Operations Management, Vol. 21, No. 2, pp. 129–149.
44. Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", Journal of Operations Management, Vol. 25, No. 4, pp. 785-805.
45. Simons ,D and Zokaei , K (2005), "Application of lean paradigm in red meat processing", British Food Journal, Vol. 107 No. 4, pp. 192-211.
46. Sink, D.s. and Tuttle, T.c. (1989), Planning and measurement in your organization of the future, Industrial Engineering and Management Press, Norcross, GA.
47. Smith, A., Oczkowski, E., Noble, C. and Macklin, R. (2003), "New management practices and enterprise training in Australia", International Journal of Manpower, Vol. 24 No. 1, p. 31.
48. Spear, S. and Bowen, H.K. (1999), "Decoding the DNA of the Toyota Production System". Harvard Business Review ,Vol. 77, No. (9/10), pp.97–106.
49. Tong, M. and Bonissone. (1980), "A linguistic approach to decision making with fuzzy sets", IEEE Trans. Systems, Man Cybernet., Vol. 10, pp. 716–723.
50. Vokurka, R.J. and O_Leary-Kelly, S.W. (2000), "A review of empirical research on manufacturing flexibility", Journal of Operations Management, Vol. 18, pp. 485–501.
51. Wacker, J.G. (2004). "A theory of formal conceptual definitions: developing theory building measurement instruments", Journal of Operations Management, Vol. 23, No. 4, pp. 629–650.
52. Wada, K. (2004), Kiichiro Toyoda and the Birth of the Japanese Automobile Industry: Reconsideration of the Toyoda-Platts Agreement, Working paper #CIRJE-F-288, University of Tokyo.
53. Womack, J.P. and Jones, D.T. (1996), Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Simon & Schuster, New York.
54. Womack, J.P., Jones, D.T., Roos, D., 1990. The Machine that Changed the World. Harper Perennial, N
55. Yager, R.R. (1995), "An approach to ordinal decision making", Int. J. Approx. Reasoning, 12, 237–261.
56. Yang, S.L. and Li, T.F. (2002), “Agility evaluation of mass customization product manufacturing”, Journal of Materials Processing Technology, Vol. 129, pp. 640–644.
57. Yen, J. and Langari, R. (1999), "Fuzzy Logic Intelligence", Information and Control, Prentice Hall.
58. Zadeh, L.A. (1965), "Fuzzy sets", Information and Control, No. 8, pp. 338–353.
59. Zadeh, L.A. (1975), "The concept of linguistic variable and its application to approximate reasoning", Information and Control. Sci. I: 8, pp.199–249; II: 8, pp. 310–357; III: 9, pp. 43–80.
60. Zadeh, L.A. (1987), "Fuzzy sets, usuality and common-sense reasoning, in: L.M. Vaina (Ed.)", Matters of Intelligence, Reidel, Dordrecht, pp. 289–309.