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Application of fuzzy logic in performance management: a literature review

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Abstract: Performance management has become in a key success factor for any organization. Traditionally, performance management has focused uniquely in financial measures, mainly using quantitative measures, but two decades ago they were extended towards an integral view of the organization, appearing qualitative measures. This type of extended view and associated measures have a degree of uncertainty that needs to be bounded. One of the essential tools for uncertainty bounding is the fuzzy logic and, therefore,the main objective of this paper is the analysis of the literature about the application of fuzzy logic in performance measurement systems operating within uncertainty environments with the aim of categorizing, conceptualizing and classifying the works written so far. Finally, three categories are defined according to the different uses of fuzzy logic within performance management concluding that the most important application of fuzzy logic that counts with a higher number of studies is uncertainty bounding.

Key words: fuzzy logic, uncertainty, performance measurement, performance management, supply chain.

1. Introduction

Performance management has become in a key success factor for organizations because it favors a better understanding of enterprise, internal and external, scenarios and it offers a more realistic view, allowing to easily understand the current situation of the organization. In addition, it allows modeling future behaviors through objective establishment and actions to achieve them, always in coherence with enterprise strategy and towards competitive results.

Traditionally, performance measurement systems have focused uniquely in financial measures but two decades ago they were extended towards an integral view of the organization considering other factors such as product quality, effectiveness and efficiency of the organization (accomplishment of delivery times, adjusted stocks, etc.), customer satisfaction o measurement of enterprise sustainability. This new approach emerges to solve the gaps encountered in the traditional measurement systems that overlooked important elements of the organizations and the increasingly competitive environment of enterprises.

Precisely, competitiveness among companies generates environments where the uncertainty plays a fundamental role and emerge new concepts such as "Green enterprises", "e-business", etc. Thus, the scope of performance measurement increases as well as the information collection needed. Enterprises and supply chains operate within uncertainty environments that are characterized by redundant and shortcoming information for decision-making causing trouble in the definition, measuring and follow-up of objectives and goals that allow to establish target levels for performance measurement.

Thus, there is a necessity to generate new performance measurement systems and approaches of increasing complexity able to deal different types of uncertainty (intra-organizational, inter-organizational) and able to manage the information collected from managers and experts that sometimes has vagueness and incompleteness and is frequently subjective.

Attending to the literature, fuzzy logic is an important tool to manage different types of uncertainty because it uses reliable parameters that adapt easily to changes in uncertainty parameters. This is due to the fact that fuzzy logic is multivariate allowing in a practical manner to deal with problems in the way they are in reality.

Thus, the present paper focuses in analyzing, classifying and contextualizing the works of the literature that link fuzzy logic to performance management-measurement.

The structure of this work is as follows: in the second section, the methodology followed to develop the work is described; in the third section, it is presented the essential characteristics and the contribution of the analyzed works; in the fourth section, the results and discussion is exposed, and finally, conclusions and future research lines and presented.

2. Review Methodology

To develop the present paper, in the first place, a set of terms were selected to establish the scope to analyze. Thus, firstly, two main terms were selected: *Fuzzy Logic* and *Performance Management*, as well as similar terms: *Performance Management, Performance Indicators, Fuzzy Theory* and *Fuzzy Set Theory*. Once the search was performed, it was seen that other terms emerge always linked to the main ones. Therefore, these terms were also included in the search, limiting the scope of study. These terms were: *Balance Scorecard* f or *Performance Management* and *AHP/ANP* and *TOPSIS* for *FuzzyLogic*. Similarly, another set of terms was encountered that linked the two initial main terms aiding to finally determine the scope of the study: *Multi-CriteriaDecisionMaking (MCDM), ManufacturingCompanies, SupplyChain, SupplyChain Management, Subjectivity, Uncertainty and LinguisticVariables*

With respect to the period to analyze, this was defined form the results obtained without any initial restriction, with the aim of accessing to to all the information of the topic of research. In Table 1 shows the distribution of papers and their corresponding period. It is observed an increasing growth starting from 2008:

Table 1. Distribution of the articles with respect to years of publication.

Year	Articles
1995	1
2000	1
2002	2
2003	2
2004	2
2006	2
2007	2
2008	8
2009	2
2010	4
2011	4
2012	3
2013	1
TOTAL	34

The databases used for the study are: Emerald, IEEE Xplore, ScienceDirect, Scopus and Web of Knowledge.

3. Basic characteristics and contribution of the works reviewed

In order to have a full understanding of the relationship between fuzzy logic and performance measurement-management, an analysis and classification of the works encountered has been performed.

The classification has been performed according to the aim of using fuzzy logic in the papers. This classification has been selected because it is the one that allows to develop a higher number of categories as well as makes evident the different applications of the fuzzy logic in the studied scope.

Thus, three main categories have been defined. The following sections describe their main characteristics:

I. Type A: Uncertainty bounding (28 References)

II. Type B: Integration of qualitative and quantitative values (2 References)

III. Type C: Conversion of linguistics variables (5 References)

3.1. Type A: Uncertainty bounding

The works within Type A conform the most numerous group, with a total of 25 references, that come from mainly Asia (16), followed by South America (4 references), North America (3 references) and Europe (5 references).

All the works within Type A have the basis on achieving uncertainty bounding in performance

measurement, sometimes in specific industry sector and other times, in a more general scope.

Thus, Pilevaril *et al.*, (2008) define a system based in the If-Then rules of the fuzzy logic to evaluate supply chain agility, bounding uncertainty in characteristics such as responsibility, competence, flexibility and speed. Mahnam *et al.*, (2008), suggest a bi-objective approach to model supply chain and use fuzzy logic to bound uncertainty in product demand and in the method to determine supplier reliability. Datta *et al.* (2011), use fuzzy logic to deal with vagueness and uncertainty in quality criteria to choose a logistic partner 3PL. Behrouzi & Wong (2010) propose the use of membership functions in fuzzy logic to bound uncertainty in selected variables that determine the level of implementation of Lean Manufacturing. Chan *et al.* (2003) and Chan & Qi (2003), create an innovative method to measure supply chain performance, focusing in performance measures, where fuzzy logic is used to establish the real situation for judgment and evaluation of processes avoiding subjectivity. Lu & Li (2006) bound uncertainty of the time required for the processes, customer demand and supplier reliability by using fuzzy logic. Cheng *et al.* (2007) provide performance estimations with more realistic results based on measuring vagueness on product quality by using fuzzy logic. Unahabhokha *et al.* (2007) propose the use of fuzzy expert systems for developing predictive performance measurement systems that allow in an automatical manner predict performance of future distributions and identify, for instance, potential problems for companies. Behesti & Lollar (2007) suggest an alternative method of performance evaluation methods in comparison with traditional quantitative methods. They focus on estimating human resource performance and suggest a model of fuzzy logic to prevent subjectivity that sometimes occur in these type of evaluations. Wei *et al.* (2008) create a framework to measure performance of ERP's (Enterprise ResourcePlanning). They use a fuzzy performance index to deal with vagueness. For that purpose, the index is first translated in a simple score and then, it comes to linguistic terms. Others interesting articles as the ones from Campuzano *et al.* (2013), Campuzano *et al.* (2010) and Mula *et al.* (2013) who tackle the harmful Bullwhip Effect in supply Chains Using fuzzy logic for replenishment orders. Tabrizi & Razmi (2013) introduce fuzzy logic to control risks originated in the uncertainty in the design of the network of supply chains. Amini & Jochem (2011) suggest that in performance measurement it is very important the role of soft factors (such as friendship or worker competency). These soft factors should be necessarily evaluated by human judgement and therefore fuzzy logic is used to control this subjectivity. Olugu & Wong (2012) use fuzzy logic to measure performance of a closed-looped supply chain. Serna *et al.* (2008) study the mathematical models that use the principles of fuzzy logic to measure supply chain performance in uncertainty environments and then, they are applied to a set of bakeries. Nunes *et al.* (2011) use a model of fuzzy system for aiding decision-making in order to choose the better alternatives to deal with supply chain disturbances. Ganga & Carpinetti (2011) propose a model of performance measurement based on fuzzy logic to predict performance with respect to causal relations that exist among indicators of the SCOR model. Muñoz *et al.* (2008), link financial performance and organization sustainability through a set of ratings that are determined using fuzzy logic. Liao *et al.* (2010) propose a performance evaluation of processes based on an index for uncertainty measures.

All the works have a similar structure: the problem is introduced; then, some definitions are presented (regarding fuzzy logic, performance measurement or the issue covered); develop the solution proposed; analyze the results y finally, present the extracted conclusions. In Table 2, the main characteristics of the works analyzed are presented (mutual characteristics for all the types of works).

3.2. Type B: Integration of Qualitative and Quantitative Values

Two recent works (Xu *et al.*, 2008; Behrouzi *et al.*, and 2011) point out fuzzy logic as a mechanism for the integration of both qualitative and quantitative values, whose main characteristics are shown in Table 3.

The integration of qualitative and quantitative variables favour the generation of more flexible methodologies for managing-measuring performance. Since most of the models bring together only quantitative variables, those models that integrate both types of variables deliver a more complete vision of performance (Xu *et al.*, 2008).

Behrouzi *et al.* (2010) point out that through the integration of qualitative and quantitative factors, it is possible to achieve a final score that accounts for the result of all the metrics applied in the assessment system, employing the fuzzy logic to obtain also discrete numeric variables for the qualitative factors.

Table 2. Basic characteristics of main papers of Type A.

Paper	Application environment	Industry sector	Objective
Ammar & Wright (1995)	Intra-Organizational	Public sector	Elimination of uncertainty in public satisfaction surveys relating the score of each question with the importance of that question
Ammar & Wright (2000)	Intra-Organizational	Public sector	Fuzzy logic application in three different cases, where the evaluation comes from panels with integrated multiple criteria
Lau *et al.* (2002)	Supply Chain	Toys industry	Supply chain management to analyze and monitor the suppliers performance based on the products quality and the delivery time
Amini & Jochem (2011)	Intra-Organizational	---	Performance measuring and evaluating of service processes
Chan & Qi (2003)	Supply Chain	---	Holistic performance measurement of complex supply chains
Chan *et al.* (2003)	Supply Chain	---	Integral performance measurement of complex supply chains, evaluating processes and the judgment actual situation
Wang & Shu (2004)	Supply Chain	---	Managing the supply chain uncertainty and inventory strategies determining when there is a lack of historical data.
Lu & Li (2006)	Supply Chain	---	Supply chain modelling based on the incorporation of the relationship between the customer satisfaction level and inventory investment.
Cheng *et al.* (2007)	Supply Chain	Technological	Uncertainty dimensioning in measuring the product quality and selecting the best performing processes.
Unahabhokha *et al.* (2007)	Intra-Organizational	Printing and Textile	Creating a performance prediction system in manufacturing environments
Pilevaril *et al.* (2008)	Supply Chain	Automotive	Determining the supply chains agility
Serna *et al.* (2008)	Supply Chain	---	Addressing uncertainty arising from the complex interrelationships taking place among the various supply chain levels
Behesti&Lollar (2008)	Intra-Organizational	---	Developing a fuzzy model for decisions making, illustrated by the application that estimates the employees performance
Muñoz *et al.* (2008)	Intra-Organizational	---	Sustainability evaluation in organizations with a fuzzy focus
Mahnam *et al.* (2008)	Supply Chain	---	Uncertainty dimension from both the demand and the reliability of suppliers in an assembly line.
Wei *et al.* (2008)	Intra-Organizational	Technological	ERP Selection based on their performance
Theeranuphattana & Tang (2008)	Supply Chain	---	Analysis of the model proposed by Chan & Qi (2003) to reduce their limitations
Arango *et al.* (2010)	Supply Chain	Food industry	Supply chain uncertainty dimensioning by generating a performance indicators system
Behrouzi & Wong (2010)	Intra-Organizational	---	Performance Evaluation of Lean manufacturing environments
Liao & Wu (2010)	Intra-Organizational	---	Processes performance evaluation based on disability index for measurements with uncertainty
Datta *et al.*(2011)	Supply Chain	Automotive	Evaluation and selection of 3PL logistics operators in fuzzy environments
Ganga & Carpinetti (2011)	Supply Chain	---	Performance prediction in supply chains based on the causal relationships of the SCOR metrics
Nunes *et al.* (2011)	Supply Chain	---	Addressing disturbances that might arise in the supply chain environments
Olugu & Wong (2012)	Supply Chain	Automotive	Performance measurement of supply chain closed loop (CLSC, Closed-Loop Supply Chain)
Tabrizi & Razmi (2013)	Supply Chain	---	Incorporation of risk management in the supply chain networks design

Tabla 3. Basic Characteristics of papers of Type B.

Paper	Application environment	Industry sector	Objective
Xu & Lim (2008)	Supply Chain	---	Supplier selection based on the literature evaluation criteria and techniques
Behrouzi *et al.* (2010)	Supply Chain	Automotive industry	Supplier performance measurement by evaluating Lean attributes

On the other hand, both works have as a goal to carry out suppliers selection processes according to their performance. Then, Behrouzi *et al.* (2010) build a highly flexible model, which integrates both qualitative and quantitative measures as well as it is able to join metrics measured in different units (time, €, etc), through the generation of non-dimensional final scores. Additionally, it fosters continuous improvement processes and it is easy to use, as it does not require a high number of metrics. Besides, Xu *et al.*(2008) develop a system whose first phase is the joint between the performance metrics and the organization's strategy. This process facilitates the selection of the most relevant metrics. Then, the weights for each criterion are worked out and both the qualitative and the quantitative measures are integrated through the application of fuzzy logic. The structure of both papers is similar from a methodological point of view, as both start with the metric/criteria selection process, they secondly develop the proposed solution and, finally, they apply the solution to a concrete example.

The main limitations of both papers are by one hand that, firstly, it is still necessary the experts' opinions in order to define the fuzzy logic rules, and by the another that it is a priori allocated more importance to some specific suppliers aspects such as cost.

3.3. Type C: Conversion of Linguistic Variables.

Five works compose the Type C, where the conversion of linguistic variables into numerical variables is studied. The 80% of them refer to the supplier selection topic, where this type of fuzzy logic application is especially convenient because of the linguistic nature of the attributes associated to both the suppliers and the manufacturing units (Jain *et al.* (2004)).

The main characteristics of each one of these papers is presented in Table 4.

Four of these five papers present a fuzzy system whereas the another establish a methodology where the fuzzy logic is incorporated. Odhar & Kumar (2004) and Jain *et al.* (2004) incorporate to the system a genetic algorithm that develops the conjoint of basic fuzzy rules. The methodology's structure of all the papers is similar: The evaluators express their preferences in linguistic terms; these preferences are then used as input variables for the selection process, where the selection criteria are weighted and the suppliers' performance measured, using for this fuzzy logic. Then, the fuzzy scores of each potential supplier is obtained. These fuzzy scored are then translated to a discrete value that allows comparison among the proposed suppliers.

Tabla 4. Basic Characteristics of papers of Type C.

Paper	Application environment	Industry sector	Objective
Jain *et al.* (2004)	Supply Chain	---	Suppliers selection through an evolutionary fuzzy approach
Ohdar & Kay (2004)	Supply Chain	metallurgical	Suppliers selection through an evolutionary fuzzy approach
Chen *et al.* (2005)	Supply Chain	---	Suppliers selection delimiting the vagueness and imprecision
Ordoobadi (2009)	Supply Chain	---	Suppliers selection incorporating fuzzy arithmetic
Ferreira *et al.* (2012)	Supply Chain	---	Supply chain performance evaluation by creating an LARG index (Lean, Agile, Resilient, Green)

The main conclusion of this group of papers is that the use of linguistic variables when measuring performance is highly beneficial when the performance values can not be expressed by numeric values, being the role of the fuzzy logic essential, as it allows the conversion from one type of variable to the another.

4. Conclusions and future research directions

Through the analysis of the different selected papers, it has been proved the high variety of applications and uses that the fuzzy logic has within the performance measurement field, being these uses the base for the classification and conceptualization carried out. Then, the next three types of papers have been determined regarding the application of fuzzy logic to the performance measurement field: Uncertainty Delimitation, Integration of Qualitative and Quantitative Values and Linguistic Variables Conversion.

Then, the analysis has shown that the main application of fuzzy logic within the performance measurement field is the uncertainty delimitation through dealing with both inaccuracy and non clear characteristics from many of the information needed to carry out a good assessment. In most cases, the inaccuracy factor comes from human valuations and experts' opinions that complete the measurement process, and it is added to the own need of dealing with the subjectivity inherent to human beings judgements.

Regarding the activity sectors where the application of fuzzy logic within the performance measurement area is more common, these are: automotive, industrial, technological and public. However, this is not a very precise categorization, as in most of the references it is not specified the type of sector, especially on these that cover the supply chain context. This is due to the fact that, in most occasions, it is only shown a general environment and, when examples are provided, these describe slightly the number of elements and how these are distributed, without presenting concrete examples. In this area, 60% of the papers are referred to the supply chain context and the another 40% to the intra-organizational context. This may due to the fact that in the last years the supply chain context is having more importance and relevance within the organizational environment. Then, the study, analysis and improvement of this ambit is the objective of more and more researching works. Regarding the fuzzy logic, the fact that there are more references related to the supply chain tan to the intra-organizational context is due to the own uncertain nature inherent to the supply chain, which makes the fuzzy logic to be an adequate option.

On the other hand, a future research line is to delimit the uncertainty base on the unpredictable factors, both internal and external, that surround both the organizations and the supply chains and that are affecting to the performance measurement process. There a multitude of unpredictable factors of different nature that may modify the performance in different aspects and whose management is beyond the capabilities that usually can be found in any organization. For instance, an internal factor that modifies the performance could be the lack of historical data regarding important aspects of the organization; on the other hand, an external aspect could be the modification of any macroeconomic variable that surround the organization, for example the oscillations in the value of the Euro.

Then, the application of fuzzy logic for delimiting the uncertainty is one of the key applications when applying a mechanism to face all these unpredictable factors.

Finally, other future research line, whose main objective were to determine in what phases of the management-measurement process is better to apply fuzzy logic, would be welcome.

References

Amini, S. & Jochem, R. (2011). A Conceptual Model based on the Fuzzy Set Theory to Measure and Evaluate the Performance of Service Processes. *15th International Enterprise Distributed Object Computing Conference Workshops*. Aug. 29-Sept. 2, 2011, Helsinki, Finland. pp. 122-131. http://dx.doi.org/10.1109/EDOCW.2011.25

Ammar, S. & Wright, R. (1995). A Fuzzy Logic Approach to Performance Evaluation. Uncertainty Modeling and Analysis, 1995, and Annual Conference of the North American Fuzzy Information Processing Society. *Proceedings of ISUMA - NAFIPS '95.*, pp. 246 - 251

Ammar, S. & Wright, R. (2000). Applying fuzzy-set theory to performance evaluation. *Socio-Economic Planning Sciences*, 34(4): 285-302. http://dx.doi.org/10.1016/S0038-0121(00)00004-5

Arango, M.D., Jaimes, W.A. & Zapata, J.A. (2010). Gestión cadena de abastecimiento - Logística con indicadores bajo incertidumbre, caso aplicado sector panificador Palmira. *Ciencia e Ingeniería Neogranadina*, 20(1): 97-115.

Beheshti, H.M. & Lollar, J.G. (2008). Fuzzy logic and performance evaluation: discussion and application. *International Journal of Productivity and Performance Management,* 57(3): 237-246. http://dx.doi.org/10.1108/17410400810857248

Behrouzi, F. & Wong, K.Y. (2010). Lean performance evaluation of manufacturing systems: A dynamic and innovative approach. *Procedia Computer Science,* 3: 388-395. http://dx.doi.org/10.1016/j.procs.2010.12.065

Behrouzi, F., Wong, K.Y. & Kuah, C.T. (2010). A Fuzzy-Based Model to Measure Supplier Performance with Lean Attributes. *Fourth Asia International Conference on Mathematical/Analytical Modelling and Computer Simulation (AMS)*, 26-28 May, 2010. Kota Kinabalu, Malaysia. pp. 372 - 377. http://dx.doi.org/10.1109/AMS.2010.81

Campuzano, F., Mula, J., Peidro, D. (2010) Fuzzy estimations and system dynamics for improving supply chains Fuzzy Sets and Systems, 161(11): 1530-1542. http://dx.doi.org/10.1016/j.fss.2009.12.002

Campuzano-Bolarín, F., Mula, J., Peidro, D. (2013). An extension to fuzzy estimations and system dynamics for improving supply chains. *International Journal of Production Research*, 51(10): 3156-3166. http://dx.doi.org/10.1080/00207543.2012.760854

Chan, T.S., Qi, H.J. (2003). An innovative performance measurement method for supply chain management. *Supply Chain Management: An International Journal,* 8(3): 209-223. http://dx.doi.org/10.1108/13598540310484618

Chan, T.S., Qi, H.J., Chan, H.K., Lau, C.W. & Ip, W.L. (2003). A conceptual model of performance measurement for supply chains. *Management decision,* 41(7): 635-642. http://dx.doi.org/10.1108/00251740310495568

Chen, C.T., Lin C.T. & Huang S.F., (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *Int. J. Production Economics,* 102: 289-301. http://dx.doi.org/10.1016/j.ijpe.2005.03.009

Cheng, S.R., Hsu, B.M. & Shu, M.H. (2007). Fuzzy testing and selecting better processes performance. *Industrial Management & Data Systems,* 107(6): 862-881. http://dx.doi.org/10.1108/02635570710758761

Datta, S., Samantra, C., Sankar, S., Mandal, G. & Majumdar, G., (2011). Appraisement and selection of third party logistics service providers in fuzzy environment. *Benchmarking: An International Journal,* 20(4): 537-548. http://dx.doi.org/10.1108/BlJ-11-2011-0087

Ferreira, A., Azevedo, S. & Fazendeiro, P. (2012). A Linguistic Approach to Supply Chain Performance Assessment". *IEEE International Conference on Fuzzy Systems*, 10-15 June, 2012. Brisbane, Australia. pp.1-5. http://dx.doi.org/10.1109/FUZZ-IEEE.2012.6251327

Ganga, G.M.D. & Carpinetti, L.C.R. (2011). A fuzzy logic approach to supply chain performance management. *Int. J. Production Economics,* 134(1): 177-187. http://dx.doi.org/10.1016/j.ijpe.2011.06.011

Jain, V., Tiwari, M. & Chan, E. (2004). Evaluation of the supplier performance using an evolutionary fuzzy-based approach. *Journal of Manufacturing Technology Management*, 15(8): 735-744. http://dx.doi.org/10.1108/17410380410565320

Lau, H.C.W., Pang, W.K. & Wong, C.W.Y. (2002). Methodology for monitoring supply chain performance: a fuzzy logic approach. *Logistics Information Management*, 15(4): 271-280. http://dx.doi.org/10.1108/09576050210436110

Lalmazloumian, M. & Wong, K.Y., (2012). A Review of Modelling Approaches for Supply Chain Planning Under Uncertainty. *9th International Conference on Service Systems and Service Management (ICSSSM)*, 2-4 July, 2012, Shanghai, China. pp. 197-203. http://dx.doi.org/10.1109/ICSSSM.2012.6252220

Liao, M.Y. & Wu, C.W., (2010). Evaluating process performance based on the incapability index for measurements with uncertainty. *Expert Systems with Applications,* 37(8): 5999-6006. http://dx.doi.org/10.1016/j.eswa.2010.02.005

Lu, C. & Li, X.W. (2006). Supply Chain Modeling Using Fuzzy Sets and Possibility Theory in an Uncertain Environment. *The 6th World Congress on Intelligent Control and Automation*, pp. 3608-3612. http://dx.doi.org/10.1109/WCICA.2006.1713042

Mahnam, M., Yadollahpour, M.R., Famil-Dardashti, V. & Hejazi, S.R. (2008). Supply chain modeling in uncertain environment with bi-objective approach. *Computers & Industrial Engineering,* 56(4): 1535-1544. http://dx.doi.org/10.1016/j.cie.2008.09.038

Mula, J., Campuzano-Bolarin, F., Díaz-Madroñero, M., Carpio, K.M. (2013). A system dynamics model for the supply chain procurement transport problem: Comparing spreadsheets, fuzzy programming and simulation approaches. *International Journal of Production Research*, 51(13): 4087-4104. http://dx.doi.org/10.1080/00207543.2013.774487

Muñoz, M., Rivera, J. & Moneva, J. (2008). Evaluating sustainability in organisations with a fuzzy logic approach. Industrial Management & Data Systems, 108(6): 829-841. http://dx.doi.org/10.1108/02635570810884030

Nunes, I.L., Figueira, S. & Machado, V.H. (2011). Evaluation of a Supply Chain Performance Using a Fuzzy Decision Support System. IEEE *International Conference on Industrial Engineering and Engineering Management (IEEM)*, 6-9 Dec., 2011. Singapore. pp. 1735-1739. http://dx.doi.org/10.1109/IEEM.2011.6118213

Ohdar R. & Kumar P. (2004). Performance measurement and evaluation of suppliers in supply chain: an evolutionary fuzzy-based approach. *Journal of Manufacturing Technology Management*,15(8): 723-734. http://dx.doi.org/10.1108/17410380410565311

Olugu, E.U. & Wong, K.Y. (2012). An expert fuzzy rule-based system for closed-loop supply chain performance assessment in the automotive industry. *Expert Systems with Applications,* 39(1): 375-384. http://dx.doi.org/10.1016/j.eswa.2011.07.026

Ordoobadi S.M. (2009). Development of a supplier selection model using fuzzy logic. *Supply Chain Management: An International Journal*, 14(4): 314-327. http://dx.doi.org/10.1108/13598540910970144

Pilevari, N., SeyedHosseini, S.M. & Jassbi, J. (2008). Fuzzy Logic Supply Chain Agility Assessment Methodology. *IEEE International Conference on Industrial Engineering and Engineering Management*, 8-11 Dec., 2008, Singapore. pp. 1113-1117. http://dx.doi.org/10.1109/IEEM.2008.4738043

Serna, M., Serna, C. & Pérez, G. (2008). Aplicaciones de lógica difusa a las cadenas de suministro. *Revista Avances en Sistemas e Informática*, 5(3), ISNN 1657-7663

Tabrizi, B.H. & Razmi, J., (2013). Introducing a mixed-integer non-linear fuzzy model for risk management in designing supply chain networks. *Journal of Manufacturing Systems,* 32(2): 295-307. http://dx.doi.org/10.1016/j.jmsy.2012.12.001

Theeranuphattana, A. & Tang, J.C.S. (2008). A conceptual model of performance measurement for supply chains, alternative considerations. *Journal of Manufacturing Technology Management,* 19(1): 125-148. http://dx.doi.org/10.1108/17410380810843480

Unahabhokha, C., Platts, K. & Tan, K.H. (2007). Predictive performance measurement system, a fuzzy expert system approach. *Benchmarking: An International Journal,* 14(1): 77-91. http://dx.doi.org/10.1108/14635770710730946

Van Der Vorst, J.G.A.J. & Beulens, A.J.M. (2002). Identifying sources of uncertainty to generate supply chain redesign strategies. *International Journal of Physical Distribution and Logistics Management*, 32(6): 409-430. http://dx.doi.org/10.1108/09600030210437951

Wang, J. & Shu, Y.F. (2009). Fuzzy decision modeling for supply chain management. *Fuzzy Sets and Systems*, 150(1): 107-127. doi:10.1016/j.fss.2004.07.005

Wei, C.C., Liou, T.S. & Lee, K.L. (2008). An ERP performance measurement framework using a fuzzy integral approach. *Journal of Manufacturing Technology Management,* 19(5): 607-626. http://dx.doi.org/10.1108/17410380810877285

Xu, L.X.X., Ma, B. & Lim, R. (2008). Supplier Performance Measurement in a Supply Chain. *6th IEEE International Conference on Industrial Informatics*, 13-16 July, 2008, Daejeon, South Korea. pp. 877-881. http://dx.doi.org/10.1109/INDIN.2008.4618224

