Fuzzy-AHP Approach for Warehouse Performance Measurement

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Abstract - **Warehouse performance evaluation is the measurement of efficient use of warehouse space, customer satisfaction level, quality of goods stored and transport, level of inventory and environmental friendly delivery. Managers and decision makers are keen to know very rapidly which decisions at what level need extra attention and have more impact on overall warehouse performance. In this paper, we propose a Fuzzy-AHP integrated approach that incorporates the linkage between the operational and strategic criteria to generate an overall warehouse performance measurement system. A numerical example illustrates the uses of the proposed model for Warehouse performance evaluation.**

Keywords - **Fonts, formatting, margins**

I. INTRODUCTION

Warehouse management has been defined as the combination of planning, decision-making and controlling inbound flow, storage and outbound flows [1]. In today's competitive environment, warehousing plays a vital role in success and failure of any organization. Warehouses are basically intermediate storage points in the logistics system where raw materials, work in process, finished goods and goods in transit are held for for a variety of purposes. The warehousing functionality today is much more than the traditional function of storage. Moreover, warehouses are most crucial components of most modern supply chains: they are likely to be involved in various stages of sourcing, production and distribution of goods. From handling of raw materials to work in process through to finished products as the dispatch point serving the next customer in the chain, they are critical to the provision of high customer service levels [2].

Warehouse performance measurement system is the evaluation of efficient use of warehouse space, customer satisfaction level, quality of goods stored and transport, level of inventory and environmental friendly delivery, etc. It provides a feedback on the quality of the strategic and operational decisions, and more importantly, on the decisions to take to improve the design and operations of the warehouse.

Due to the complexity of logistics network and the digital transformation, the importance of rapid and prompt warehouse transformation is increased. Due to globalization and ever rising competitions, supply chain is getting complex day by day and ways of warehouse performance measurement are also varies from decision making level to type of warehouse system. Warehouse operations have direct impact on company's performance and increase transportation cost, and reduce customer service level.

Appropriate decision making in modern, complex and uncertain industrial environment has posed a significant challenge to the contemporary managers. The managers are always in search of the right kind of decision support aid to meet that requirement [3]. According to [4], warehouse performance measurement did not get significant attention from academician and practitioners. Moreover, literature related to overall warehouse performance and the relation between short-term on long-term decisions is limited. In one hand, warehouse design decisions and changes (warehouse structure, size and dimension, layout, equipment selection, etc.) have direct impact in the warehouse operations [5]. On the other hand, the relation between design and operational decisions is difficult to identify due to the use of different attributes for performance evaluation which are difficult to estimate in some cases. Finally, every warehouse in an industry segment is different. Therefore, this paper is an attempt to overcome this gap.

In order to take effective decisions, use of experts in various fields is important. In warehouse performance measurement system, decision makers has to deal with conflicting criteria such as cost and customer service and to reduce cost associated with each operation of warehouse. There are many tools and techniques available in literature which can be used to minimize human inconsistency. Fuzzy group decision making and Analytical hierarchal process (AHP) are most widely used tools in many applications [6].

The major problem in measuring overall warehouse performance is as follows:

i) The growing warehouse operation complexity and the easy information access have led companies need to have effective and efficient warehouse performance measurement.

ii) Available literature in measuring overall warehouse performance is limited and we observe that the literature on warehouse subject is limited in aggregated model to measure warehouse performance.

iii) Decision makers needs a system that helps them to measure the effect of decisions that they are taking at long-term decision criteria (strategic and tactical) on short-term level (operational) and overall warehouse performance.

In order to address above mentioned problems, the proposed methodology is based on integrated Fuzzy-AHP. A hybrid approach is useful because Human

978-1-5090-3665-3/16/$31.00 ©2016 IEEE

are often uncertain in assigning the evaluation scores in crisp. Thus, a hybrid approach can capture this difficulty. Moreover, an integrated approach not only mathematically represents uncertainty but also provide formalized tools for dealing with the imprecision intrinsic to performance assessment process. Finally, a Fuzzy-AHP approach for measuring warehouse performance can minimize ambiguity and uncertainties which is inherent in measuring system performance.

Fuzzy set theory was first introduced by [7] in 1965. He was motivated by observing that human reasoning can utilize concepts and knowledge that don't have well-defined boundaries [8], Fuzzy set theory (FST) is a generalization of the ordinary set theory as shown in figure 1.

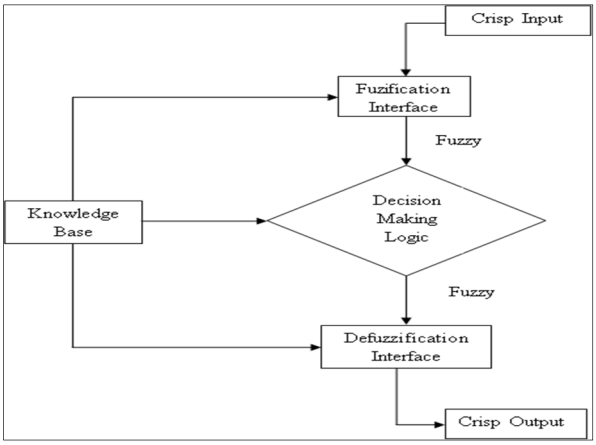

Fig. 1. A framework component comprising a fuzzy decision making system (FDMS) (Adopted from [9])

The AHP, developed at the Wharton School of Business by [10] in 1980, is one of the most powerful and flexible weighted scoring decision making process to help people set priorities and make the best decision. AHP has been widely used to solve multi-criteria decision making in both academic research and in industrial practice. According to [11], AHP has been implemented in almost all applications related to decision-making and is currently predominantly used in the theme of selection and evaluation especially in the area of engineering, personal and social categories.

II. METHODOLOGY

As the main objective of this paper is to develop an integrated warehouse performance measurement system as mentioned in previous section we need a systematic approach that provide decision makers measure the warehouse performance and see the impact of decisions (long-term and short-term) on overall performance. From literature we found that long-term decisions are size of warehouse (associated performance criteria is Storage utilization), Inventory management (associated performance criteria is inventory count accuracy), customer service (associated performance criteria is order fulfillment rate) and capital investment (associated performance criteria is inventory level). Similarly, for Short-term decisions are transportation management (associated performance criteria are damaged inventory, on time delivery and cost / order), inventory management (associated performance criteria is inventory turn ratio) and order management (associated performance criteria is order fill rate, order accuracy,).

We propose an approach for Warehouse performance measurement composed of different steps as shown in figure 2.

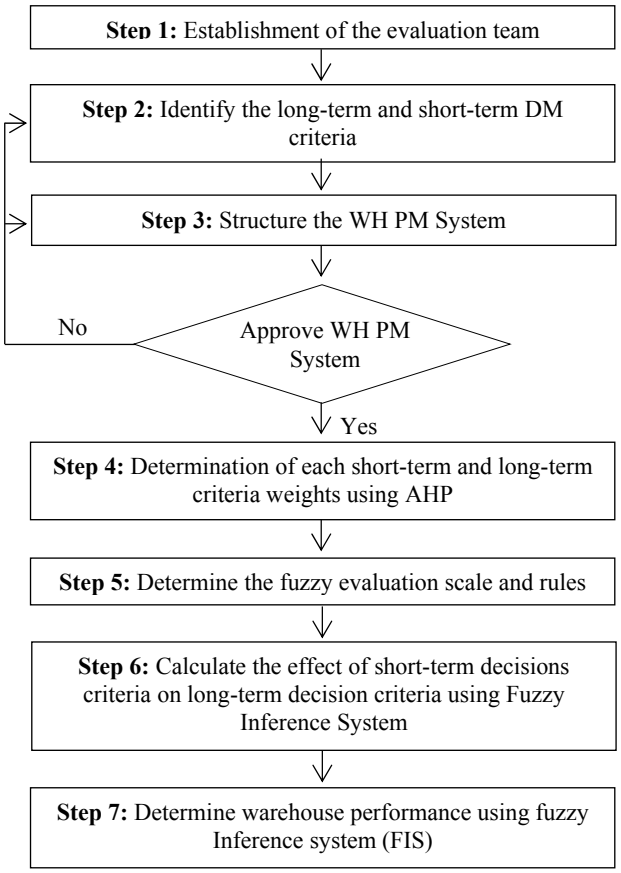

Fig.2. Methodology of proposed framework

Step 1: Establishment of the evaluation team
In the first step, a team of experts is formed with main stakeholders involved in warehousing operations and decision making such as warehouse supervisor, operations manager, logistics manager, supply chain executive, production manager and finance executive.

Step 2: Identify the long-term and short-term DM criteria
In this step, we will identify short-term and long-term criteria based on company's need and expert opinion. There are many key performance indicators are available which can be used as a starting point.

Step 3: Structure the Warehouse Performance Measurement System (WH PM) System
Once the long-term and short-term decision criteria were identified and approved, we will develop a framework that measures overall warehouse performance. At this point it is important to mention that our proposed

methodology is flexible and can be used for other sectors with some sector specific characteristics changes and decision criteria. Structure of the proposed framework will be shown in figure 3.

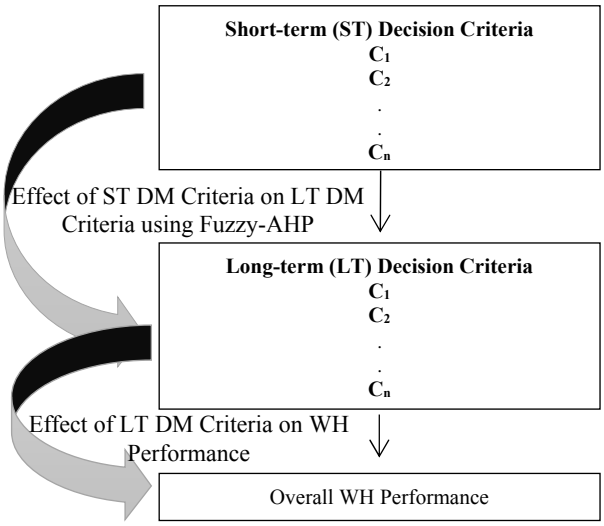

Fig.3. WH PM System Structure

Step 4: Determination of each short-term and long-term criteria weights using AHP
In this step, local weights of identified short-term decisions criteria will be calculated. Pair-wise matrices will be formed and expert's (evaluation team) will be asked to perform pair-wise comparison using Saaty scale.

Step 5: Determine the fuzzy evaluation scale and rules
Expert's (evaluation team) developed fuzzy knowledge-base (if- then rules) and fuzzy membership function scale (Low, Medium, High) based on their experience and logic.

Step 6: Calculate the effect of short-term decisions criteria on long-term decision criteria using Fuzzy Inference System (FIS)
In this step, we will develop fuzzy inference system to run the fuzzy steps mentioned in figure 1. Experts will define if-then rules, range and type of membership function. Figure 4 shows Integrated FIS to measure overall WH performance.

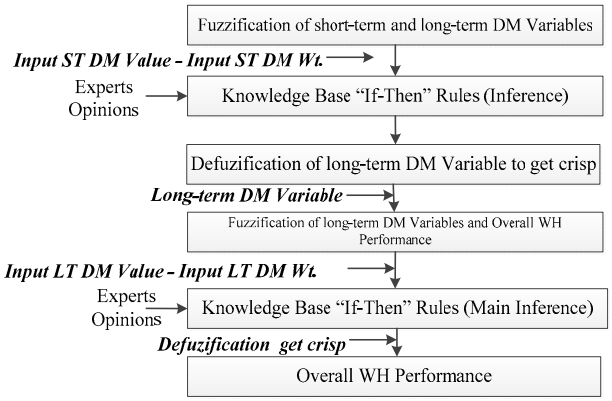

Fig.4. Integrated FIS to Measure Overall WH Performance

Step 7: Determine warehouse performance using FIS
In this step we will measure overall warehouse performance using value of long-term decision criteria that we got in step 6 and importance weight of each long-term criteria from step 4.

III. RESULTS

In order to demonstrate how our proposed methodology in previous section works, we used numerical example from a case company which are expert in injection molding part manufacturer) by following the steps as mentioned in figure 2.

Step 1: Establishment of the evaluation team
In this step team of experts were formed in a case company. All members have experience between 5-10 years in the field of warehouse management and system.

Step 2: Identify the long-term (LT) and short-term (ST) DM criteria
From literature we identified performance measurement criteria to measure overall warehouse performance. Experts were asked to validate those criteria and categorize them as short-term and long-term decision criteria. Table 1 shows the finalized long-term and short-term criteria and its definitions.

TABLE 1
WAREHOUSE PERFORMANCE CRITERIA AND ITS DEFINATIONS

Decisions	Decision Making Level	Decision Performance Criteria	Definition
Transportation Management	Short-term	Cost / Order (C /O)	Cost that required to handle an order
	Short-term	Damaged Inventory (DI)	% of inventory damaged
	Short-term	On time Delivery (OTD)	% of orders delivered on time
Order Management	Short-term	Order Fill Rate (OFR)	% of order fully dispatch
	Short-term	Order Accuracy (OA)	% of order delivered correctly
Inventory Managment	Short-term	Inventory Turnover (ITO)	No. of times inventory replenish
Size of Warehouse	Long-term	Storage Utilization (SU)	% of space fully utilized
Inventory Management	Long-term	Inventory Count Accuracy (ICA)	% of inventory accuracy with system and physical count
Customer Service	Long-term	Order Fulfilment Rate(OFR)	% of order fulfil for a customer
Capital Investment	Long-term	Inventory Level (IL)	% of inventory available in WH

Step 3: Structure the WH PM System
Once we have approved LT and ST criteria, we will develop a WHPM system using FIS. FIS is the process of formulating the mapping from a given input to an output

using fuzzy logic. The mapping then provides a basis from which decision can be made.

Step 4: Determine the importance of each short-term criteria using AHP

In this step, experts were asked to perform pair-wise comparison using Saaty scale. Table 2 shows the weights for ST and LT criteria.

TABLE 2
ST AND LT CRITERIA WEIGHTS USING AHP

PERFORMANCE CRITERIA	WEIGHTS
Cost / Order (C /O)	0.5
Damaged Inventory (DI)	0.1
On time Delivery (OTD)	0.1
Order Fill Rate (OFR)	0.1
Order Accuracy (OA)	0.1
Inventory Turnover (ITO)	0.1
Storage Utilization (SU)	0.1
Inventory Count Accuracy (ICA)	0.3
Order Fulfilment Rate(OFR)	0.3
Inventory Level (IL)	0.3

Step 5: Determine the fuzzy evaluation scale and rules

In this step, experts were asked to develop fuzzy knowledge-base (if- then rules) and fuzzy membership (in this case we used triangular membership function) and scale [Low (L), Medium (M), and High (H)] based on their experience and logic. Table 3 shows the example of If-then rules (knowledge-base).

TABLE 3
RULES EXAMPLE

	Storage Utilization			
		Cost / Order Wt.		
Cost / Order		L	M	H
	L	H	H	M
	M	M	M	M
	H	L	L	L

Step 6: Calculate the effect of short-term decisions criteria on long-term decision criteria using Fuzzy Inference System (FIS)

In order to measure the effect of ST decision criteria on LT decision criteria, we need to develop FIS in Matlab software. We need value (actual value from case company) and weight of ST criteria (set in step 4). FIS system run all the rules developed in step 5 and gives value of long-term criteria based on fuzzy rules (if-then) and scale of membership functions set by expert's(evaluation team) in step 5. Figure 5 shows the effect of ST decision criteria on LT.

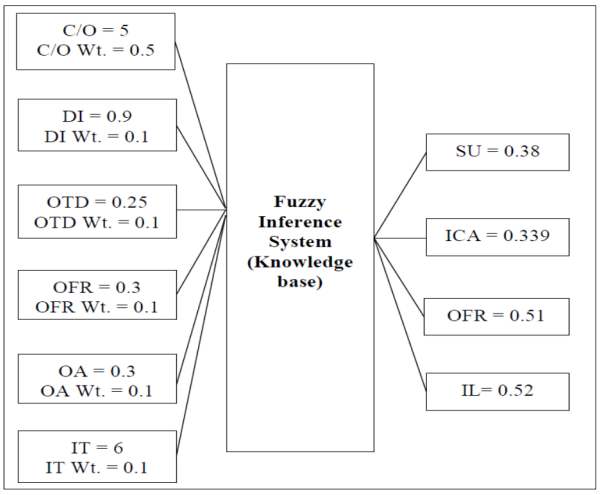

Fig.5. Values of ST DM on LT DM (Matlab)

Step 7: Determine warehouse performance using FIS

To calculate overall warehouse performance, we need value (actual value) and weight of long-term criteria (calculated in step 6 by FIS). FIS system run all the rules developed in step 5 and calculate warehouse performance based on fuzzy rules (if-then) and scale of membership functions set by expert's (evaluation team) in step 5. Figure 6 shows the warehouse performance based on LT decision criteria.

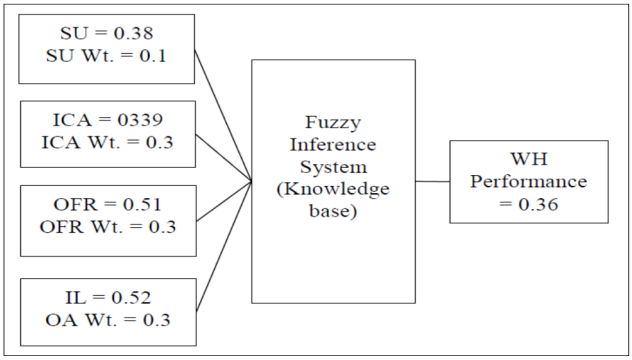

Fig.6: Warehouse Performance

IV. DISCUSSION

Figure 6 shows the overall warehouse performance which is 36%. In order to provide basis to decision makers to see the impact of their ST decision on overall performance, we conducted some scenario that shows how over proposed methodology helps decision makers to see impact of ST decision criteria on LT decision criteria and on overall warehouse performance.

In first scenario, we choose three random values of C/O and experts adjusted the other parameter (DI, OTD, OFR, and OA) on linguistic scale (Low, Medium and High). It can be seen from the graph (figure 7, figure 8, and figure 9) that C/O has an impact on IL and it decreases (from 0.519 to 0.423) as C/O increases (from 5 to 75). Similarly, WH performance is increases (from 36.5% to 43.9 %) as C/O increases from 5 to 75). We

gave maximum importance to the C / O which is 0.50 at short-term DM.

Fig.7: Effect of C / O on IL

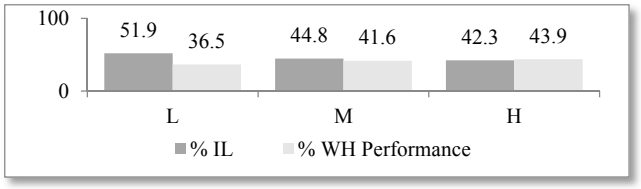

Fig.8: Effect of IL on WH Performance

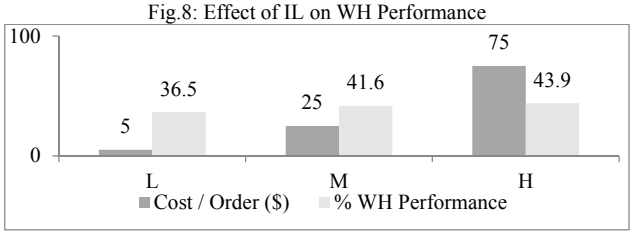

Fig.9: Effect of C / O on WH Performance

In second scenario, we choose three random values of IT and experts adjusted the other parameter (DI, OTD, OFR, and OA) on linguistic scale (Low, Medium and High). It can be seen from the graph (figure 10, figure 11, and figure 12) that IT has an impact on IL and it decreases (from 50.03 to 37.90) as IT increases (from 6 to 15). Similarly, WH performance is increases (from 36% to 46.8 %) as IT increases from 6 to 15). We gave maximum importance to the C / O which is 0.50 at short-term DM.

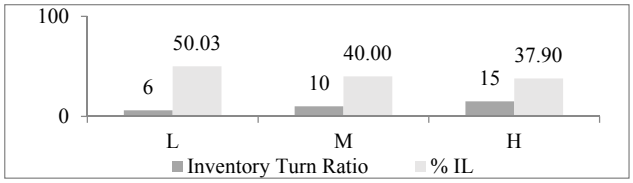

Fig.10: Effect of IT on IL

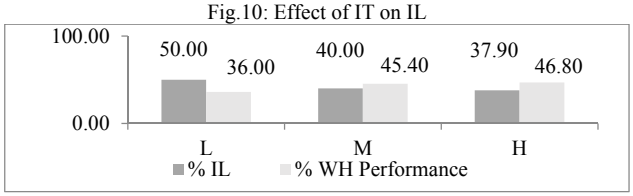

Fig.11: Effect of IL on WH Performance

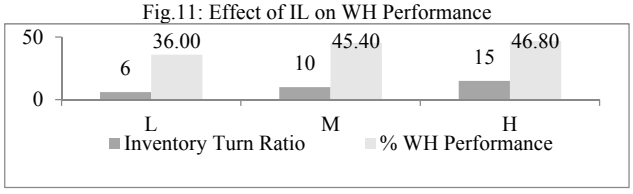

Fig.12: Effect of IT on WH Performance

V. CONCLUSION

This paper used fuzzy inference system to develop integrated warehouse performance measurement system that establishes a direct relation between strategic and operational attributes. The main contribution of this paper is that the proposed approach allows decision makers and managers to know the impact of their long term decisions on short term decision and the overall warehouse performance. Moreover, it also helps managers and decision makers in developing the right strategy by simulating different scenarios. Our proposed methodology is mainly based on experts who have to develop knowledge-base and perform pairwise comparison for short term and long term decision criteria weights. Since every warehouse is different, therefore, for each industry segment, we need to validate the criteria as well as knowledge-base and pair-wise comparison.

ACKNOWLEDGMENT

The authors would like to thanks anonyms referees for their constructive comments and case company experts.

REFERENCES

[1] N. Faber and K.A. Smidts, "Organizing warehouse management", International Journal of Operations & Production Management, Vol. 33, No. 9 pp. 1230 – 1256, 2013.

[2] S.A. Khan and S. A. Zaidi, “Warehouse Location Decision in Pakistan: A Real Case Study”, *International Journal of Supply Chain Management*, Vol. 2, No.2, pp.70-83, 2013.

[3] B. Dey, B. Bairagi, B. Sarkar, and S. Sanya,“Multi objective performance analysis: A novel multi-criteria decision making approach for a supply chain”, *Computers & Industrial Engineering*,” Vol. 94, No. , pp. 105–124, 2016.

[4] A. Johnson and L. McGinnis, “Performance measurement in the warehousing industry”,. *IIE Transactions*, Texas A&M University Libraries. Vol. 43, pp 220-230, 2010.

[5] G.Jinxiang, M. Geotschalckx, and L.McGinnis, “Research on warehouse design and performance evaluation: A comprehensive review”, European Journal of Operational Research, Vol.203, No. 3, pp.539-549, 2010.

[6] T. Özcan, N. Çelebi, and S. Esnaf, “Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem”, *Expert Systems with Applications*, Vol. 38, No.8, pp. 9773–9779, 2011.

[7] L.A. Zadeh, “Fuzzy sets”, *Information Control*, Vol. 8, No.3, pp.338–353, 1965.

[8] J. Yen and R. Langari, “Fuzzy Logic Intelligence, Control, and Information”, Prentice Hall Publishing Company, 1999.

[9] F. Dweiri and M. Kablan, “Using fuzzy decision making for the evaluation of the project management internal efficiency”, *Decision Support Systems*, Vol. 42 , pp. 712–726, 2006.

[10] F. Dweiri, “Fuzzy development of crisp activity relationship charts for facilities layout”, *Computers and Industrial Engineering*, Vol. 36, pp. 1 – 16, 1999.

[11] C. Lee “Fuzzy logic in control systems: fuzzy logic parts I, II”, *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 20, pp. 404,1990.

[12] A. Kandel , Fuzzy Expert Systems, CRC PRESS, Boca Raton, FL,1992.