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Performance measurement of individual manufacturing firm under fuzzy performance index model

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Abstract - *In last decade, each firm has begun to establish the production with rapid rate in compensating the high demand of goods with rich-quality of service level. In order to respond these, many firm perceived the necessity to balance the production chain of organization. In the presented research work, a 2nd second level hierarchical Lean-Resilient supply chain module structure has been constructed, where Fuzzy Performance Index model has been applied to assess the overall performance of crank and shaft vendor firm.*

***Key Words*: Benchmarking, L-R (Leanness-Resilient) Supply Chain, Performance Measurement (PM), Fuzzy Performance Index (FPI).**

1. INTRODUCTION

Supply Chain Management (SCM) is described as the procedure of planning and executing, and at the same time managing the supply chain by the mainly efficient potential way. Supply chain management involves controlling of finished products from the source of origin the consumption level. The conventional supply chain concerned with two or more firms, which were enabled the connection among the consumers and the vendors. In this conventional technique, therefore the finished products are delivered to the purchasers through a chain of warehouses. SC is a system of business that are involved, through upstream and downstream connection, in the dissimilar procedure and actions, which create worth in the term of goods and services in the hands of the final purchasers.

SCM integrate vendors, goods producers, warehouses and stores, in order that goods / services are produced and distributed to the consumers at right quantity, at right site, at right time, at right price by removing the system wide price while fulfilling the service level requirement of customers. Performance measurement is counted as vital constituent of effective forecast and controlling as well as decision making. It provides essential criticisms or information to expose growth, augment in enthusiasm and identify problems. Performance measurement is consider as a part of methods, metrics, courses and systems , used in firms to explain strategies into tactics, observe implementation, and supply insight to get better financial and operations. Supply chain management networking is shown in Fig.1.

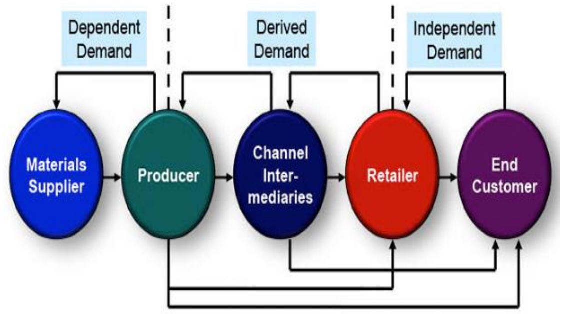

Fig.1. Supply chain management networking

2. FUZZY SET THEORY:

Prof. Zadeh proposed the concept of fuzzy logic in 1965. Fuzzy logic theory is a control tool and technique, which encompasses the data by allowing partial set membership rather than crisp set membership or non-membership.
Fuzzy logic deals with the concept of partial truth, where the truth value may range between completely true and completely false. Fuzzy logic found their application where the valuable information is neither completely true nor completely false, or which are partly true and partly false (Sahu et al., 2015a, b, Sahu et al., 2016c, Sahu et al., 2017b, e).

Fuzzy logic deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets. Fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

3. RESEARCH OBJECTIVES:

After reviewing the content of research gap, It is observed that, many philosophies were introduced in loop of supply chain management in order to solve various problems of industrial sectors i.e. assessment of resiliency of supplier against disasters, waste management equipments availability in evaluated manufacturing firms, green performance, responses of firms towards their clients etc.

Amongst proposed SC philosophies, Lean-Resilient (L-R) strategies of SC worked seminal to solve many problems of firms. Performance measurement is utilized as a tool to quantify overall efficiency cum effectiveness via Lean-Resilient (L-R) assist to reduce the waste and assess the capability of firm against disasters. After literature survey, it is realized that there is need to develop a multi criterion decision making performance appraisement hierarchical module (constituted by mixing the segregated Lean-Resilient L-R 2nd layers of SC measures / drivers and their corresponding interrelated metrics conjunctive with Fuzzy Performance Index model in purpose to estimation the overall performance of individual firm.

4. METHODS:

Considering an L-R, 2nd level appraisement hierarchical module, included criterion at 1st and 2nd level followed below said notations to compute the performances of Choice / Alternative crank manufacturing and shaft manufacturing firms.

C_i = i^{th} 1st level assessment index; $i = 1, 2, \ldots, m.$

C_{ij} = j^{th} 2nd level assessment index which is under i^{th} 1st level assessment index C_i ; $j = 1, 2, \ldots, n.$

The calculated fuzzy rating of individual 1st level assessment criterion-attribute can be computed as (Equa. 7), (Lin et al., 2006, Sahu et al., 2014).

$$U_i = \frac{\sum_{j=1}^{n} \left(w_{ij} \otimes U_{ij} \right)}{\sum_{j=1}^{n} w_{ij}}$$

……………………………………………………………………(1)

Here U_{ij} represents aggregated fuzzy performance (rating) of core derivers and w_{ij} represent aggregated fuzzy importance grade with respect to attributes C_{ij} at 2nd level. Also, U_i represents the calculated fuzzy performance (rating) of core derivers with respect to the index C_i at 1st level. Thus, overall fuzzy performance index $U(FPI)$ can be acquired as follows.

$$U(FPI) = \frac{\sum_{i=1}^{m} \left(w_i \otimes U_i \right)}{\sum_{i=1}^{m} w_i}$$

…………………………………………………………………… (2)

Here U_i = rating of i^{th} 1st level assessment index C_i ; w_i = Importance grade of i^{th} 1st level assessment index C_i .

Defuzzifying the fuzzy performance importance index is done in comparing the performance in case of numerical value (may be set by executives of cross functional departments of manufacturing firm).

Also the single numerical value of the fuzzy number $\tilde{A} = (a_1, a_2, a_3, a_4)$ based on Center of Area (COA) technique can be articulated by following relation:

$$defuzz(\hat{A}) = \frac{\int x \cdot \mu(x)dx}{\int \mu(x)dx}$$

$$= \frac{\int_{a_1}^{a_2} \left(\frac{x - a_1}{a_2 - a_1} \right) \cdot xdx + \int_{a_2}^{a_3} xdx + \int_{a_3}^{a_4} \left(\frac{a_4 - x}{a_4 - a_3} \right) \cdot xdx}{\int_{a_1}^{a_2} \left(\frac{x - a_1}{a_2 - a_1} \right) dx + \int_{a_2}^{a_3} dx + \int_{a_3}^{a_4} \left(\frac{a_4 - x}{a_4 - a_3} \right) dx}$$

$$= \frac{-a_1 a_2 + a_3 a_4 + \frac{1}{3}(a_4 - a_3)^2 - \frac{1}{3}(a_2 - a_1)^2}{-a_1 - a_2 + a_3 + a_4}.$$

……………………………………(3)

5. PROPOSED LEAN-RESILIENT (L-R) SUPPLY CHAIN EVALUATION MODEL: EMPIRICAL CASE RESEARCH:

The practical steps for measuring the performance of a crank and shaft manufacturing firm under Lean-Resilient (L-R) supply chain actions are presented.

Step 1: Construction of a cluster of expert's panel for assessing the overall Lean-Resilient (L-R) performances of supply chain management of crank and shaft manufacturing firm.
Step 2: Evaluation of suitable linguistic scale in terms of appropriateness ratings and importance weight against evaluation criterion.
Step 3: Evaluation of performance ratings as well as weights against criterion associated with module up to 2nd level hierarchy and weight of 1st level hierarchy.
Step4: Transform the linguistic variables into generalized trapezoidal fuzzy number set (GTFNs) and then aggregated the assigned linguistic terms (as rating and weights) converts into single responses.
Step 5: Applied fuzzy performance index model to calculate the ratings of 1st level criterion.
Step 6: Estimation of overall performance of firm under Lean-Resilient (L-R) supply chain.

6. An empirical case research of crank and shaft manufacturing firm:

A case research of crank and shaft manufacturing firm is carried out, where Lean-Resilient (L-R) supply chain based appraisement module is constructed in purpose to measure the performance of an crank and shaft manufacturing firm. In the presented work, a decision support system (consist of multi criterion hierarchical module coupled with fuzzy performance index model) is proposed to calculate the performance of said firm under lean-resilient supply chain management strategies. In proposed module, Lean (L) and Resilient (R) has considered as strategy, while Technology leanness, (C_1), Work force leanness, (C_2), Manufacturing management, (C_3), Collaborative planning, (C_4), Resiliency, (C_5) have counted as 1st level drivers. Apart from that, Systematic process control, ($C_{1,1}$), Use of TQM tools, ($C_{1,2}$), Maintenance of machines, ($C_{1,3}$), Reduction of non-value adding cost via techniques, ($C_{1,4}$), Identification and prioritization of critical machines, ($C_{1,5}$), Products designed for easy manufacturing, ($C_{1,6}$), Flexible workforce for adaptation of new technologies, ($C_{2,1}$), Multi-skilled personnel, ($C_{2,2}$), Strong employee spirit and cooperation, ($C_{2,3}$), Employee empowerment, ($C_{2,4}$), Improvement culture, ($C_{3,1}$), JIT delivery to customers, ($C_{3,2}$), Optimization of processing sequence and flow in shop floor, ($C_{3,3}$), Overall Manufacturing waste reduction, ($C_{3,4}$), Material planning, ($C_{4,1}$), Production planning, ($C_{4,2}$), Supplier planning, ($C_{4,3}$), Distributor inventory planning, ($C_{4,4}$), Effective handling of question and answer, ($C_{5,1}$), Information discovery, ($C_{5,2}$), Decision-coordination, ($C_{5,3}$), Business intelligence, ($C_{5,4}$) have considered as core drivers.

The multi level hierarchical appraisement module, shown in Table 1. An appropriate linguistic scale is elected, shown in Table 2, which facilitated the experts to state their oral opinions in the terms of priority weight (significances) and appropriateness ratings against evaluation criterion. For computing importance and ratings of criterion, available at different hierarchical levels, a committee of six expert's panel, $DM_1, DM_2' DM_3$ DM_4, DM_5 and DM_6 is formed to express priority weight (significances) and appropriateness ratings in terms of linguistic variables against 2nd level indices, shown in Tables 3-4 for crank and shaft manufacturing firm.

Similarly, Expert's panel (E) expressed their importance in linguistic terms against 1st level criterion for alternative, shown in Tables 5. By using trapezoidal fuzzy operators given by (Arbos 2002), (Beamon 1999), the fuzzy importance and ratings against individual 2nd level criterion for alternative is aggregated, depicted in Table. 6. Next same trapezoidal fuzzy operators given by (Arbos 2002), (Beamon 1999), is used to compute importance against individual 1st level criterion as shown in Table 6. Considering a Lean-Resilient (L-R) supply chain activities 2nd level appraisement hierarchical module, included criterion at 1st and 2nd level, followed, Equation 1 is used to compute the rating performances of 1st level and Equation 2 for computing overall FPI, which computed as **(0.508179, 0.639028, 1.085557; 1.356745)** for alternative crank and shaft manufacturing firm. The crisp score has computed as **0.90** by exploring (Equ. 3).

Table: 1 L-R SC performance appraisement module

Goal		1st level driver	2nd level indices /metrics	Sources
Fuzzy-Performance measurement of a firm under L-R	Lean (L) strategy,C1	Technology leanness, (C_1)	Systematic process control, ($C_{1,1}$)	Matawale, 2016
			Use of TQM tools, ($C_{1,2}$)	Matawale, 2016
			Maintenance of machines, ($C_{1,3}$)	Matawale, 2016
			Reduction of non-value adding cost via techniques, ($C_{1,4}$)	Matawale, 2016
			Identification and prioritization of critical machines, ($C_{1,5}$)	Matawale, 2016
			Products designed for easy manufacturing, ($C_{1,6}$)	Matawale, 2016
		Work force leanness, (C_2)	Flexible workforce for adaptation of new technologies, ($C_{2,1}$)	Sahu et al., 2015a,b
			Multi-skilled personnel, ($C_{2,2}$)	Srivastava, 2007
			Strong employee spirit and cooperation, ($C_{2,3}$)	Srivastava, 2007

supply chain, (C)			Employee empowerment, $(C_{2,4})$	Green et al., 1998
		Manufacturing management, (C_3)	Improvement culture, $(C_{3,1})$	Sahu et al., 2016a,b
			JIT delivery to customers, $(C_{3,2})$	Sahu et al., 2016a,b
			Optimization of processing sequence and flow in shop floor, $(C_{3,3})$	Sahu et al., 2017a,c,d
			Overall Manufacturing waste reduction, $(C_{3,4})$	Sahu et al., 2017a,c,d,f,g
	Resilient (R) staregy, C_2	Collaborative planning, (C_4)	Material planning, $(C_{4,1})$	Sahu et al., 2017a,c,d,f,g
			Production planning, $(C_{4,2})$	Green et al., 1998
			Supplier planning, $(C_{4,3})$	Sahu et al., 2017a,b,c,d,e,f,g
			Distributor inventory planning, $(C_{4,4})$	Sahu et al., 2017a,b,c,d,e,f,g
		Resiliency, (C_5)	Effective handling of question and answer, $(C_{5,1})$	Sahu et al., 2017a
			Information discovery, $(C_{5,2})$	Sahu et al., 2017c
			Decision-coordination, $(C_{5,3})$	Kainumaa and Tawara 2006
			Business intelligence, $(C_{5,4})$	Kainumaa and Tawara 2006

Table 2: Nine-member linguistic terms and their corresponding fuzzy representations

Linguistic terms for weights	Linguistic terms for performance ratings	Fuzzy representation
DL: Definitely low	DL: Definitely low	(0.0, 0.0, 0.0, 0.0; 1.0)
VL: Very low	VL: Very low	(0.0, 0.0, 0.02, 0.07; 1.0)
L: Low	L: Low	(0.04, 0.10, 0.18, 0.23; 1.0)
ML: More or less low	ML: More or less low	(0.17, 0.22, 0.36, 0.42; 1.0)
M: Middle	M: Middle	(0.32, 0.41, 0.58, 0.65; 1.0)
MH: More or less high	MH: More or less high	(0.58, 0.63, 0.80, 0.86; 1.0)
H: High	H: High	(0.72, 0.78, 0.92, 0.97; 1.0)
VH: Very high	VH: Very high	(0.93, 0.98, 1.0, 1.0; 1.0)
DH: Definitely high	DH: Definitely high	(1.0, 1.0, 1.0, 1.0; 1.0)

Table 3: Weights of 2nd level indices assigned by DMs

2nd level indices	Weights of 2nd level indices assigned by DMs					
	DM1	DM2	DM3	DM4	DM5	DM6
C_{11}	H	H	VH	H	H	VH
C_{12}	MH	H	H	MH	H	H
C_{13}	H	MH	MH	H	MH	MH
C_{14}	MH	MH	MH	MH	MH	MH
C_{15}	MH	MH	MH	MH	MH	MH
C_{16}	MH	MH	MH	MH	MH	MH
C_{21}	VH	VH	DH	VH	VH	DH
C_{22}	H	VH	DH	H	VH	DH
C_{23}	VH	H	VH	VH	H	VH
C_{24}	DH	H	H	DH	H	H
C_{31}	MH	H	MH	MH	H	MH
C_{32}	H	MH	H	H	MH	H
C_{33}	MH	M	MH	MH	M	MH
C_{34}	MH	M	H	MH	M	H

C_{41}	H	MH	ML	H	MH	ML
C_{42}	MH	M	M	MH	M	M
C_{43}	M	MH	ML	M	MH	ML
C_{44}	MH	MH	L	MH	MH	L
C_{51}	L	ML	L	L	ML	L
C_{52}	VL	ML	ML	VL	ML	ML
C_{53}	ML	L	ML	ML	L	ML
C_{54}	DL	L	L	DL	L	L

Table 4: Rating of 2nd level indices assigned by DMs

2nd level indices	Rating of 2nd level indices assigned by DMs					
	DM1	DM2	DM3	DM4	DM5	DM6
C_{11}	VH	H	MH	VH	H	MH
C_{12}	H	M	MH	H	M	MH
C_{13}	M	H	VH	M	H	VH
C_{14}	VH	VH	VH	VH	VH	VH
C_{15}	VH	VH	VH	VH	VH	VH
C_{16}	VH	VH	VH	VH	VH	VH
C_{21}	H	VH	VH	H	VH	VH
C_{22}	VH	VH	H	VH	VH	H
C_{23}	H	M	NH	H	M	NH
C_{24}	H	M	MH	H	M	MH
C_{31}	VH	H	DH	VH	H	DH
C_{32}	VH	H	DH	VH	H	DH
C_{33}	H	VH	VH	H	VH	VH
C_{34}	DH	VH	VH	DH	VH	VH
C_{41}	VH	VH	H	VH	VH	H
C_{42}	H	H	DH	H	H	DH
C_{43}	VH	M	H	VH	M	H
C_{44}	DH	M	VH	DH	M	VH
C_{51}	H	MH	H	H	MH	H
C_{52}	VH	MH	H	VH	MH	H
C_{53}	MH	H	VH	MH	H	VH
C_{54}	MH	H	DH	MH	H	DH

Table 5: Weights of 1st level drivers assigned by DMs

1st level indices	Weights of 1st level indices assigned by DMs					
	DM1	DM2	DM3	DM4	DM5	DM6
C_1	VH	DH	H	VH	DH	H
C_2	H	H	H	H	H	H
C_3	DH	VH	DH	DH	VH	DH
C_4	MH	H	MH	MH	H	MH
C_5	MH	M	MH	MH	M	MH

Table 6: Aggregated fuzzy importance weights and calculated fuzzy ratings of 1st level drivers

1st level indices	Aggregated fuzzy importance grade, w_i	Computed fuzzy rating, U_i
C_1	[0.638, 0.691, 0.8323, 0.898;1]	[0.518, 0.642, 1.050, 1.250;1]
C_2	[0.720, 0.780, 0.920, 0.970;1]	[0.627, 0.808, 0.923, 1.025;1]

C_3	[0.976, 0.993, 1.000, 1.000;1]	[0.605, 0.748, 1.223, 1.466;1]
C_4	[0.626, 0.680, 0.840, 0.896;1]	[0.467, 0.624, 1.203, 1.554;1]
C_5	[0.493, 0.556, 0.726, 0.790;1]	[0.229, 0.458, 1.531, 2.986;1]

RESULTS:

The result has shown that evaluated fuzzy performance is (0.508179, 0.639028, 1.085557; 1.356745;1) in term of fuzzy scale and 0.90 in crisp value, can be compared with the actual/standard performance of firm.

Performance can be escalated by enchaining the performance of measures.

CONCLUSIONS:

In the presented work, the constructed multi criterion decision making performance appraisement module (constituted by mixing the segregated the Lean-Resilient (L-R) SC strategy and their corresponding five (5) core drivers and twenty two (22) interrelated metrics) conjunctive with Fuzzy Performance Index model called DSS (Decision Support System) has been practical implemented on crank and shaft manufacturing firm to estimation the overall performance of a organization. The evaluated fuzzy performance is (0.508179, 0.639028, 1.085557; 1.356745; 1) in term of fuzzy scale and 0.90 in crisp value, which can be compared with the actual performance of firm. Performance can be hiked by enchaining the performance of criterion.

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