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Evaluation and Selection of Predicaments in Pharmaceutical Supply Chain using AHP under Fuzzy Environment

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Abstract. Pharmaceutical sector plays an important role in the medical and health system. Due to the globalization of the business, increasing demand and supply for drugs, growing regulatory requirements, all stages of the pharmaceutical supply chain (SC) are facing numerous predicaments. The traditional way of selection and evaluation of these predicaments is customarily done using technical information. This approach lacks the ability to project the burning issue that to be addressed first. Hence, a computing method of selecting the crucial issue from the existing issues is essential in a pharmaceutical supply chain. This paper considers seven different predicaments as criteria and five sub-criteria under each main predicament of a pharmaceutical supply chain. The intention of this project is to manifest the process of assessing and selecting the issue that to be addressed first by using multi-criteria decision making technique (MCDM), i.e., fuzzy analytical hierarchy process (FAHP). The criteria and sub-criteria weights are calculated and priority assessment of the predicaments is done by using FAHP. Finally, from the findings of this work, the predicaments are ranked from most important to least important. This gives information to the decision maker (DM) to solve the issue that is affecting the SC the most with respect to the others.

1. Introduction

Pharmaceuticals are the most significant elements of present day scenario. For the Product to reach the customer, the product has to be subjected to many processes such as manufacturing, packing and transporting from the industries. This sequence of processes is known as supply chain (SC). In order to deliver the product in a good quality and in fail safe condition to the customer, one has to check the SC and study the components in detail. In this sequence of processes, the industry faces a lot of predicaments to achieve high productivity.

These pharmaceuticals are the people's life and death matter, so manufacturers are corroborating quality and reliability in each and every part of the SC. If a healthy SC is to be obtained, the factors which are affecting the SC should be taken care with proper guidance. Many authors addressed the pharmaceutical SC's. Mousazadeh et al. [1] developed a bi-objective mixed integer linear programming (BOMILP) for the design of pharmaceutical SC, explaining strategic issues like opening of an industry and the distribution centres. Weraikat et al. [2] investigated the pharmaceutical reverse SC using Lagrangian relaxation method. A bonus sharing technique is also proposed based on each investment. Lemmens et al. [3] reviewed the SC network model to find the relevancy of the network design to the issues pertaining to it. They also addressed the scepticism in the reviewed literature and embraced the variability in lead time and demand. Dua Weraikat [4] explored the role of providing the incentives to customers and to improve sustainability for a real pharmaceutical reverse supply chain (RSC). A technique is proposed to share the RCV's saving among the producer and the 3PL companies. Sometimes the factors which are affecting the SC might be skimmed off when the demand is high. So these problems are to be listed according to the effect they make on the SC. To achieve these requirements, MCDM techniques are taken into consideration. From these set of techniques in MCDM, the AHP method is one. Karanik [5] worked on how to choose best alternative by using Analytic hierarchical process (AHP). A new way is developed to reconstruct the inconsistent matrix. Luthra et al.

[6] investigated the barriers in the SC to implement sustainable consumption and production (SCP) and found 15 hindrances using AHP. Sivakumar et al. [7] adopted AHP technique based on pairwise comparisons and designed a framework to perform sensitivity analysis which is a measure to alleviate subjectivity of the judgments. Before making a common decision the Consensus reaching models are mainly used to make decision making. Dong and Cooper [8] discussed the peer-to-peer dynamic adaptive consensus and within the group, they adopted AHP A Markov chain method to determine the decision makers 'weights of importance with respect to other group members. Dağdeviren et al. [9] proceeded with the AHP and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) for selecting the best and optimal weapon in Defence systems. To resolve the problems that were arising frequently in the present information and to do reduce the bias for the fuzziness in human judgment and preference, the fuzzy set theory is introduced to treat ill-defined MCDM problems. Tavana et al. [10] identified admissible criteria and sub-criteria by using SWOT analysis and then Intuitionistic FAHP is embraced to find the weights for criteria and sub-criteria in Reverse Logistics outsourcing.

Wang and Chin [11] explained the drawback of FAHP process, fuzzy preference programming (FPP) and then proposed a new technique: Logarithmic fuzzy preference programming (LFPP) for FAHP priority derivation. Authors concluded by showing that LFPP methodology will produce unique optimal priority vector for any fuzzy pairwise comparison matrix. Gao et al [12] assessed the tunnel fire risk assessment of subway in hardware facilities by combining the fuzzy consistent matrix and AHP. Kusumawardani and Agintiara [13] investigated the use of the FAHP-TOPSIS method to the difficulty of human resource selection. Russo and Camanho [14] unfolded a systematic review of the literature on the real cases that applied AHP to evaluate how the criteria are being defined and measured. Authors pointed that the three main AHP methodology functions are: structuring complexity, measurement, and synthesis. Kong and Liu [15] evaluated the success on E-Commerce and found the factors of success in E-Commerce by applying FAHP process. Mikhailov and Tsvetinov [16] addressed uncertainty and imprecision in the service process. They applied Analytic Hierarchy Process to prioritize the best alternatives and offers for decision makers. Liu et al. [17] adopted improved fuzzy AHP process to make a decision on the wind power integration schemes. Various MCDM (Multiple Criteria Decision Making) techniques are used in the literature which includes several algorithms such as AHP, Fuzzy AHP, TOPSIS, and Fuzzy TOPSIS etc.

In the above-mentioned techniques, Fuzzy AHP is used in the present study to evaluate the issue that is most affecting the pharmaceutical supply chain.

The remnants of the paper are organized as follows. Evaluation Criteria, Methodology, and Fuzzy AHP process are explained in section 3. Then in section 4 Numerical Illustration is carried out and the results are explained. Finally, section 5 concludes the paper.

2. Constructing the Evaluation Criteria

In this section, we describe the required evaluation criteria used for predicaments selection. The necessary data were determined and Table 1 presents the final set of criteria for the evaluation of the predicaments.

Table 1. The Evaluation Criteria

Notation	Main Criteria	Sub-criteria	Notation
C_1	**Order management**	Accurately promising dates based on fulfillment planning lead times/estimates.	M1
		Responding to changing customer order delivery expectations.	M2
		Managing different rules and order management process for each customer.	M3
		Combating the rising costs related to the fulfillment.	M4
		Number of staff required to manage order entry process	M5
C_2	**Ware house management**	Inaccurate quantities.	M6
		Capacity	M7
		Damage	M8
		Product identification	M9
		Lack of training	M10
C_3	**Shortage avoidance**	Lack of advanced warning systems.	M11
		Supply/demand issues.	M12
		Manufacturing difficulties.	M13
		Shortage of raw materials.	M14
		Business/economic issues.	M15
C_4	**Temperature control**	Monitoring the high-risk products	M16

		Failures of the refrigerators.	M17
		Failures of temperature monitors.	M18
		Transportation with inbuilt coolers and refrigerators.	M19
		wrong calibration of thermometers	M20
C_5	**Shipment**	High cost	M21
		Optimal fleet management	M22
		Risk management	M23
		Leasing of vehicles	M24
		Availability of labor	M25
C_6	**Expiration**	Running of old stocks/high supply than demand.	M26
		Wastage of the products	M27
		Storage conditions.	M28
		Package conditions.	M29
		Transport conditions.	M30
C_7	**Inventory management**	Unqualified managers.	M31
		Forecast management	M32
		Lack of communication.	M33
		Having too many stocks keeping units(SKU)	M34
		Wrong denoting of the stockpiles	M35

3. Methodology

The focus is to evaluate the major issues affecting the SC and to pick the most important issue which is to be addressed first. For doing this, an example has been taken with seven main criteria and five sub-criteria under each and this will be evaluated using AHP method under Fuzzy environment to approach the evaluation. After the criteria are evaluated, the sub-criteria is addressed using the approach as mentioned above. Finally, the main issue governing the SC will be revealed.

3.1 The Fuzzy AHP Methodology

Step1. Construction of fuzzy pair-wise comparison matrix:

The fuzzy judgment matrix A= $\{a_{ij}\}$ of n criteria using pair-wise comparison is made by the use of TFNs as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}$$

Where a_{ij} is a fuzzy triangular number.

Step2.Calculating the value of Fuzzy Synthetic Extent

The value of fuzzy synthetic extent S with respect to the i_{th} criterion is computed based on the aggregated pair-wise comparison matrix, $A = \{a_{ij}\}$, as follows

$$S_i = \sum_{j=1}^{n} a_{ij} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij}]^{-1}$$

Where

$$\sum_{j=1}^{m} a_{ij} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \text{ and } \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} = \left(\sum_{i=1}^{n} l_j, \sum_{i=1}^{n} m_j, \sum_{i=1}^{n} u_j \right)$$

Step3. Approximation of fuzzy priorities

The relative preferences of one criterion when compared to others i.e. the degree of possibility are computed using Chang's method as expressed below on the basis of these fuzzy synthetic values

$$V(S_i \geq S_j) = \begin{cases} 1, & if\ m_i \geq m_j \\ \dfrac{(u_i - l_j)}{(u_i - m_i) + (m_j - l_j)}, & if\ l_j \leq u_i \\ 0, & others \end{cases},$$

where $i, j = 1,........, n; j \neq i$

The relative preferences for a TFN S_i to be higher than the number of n TFNs can be expressed as $V(S_i \geq S_1, S_2, S_3,.....S_k) = \min\,(S_i \geq S_{1,} S_i \geq S_2,....,S_i \geq S_k) = w(S_i)$ where $k \neq i$ .Each value of w (S_i) represents the relative preference of one criterion over others or weight which is a non-fuzzy number.

Step4. Determination of Normalized Weights

The normalized weights W(S_i) will be formed in terms of a weights vector as follows:

$$W = (w(S_1), w(S_2), ...\ w(S_n))^T$$

Step5. Establish final global weights

4. Numerical Illustration

In the following section, fuzzy AHP method is proposed for selecting the burning predicament of the pharmaceutical supply chain that to be addressed first. A pair-wise comparison matrix is built by three decision makers using fuzzy linguistic variables shown in Table 2.

The synthetic fuzzy extent value for main criteria is calculated as

S1= (7.03, 9.93, 17) ⊗ (49.754, 64.6740, 95.6480)
= (0.0735, 0.1535, 0.3417)

S2= (9.2, 11.486, 15.38) ⊗ (49.754,64.6740,95.6480)
= (0.0962, 0.1776, 0.3091)

S3 = (7.65, 10.3, 16.6) ⊗ (49.754, 64.6740, 95.6480)
= (0.08, 0.1593, 0.3336)

S4= (9.288, 11.278, 14.668) ⊗ (49.754, 64.6740, 95.6480)
= (0.0971, 0.1744, 0.2948)

S5= (2.6, 3.2, 3.8) ⊗ (49.754,64.6740,95.6480)
= (0.0272, 0.0495, 0.0764)

S6= (5.63, 7.8, 13.3) ⊗ (49.754, 64.6740, 95.6480)
= (0.0589, 0.1206, 0.2673)

S7= (8.356, 10.68, 14.9) ⊗ (49.754, 64.6740, 95.6480)
= (0.0874, 0.1651, 0.2995)

Table 2. Linguistic Variables

Linguistic scale of importance	Triangular Fuzzy Numbers
Equal	(0,0,0)
Extremely low advantage	(0,0.1,0.2)
Very low advantage	(0.1,0.2,0.3)
Medium low advantage	(0.3,0.4,0.5)
Medium advantage	(0.4,0.5,0.6)
Medium high advantage	(0.5,0.6,0.7)
High advantage	(0.6,0.7,0.8)
Very high advantage	(0.7,0.8,0.9)
Extremely high advantage	(0.8,0.9,1)

Table 3. The Fuzzy Evaluation Matrix for Main Criteria

Criteria no.	1	2	3	4	5	6	7
1	(0,0,0)	(0.3,0.4,0.5)	(0.1,0.2,0.3)	(0.6,0.7,0.8)	(2.5,3.33,5)	(3.33,5,10)	(0.2,0.3,0.4)
2	(2,2.5,3.33)	(0,0,0)	(2,2.5,3.33)	(0.2,0.3,0.4)	(1.25,1.428,1.66)	(1.25,1.428,1.66)	(2.5,3.33,5)
3	(3.33,5,10)	(0.3,0.4,0.5)	(0,0,0)	(0.5,0.6,0.7)	(1.66,2,2.5)	(1.66,2,2.5)	(0.2,0.3,0.4)
4	(1.25,1.428,1.66)	(2.5,3.33,5)	(1.428,1.66,2)	(0,0,0)	(1,1.11,1.25)	(1.11,1.25,1.428)	(2,2.5,3.33)
5	(0.2,0.3,0.4)	(0.6,0.7,0.8)	(0.4,0.5,0.6)	(0.8,0.9,1)	(0,0,0)	(0.1,0.2,0.3)	(0.5,0.6,0.7)
6	(0.1,0.2,0.3)	(0.6,0.7,0.8)	(0.4,0.5,0.6)	(0.7,0.8,0.9)	(3.33,5,10)	(0,0,0)	(0.5,0.6,0.7)
7	(2.5,3.33,5)	(0.2,0.3,0.4)	(2.5,3.33,5)	(0.3,0.4,0.5)	(1.428,1.66,2)	(1.428,1.66,2)	(0,0,0)

Table 4: The Sub Criteria fuzzy evaluation matrix with respect to C_1

Criteria	M1	M2	M3	M4	M5	Row total	Normalised Weights
M1	(0,0,0)	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.6,0.7,0.8)	(0.8,0.9,1)	(2.2,2.6,3)	0
M2	(2,2.5,3.33)	(0,0,0)	(0.4,0.5,0.6)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(3.7,4.5,5.67)	0.169298
M3	(1.42,1.66,2)	(1.66,2,2.5)	(0,0,0)	(0.4,0.5,0.6)	(0.5,0.6,0.7)	(3.98,4.76,5.8)	0.184426
M4	(1.25,1.42,1.66)	(1.25,1.42,1.66)	(1.66,2,2.5)	(0,0,0)	(0.2,0.3,0.4)	(4.36,5.14,9.67)	0.280859
M5	(1,1.11,1.25)	(1.11,1.25,1.42)	(1.42,1.66,2)	(2.5,3.33,5)	(0,0,0)	(6.03,7.35,9.67)	0.365417

These values are compared as per the above mentioned methodology and the V values are obtained:
$V(SC_1 \geq SC_2)= 0.8337$ $V(SC_1 \geq SC_3)= 0.9619$
$V(SC_1 \geq SC_4)= 0.8512$ $V(SC_1 \geq SC_5)=1$
$V(SC_1 \geq SC_6)=1$ $V(SC_1 \geq SC_7)= 0.9202$

$V(SC_2 \geq SC_1)=1$ $V(SC_2 \geq SC_3)= 1$
$V(SC_2 \geq SC_4)=1$ $V(SC_2 \geq SC_5)=1$
$V(SC_2 \geq SC_6)=1$ $V(SC_2 \geq SC_7)=1$

$V(SC_3 \geq SC_1)=1$ $V(SC_3 \geq SC_2)= 0.8619$
$V(SC_3 \geq SC_4)= 0.882$ $V(SC_3 \geq SC_5)=1$
$V(SC_3 \geq SC_6)=1$ $V(SC_3 \geq SC_7)= 0.9559$

$V(SC_4 \geq SC_1)=1$ $V(SC_4 \geq SC_2)= 0.9634$
$V(SC_4 \geq SC_3)=1$ $V(SC_4 \geq SC_5)=1$
$V(SC_4 \geq SC_6)=1$ $V(SC_4 \geq SC_7)=1$

$V(SC_5 \geq SC_1)=1$ $V(SC_5 \geq SC_2)=1$
$V(SC_5 \geq SC_3)= 0.425$ $V(SC_5 \geq SC_4)= 0.225$
$V(SC_5 \geq SC_6)= 0.1256$ $V(SC_5 \geq SC_7)= 0.196$

$V(SC_6 \geq SC_1)= 0.7464$ $V(SC_6 \geq SC_2)= 0.5266$
$V(SC_6 \geq SC_3)= 0.6933$ $V(SC_6 \geq SC_4)= 0.5356$
$V(SC_6 \geq SC_5)= 1$ $V(SC_6 \geq SC_7)= 0.6319$

$V(SC_7 \geq SC_1)=1$ $V(SC_7 \geq SC_2)= 0.8761$
$V(SC_7 \geq SC_3)=1$ $V(SC_7 \geq SC_4)= 0.9037$
$V(SC_7 \geq SC_5)=1$ $V(SC_7 \geq SC_6)=1$

Then priority weights are calculated as per the methodology
$d'(C_1)$ =min (0.8337,0.9619,0.8512,1,1,0.9202) = 0.8337
$d'(C_2)$ =min (1,1,1,1,1,1) = 1
$d'(C_3)$ =min (1,0.8619,0.882,1,1,0.9559) = 0.8619
$d'(C_4)$ =min (1,0.9634,1,1,1,1) = 0.9634
d'(C5) =min (1,1,0.425,0.225,0.1256,0.196) = 0.1256
$d'(C_6)$ = min (0.7464,0.5266,0.6933,0.5356,1,0.6319) = 0.5266
$d'(C_7)$ = min (1,0.8761,1,0.9037,1,1) = 0.8761
Priority weights form W'= (0.8337, 1, 0.8619, 0.9634, 0.1256, 0.5266, 0.8761)
These weights are to be normalized and the new weights are projected as

W’ = (0.160719, 0.192779, 0.166156, 0.185723, 0.024213, 0.101517, 0.168893)

After the calculation of the priority weights of the main criteria, we go for the calculation of the priority weights of the sub criteria or alternatives w.r.t each main criteria are determined.After the evaluation of main criteria we go for the sub-criteria with same methodology:Considering order management first, the evaluation of the sub-criteria is shown below. The normalized weights are calculated using fuzzy AHP. Normalized Weights for all the sub-criteria with respect to their corresponding main criteria is tabulated in Table 5.

Table 5. Normalized weights of sub-criteria

Under C_1	Under C_2	Under C_3	Under C_4	Under C_5	Under C_6	Under C_7
0	0	0	0.008467	0.008723	0.012159	0
0.169298	0.255825	0.274003	0.28828	0.078	0.16426	0.070715
0.184426	0.25494	0.269865	0.342783	0.3225	0.256991	0.233963
0.280859	0.260356	0.193144	0.15744	0	0.270039	0.311208
0.365417	0.228879	0.262988	0.20303	0.5869	0.296551	0.384113

Now from all these normalized weights we calculate the overall global weights.

Table 6. Overall Global Weights

Weights of main criteria	Sub-criteria weights						Overall weights
0.160719	w.r.t C1	0	0.169298	0.1844	0.2808	0.365417	0.160705
0.192779	w.r.t C2	0	0.255825	0.25494	0.2603	0.228879	0.192768
0.166156	w.r.t C3	0	0.274003	0.269865	0.193144	0.262988	0.166156
0.185723	w.r.t C4	0.0084	0.28828	0.342783	0.15744	0.203	0.185705
0.024213	w.r.t C5	0.008723	0.078	0.3225	0	0.5869	0.04119
0.101517	w.r.t C6	0.012159	0.16426	0.256991	0.270039	0.296551	0.101517
0.168893	w.r.t C7	0	0.070715	0.233963	0.311208	0.384113	0.168893
						Total	1.000000

From Table 6. From the overall weights calculated, the sequence of the criteria that we can inference is
C2 > C4 > C7 > C3 > C1 > C6 > C5.

In this manner, the quality engineer can approach the issues of the pharmaceutical supply chain according to the above-obtained order.

5. Conclusion

In this paper, the evaluation and selection of predicaments that are majorly affecting the SC of pharmaceutical industries are elevated. The fuzzy AHP methodology is implemented in order to know the order in which the issues affecting the pharmaceutical supply chain are to be addressed. This approach projects the burning issue that to be addressed first. Then the numerical illustration of seven main criteria and five sub-criteria under each main criteria is taken into consideration and the methodology is applied to it. From the above illustration, it is clear that the main governing issue for SC’s in pharmaceutical industries is WAREHOUSE MANAGEMENT. Here in Fuzzy AHP the usage of criterion weights and the sub-criteria weights makes the problem more accurate and reliable. This helps the decision maker (DM) to find and correct the issue that affects the SC the most than the rest. By approaching the Ware House Management predicament first the entire SC can be more profitable than addressing other issues first.

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