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Pharmaceutical Supply Chain risk assessment in the time of COVID 19/ Case Study

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Abstract As of March 11, 2020 the world Health Organization (WHO) declared Corona virus disease 2019 (COVID-19) as a pandemic. The disastrous outbreak of Covid-19 is described as humanity's worst crisis since World War II. Effectively, not only has it caused severe disruptions around the world at different levels –social, economic, political-but it has also acutely disrupted supply chains worldwide. Pharmaceutical supply chain is a significant component of the health system as to supplying medicines. Today, pharmaceutical companies face a tremendous array of risks. The purpose of this research is to assess different risks in Tunisian pharmaceutical supply chain during this challenging period due to COVID-19 pandemic by providing quantified empirical results. Based on the review of literature, some major risks affecting the pharmaceutical supply chain are identified as regulatory risk, inventory risk, counterfeit risk and financial risk. The fuzzy AHP method is used, in this work, in order to identify the most important risk. It has to be noted that the top risk identified in pharmaceutical supply chain is that related to the Supply and suppliers.

Keywords: Supply chain risk assessment, fuzzy AHP, COVID-19

1 Introduction

Supply chain has become an essential part of global business and economy in this rapidly changing world in terms of innovation and globalization (Kamalahmadi and Parrast, 2016). In fact, supply chain is represented as a complex network. It includes procurement, internal operations, inventory, marketing etc. (Cooper, 1999).

The risks in supply chains are mainly caused by operational fluctuations such as demand uncertainties, and price variability (Juttner, 2005), natural events such as earthquakes, epidemics and manmade crises such as terrorist attacks and economic recessions (Kleindorfer and Saad, 2005). Thereby, in the Supply Chain, risks can be found during a product delivery or service to a customer in terms of cost, timely delivery and impact on image.

Since 1950s, the number and impact of both human and natural catastrophes have been increasing (Boonmee, 2017). Among the different types of disasters, epidemic disease outbreaks can pose tremendous treats for human beings (Büyüktaktın, 2018), and it may, if ineffectively controlled, further become a pandemic and lead to a global crisis. Accordance to the World Health Organization (WHO), an epidemic outbreak is “the occurrence of disease cases in excess of normal expectancy”, which is usually caused by an infectious disease through human-to-human transmission and animal-to-human transmission or by the exposure to radioactive and hazardous chemical sources (Hao Yu et al, 2020).

The COVID-19 pandemic is impacting global health product supply chains, chiefly key materials and ingredients, finished health products, logistics and shipping. The Global Fund is constantly and closely working with suppliers and partners to assess the impact on core health product supplies and provide recommendations for implementing partners on how to manage the impact.

Furthermore, the pharmaceutical supply chain is a major component of the health system it includes all procedures, information, resources and players like suppliers, manufacturers, intermediaries, logistics activities, third-party service providers, merchandising and sales activities, finance and information technology (Jaberidoost et al, 2013).

The aim of this study was to analyze the overall impact of COVID-19 on pharmaceutical supply chain risks.

This paper is organized as follows: the first section sheds light on supply chain risk management. The second Section represents risk definitions. The next two sections (section 3+4) examine the pharmaceutical supply chain, focusing on coordination and decision making issues under business risks and also considering SCRM implementation issues for specific sectors as well as the application. Section 5 includes the closing remarks, identifies gaps in the research and proposes future research directions.

2 Supply chain risk management

Supply chain, apart from being subject to different types of risks -organizational, operational, strategic, commercial or external, is also confronted with real threats relating to cost precariousness, materials scarcity, supplier financial problems and failures, and man-made or natural accidents.

The topic of risk is not novel in management, yet it is a newest area extending in the field of supply chain management. Supply chain risk management (SCRM) consists in taking necessary measures to determine measure and attenuate risks of the supply

chain of an organization. The execution of risk management approaches can assist a firm to work more efficiently, decrease expenses and improve service customer. . SCRM can be considered as a significant part of Enterprise Risk Management (ERM) focusing on the execution of strategies operating with daily and occasional risks continuously across the supply chain, in order to decrease sensitivity and guaranty durability in risk event. Indeed, it decreases the vulnerability of the supply chain through a concerted and joint procedure, taking part in the supply chain all decision maker even subcontractors.

3 Pharmaceutical Supply Chain

Due to the difficulty and sensitivity of the pharmaceutical industry, the standard supply chain is very important and complex since this industry is exposed at the same time to rigorous control and good practices. Furthermore, the intricacy of pharmaceutical supply chain framework is aggravated with weighty supervising of controller, manufacturers, and consumers.

Numerous stressors are heightening, in most cases, the pharmaceutical supply chain with ever-changing regulatory requirements and client waiting due to the obvious development of the numerical economy. Theses supply chain obstacles can be surmounted by both analyzing tendencies in the pharmaceutical supply chain that are molding the future of this industry and considering their collective effect on several supply chain processes.

Therefore, the pharmaceutical supply chain is considered as an important element of the health scheme enclosing all the procedures, information, resources and actors such as suppliers, manufacturers, intermediaries, logistics activities, merchandising, finance and technologies information (Shah, 2015).

Thus, the pharmaceutical supply chain delivers drugs in good quantity, in the best quality and to the right person, on the one hand. On the other hand delivery is at the same time, in the right locality and to the right purchasers, at the appropriate time and with weak charge under standard conditions (Jaberidoost et al, 2013). Thus, bad drug distributions affect reputations, profits of organizations and customer fulfillments in that they deliver patient recovery processes and generate negative impact on public fitness.

Actually, the pharmaceutical supply chain may be subject to risks yielding to wasted resources as well as menacing the lives of patients by restraining drugs access (Schneider, 2010). Nowadays, these risks are rising proportionally.

The PSC was defined in previous studies as an “intricate suitable framework” and was employed as a pragmatic study purpose. From this point of view supply chains have a more general tendency to be exploited "like a system", and therefore to gain more interest they should be conceptualized, modeled and managed as such. Especially, the supply chain can be seen as a system including elements and connections of a socio-technical nature.

The vitality of pharmaceutical products as well as their availability and accessibility to companies and governments make the pharmaceutical supply chain very difficult.

The PSC considered as a socio-technical system helps businesses not only in allowing the health status evolution due to drugs affording, but also in integrating additional and different process products and technologies.

Besides the various products types yielded from pharmaceutical supply chains, other specific problems exists like product variety, refund, prices quoted by ministries, sales models, 3PLs (Third Party Logistics), strict regulations, product life cycle rigor prediction, R&D products dispatching for health investigations. Pharmaceutical supply chain can be included in a new type named "life sciences" and "health supply chain (LSHC)", due to previous factors.

The pharmaceutical value chain is made up of many connected components that have been significantly decentralized and optimized to reduce production and distribution costs. The COVID-19 pandemic has further exposed the potential for disruption to the supply chain upon which this model is based.

4 Fuzzy AHP method

4.1 Definition

The Analytic Hierarchy Process (AHP) is a method developed by Saaty (1980) to support the multi-criteria decisions. It is one multi-criteria decision making method, which has been extensively applied to a variety of decision-making situations.

AHP is probably the best-known and the most widely used model in decision making. It is a powerful decision-making methodology in order to determine the priorities among different criteria.

To deal quantitatively with imprecision or uncertainty, fuzzy set theory is primarily concerned with imprecision and vagueness in human thoughts and perceptions (Beskese, Kahraman, & Irani, 2004).

In this research, triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$, are used to represent subjective pair wise comparisons of patient requirements in order to capture the vagueness. A fuzzy number is a special fuzzy set. $F = \{(x, \mu_F(x), x \in \mathbb{R})\}$, where x takes its values on the real line \mathbb{R} , $-\infty \leq x \leq +\infty$ and $\mu_F(x)$ is a continuous mapping from \mathbb{R} to the closed interval $[0, 1]$. A triangular fuzzy number is denoted as $M = (a, b, c)$, where $a \leq b \leq c$, has the triangular-type membership given by equation 1.

$$\mu_{F(x)} = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & x > c \end{cases} \quad (1)$$

One of the most important concepts of fuzzy sets is the concept of an α -cut. For a fuzzy number M and any number $\alpha \in [0, 1]$, the α -cut, M_α , is the crisp set (Klir & Yuan, 1995) $M_\alpha = \{x / M(x) \geq \alpha\}$. The α -cut of a fuzzy number M is the crisp set M_α that contains all the elements of the universal set U whose membership grades in C are greater than or equal to the specified value of α . By defining the interval of confidence at level α , the triangular fuzzy number can be characterized (Cheng, 1996, 1999; Cheng & Mon, 1994; Juang & Lee, 1991; Kaufmann & Gupta, 1991)

4.2 Procedure of fuzzy AHP

The procedure of fuzzy AHP is summarized as follows (Kwong and Bai, 2002):

Step1: Comparing the performance score: Triangular fuzzy numbers ($\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}$) are used to indicate the relative strength of each pair of elements in the same hierarchy.

Step2: Constructing the fuzzy comparison matrix: By using triangular fuzzy numbers, via pair wise comparison, the fuzzy judgment matrix $\tilde{A}(a_{ij})$ is constructed as shown in equation 2:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (2)$$

Where $\tilde{a}_{ij} = \begin{cases} 1 & i = j \\ \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} \text{ or } \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} & i \neq j \end{cases}$

Step3: Solving fuzzy eigenvalues. A fuzzy set eigenvalue λ is defined by equation 3.

$$\tilde{A}\tilde{x} = \tilde{\lambda}\tilde{x} \quad (3)$$

where \tilde{A} is a $n \times n$ fuzzy matrix containing fuzzy numbers \tilde{a}_{ij} and \tilde{x}_i .

To perform fuzzy multiplications and additions using the interval arithmetic and α -cut, equation 1 is equivalent to equation 4.

$$\left[a_{i1}^\alpha x_{i1}^\alpha, a_{iu}^\alpha x_{iu}^\alpha \right] \oplus \dots \oplus \left[a_{in}^\alpha x_{in}^\alpha \right] = \left[\lambda x_{il}^\alpha, \lambda x_{iu}^\alpha \right] \quad (4)$$

Where as in equation 5,

$$\tilde{A} = \left[\tilde{a}_{ij} \right], \tilde{x} = (\tilde{x}_1, \dots, \tilde{x}_n), \tilde{a}_{ij}^\alpha = \left[\tilde{a}_{ijl}^\alpha, \tilde{a}_{iju}^\alpha \right], \tilde{x}_i^\alpha = \left[x_{il}^\alpha, x_{iu}^\alpha \right], \tilde{\lambda}^\alpha = \left[\lambda_l^\alpha, \lambda_u^\alpha \right] \quad (5)$$

for $0 \leq \alpha \leq 1$ and all i, j , where $i=1,2,\dots,n, j=1,2,\dots,n$.

Degree of satisfaction for the judgment matrix \tilde{A} is estimated by the index of optimism μ . The larger value of the index μ indicates the higher degree of optimism. The index μ is a linear convex combination (Lee, 1999) defined as in equation 6:

$$\tilde{a}_{ij}^\alpha = \mu a_{iju}^\alpha + (1 - \mu) a_{ijl}^\alpha \forall \mu \in [0,1] \quad (6)$$

Once α is fixed, the following matrix (equation 7) can be obtained after setting the index of optimism μ in order to estimate the degree of satisfaction.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12}^\alpha & \dots & \tilde{a}_{1n}^\alpha \\ \tilde{a}_{21}^\alpha & 1 & \dots & \tilde{a}_{2n}^\alpha \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1}^\alpha & \tilde{a}_{n2}^\alpha & \dots & 1 \end{bmatrix} \quad (7)$$

The eigenvector is calculated by fixing the μ value and identifying the maximal eigenvalue.

5 An illustrative application

COVID-19 is the bad event that forced many companies, and industries, to transform their global supply chain model. As a matter of fact, Corona-virus pandemic has affected almost all countries and has had a significant impact on the available healthcare facilities and treatment systems. In this way, all risks affecting the pharmaceutical companies could disturb the supply of medicines and affect the health system quality. The purpose of this research is to assess different risks in pharmaceutical supply chain by providing quantified empirical results. Based on the review of literature like in table 1, some major risks affecting the pharmaceutical supply chain are identified as regulatory risk, inventory risk, counterfeit risk and financial risk. Accordingly, we opted for the application of Analytical Hierarchy Process model.

Table1. Pharmaceutical Risks identified

Supply and suppliers risk (C1)	Delivery reliability (CR1)
	Environmental assessment (CR2)
	Technology level (CR3)
	Information systems (CR4)
	Technology development (CR5)

	Flexibility in delivering (CR6)
	Flexible quantities (CR7)
	Flexibility in product variety (CR8)
	Timely delivery (CR9)
	Quality management system (CR 10)
Organization & strategies issues (C2)	Visibility on stock (CR11)
	Organization & process (CR12)
	Time to market (CR13)
	Production cost (CR14)
Financial (C 3)	Tax payable change (CR15)
	Financial risks (CR16)
	Financial Tariff policies changes (CR17)
	Costs related to supply (CR18)
	Interest rate (CR19)
Logistic (C4)	Transportation (CR 20)

An example of results is presented below in order to explain the procedures in this study as in equation 8:

$$c2 = FCM_2 = \begin{matrix} CR_{11} \\ CR_{612} \\ CR_{13} \\ CR_{14} \end{matrix} \begin{bmatrix} 1 & \tilde{1} & \tilde{3} & 1 \\ \tilde{1} & 1 & \tilde{5} & \tilde{1} \\ \tilde{3}^{-1} & \tilde{5}^{-1} & 1 & \tilde{1} \\ \tilde{1}^{-1} & \tilde{1}^{-1} & \tilde{1}^{-1} & 1 \end{bmatrix} \quad (8)$$

The lower limit and upper limit of the fuzzy numbers with respect to the α can be defined as follows, in equations 9 to 13, by applying equation 4.

$$\tilde{1}_\alpha = [1, 3 - 2\alpha] \quad (9)$$

$$\tilde{3}_\alpha = [1 + 2\alpha, 5 - 2\alpha], \quad \tilde{3}_\alpha^{-1} = \left[\frac{1}{5 - 2\alpha}, \frac{1}{1 + 2\alpha} \right] \quad (10)$$

$$\tilde{5}_\alpha = [3 + 2\alpha, 7 - 2\alpha], \quad \tilde{5}_\alpha^{-1} = \left[\frac{1}{7 - 2\alpha}, \frac{1}{3 + 2\alpha} \right] \quad (11)$$

$$\tilde{7}_\alpha = [5 + 2\alpha, 9 - 2\alpha], \quad \tilde{7}_\alpha^{-1} = \left[\frac{1}{9 - 2\alpha}, \frac{1}{5 + 2\alpha} \right] \quad (12)$$

$$\tilde{9}_\alpha = [7 + 2\alpha, 11 - 2\alpha], \quad \tilde{9}_\alpha^{-1} = \left[\frac{1}{11 - 2\alpha}, \frac{1}{7 + 2\alpha} \right] \quad (13)$$

For example, let $\alpha = 0.5$ and $\mu = 0.5$ all the α cuts fuzzy comparison matrices can be obtained as follows in equation 14.

$$c_2 = FCM_2 = \begin{matrix} CR_{11} \\ CR_{12} \\ CR_{13} \\ CR_{14} \end{matrix} \begin{bmatrix} 1 & [1 \ 2] & [2 \ 4] & [1 \ 2] \\ \begin{bmatrix} \frac{1}{2} & 1 \end{bmatrix} & 1 & [4 \ 6] & [1 \ 2] \\ \begin{bmatrix} \frac{1}{4} & \frac{1}{2} \end{bmatrix} & \begin{bmatrix} \frac{1}{6} & \frac{1}{4} \end{bmatrix} & 1 & [1 \ 2] \\ \begin{bmatrix} \frac{1}{2} & 1 \end{bmatrix} & \begin{bmatrix} \frac{1}{2} & 1 \end{bmatrix} & \begin{bmatrix} \frac{1}{2} & 1 \end{bmatrix} & 1 \end{bmatrix} \quad (14)$$

Equation 3 and MATLAB are used to calculate eigen vectors for all comparison matrices.

$FCM_3^{0.5}$ can be obtained as shown below by equation 15 after applying equation 3.

$$C_3 = FCM_3 = \begin{matrix} CR_{15} \\ CR_{16} \\ CR_{17} \\ CR_{18} \\ CR_{19} \end{matrix} \begin{bmatrix} 1 & 0,208 & 0,208 & 0,208 & 0,208 \\ 5 & 1 & 5 & 7 & 0,208 \\ 5 & 0,208 & 1 & 3 & 0,208 \\ 5 & 0,145 & 0,375 & 1 & 0,208 \\ 5 & 5 & 5 & 5 & 1 \end{bmatrix} \quad (15)$$

Let $FCM_3^{0.5} = A$, eigen values of the matrix A can be calculated as follows (equation 16) by solving the characteristic equation of A, $\det(A - \lambda I) = 0$, the largest value of λ_1 is $\lambda_1 = 6,0848$. The corresponding eigenvectors of A can be calculated as follows by substituting the λ_1 into the equation, $AX = \lambda X$

$$X_1 = (0,0672 \ 0,4706 \ 0,1959 \ 0,1287 \ 0,8480) \quad (16)$$

After normalization, the importance weights can be determined as shown below in equation 17.

$$C = [W_{C1} \ W_{C4} \ W_{C3} \ W_{C2}] = [0,360 \ 0,310 \ 0,220 \ 0,110] \quad (17)$$

Following the similar calculation, the importance weights C1 to C4

We notice that the pairwise comparison of the supply chain functions indicated that Supply and suppliers risk is the most important function to be managed with a priority of 0.360. Then we find Logistic (0.310), Financial (0.220), and Organization & strategies issues (0.110).

Nevertheless, before the lockdown caused by Covid-19 pandemic the financial risk has been ranked at the top of the list of risks.

6 Conclusion

Risks exist in all firms. Risk identification in pharmaceutical companies can increase business risk, and help health systems to meet goals of supply chain management. This paper has investigated risk assessment in pharmaceutical industry in Tunisia in

the time of COVID-19 pandemic. Thus, the fuzzy AHP method is used. It has to be noted that the top risk identified in pharmaceutical supply chain is that related to the Supply and suppliers.

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