Decision modeling of risks in pharmaceutical supply chains

Abstract

Purpose - Managing risks is becoming a highly focused activity in the health service sector. In particular, due to the complex nature of processes in the pharmaceutical industry, several risks have been associated to its supply chains. This paper therefore aims at identifying and analyzing the risks occurring in the supply chains of the pharmaceutical industry and proposing a decision model, based on the Analytical Hierarchy Process (AHP) method, for evaluating risks in pharmaceutical supply chains.

Design/methodology/approach – The proposed model was developed based on the Delphi method and AHP techniques. The Delphi method helped to select the relevant risks associated to pharmaceutical supply chains. Sixteen sub-risks within four main risks were identified through an extensive review of the literature and by conducting a further investigation with experts from five pharmaceutical companies in Bangladesh. AHP contributed to the analysis of the risks and determination of their priorities.

Findings – The results of the study indicated that supply related risks such as fluctuation in imports arrival, lack of information sharing, key supplier failure and non-availability of materials should be prioritised over operational, financial and demand related risks.

Originality/value – This work is one of the initial contributions in the literature that focused on identifying and evaluating PSC risks in the context of Bangladesh. This research work can assist practitioners and industrial managers in the pharmaceutical industry in taking proactive action to minimize its supply chain risks. To the end, we performed a sensitivity analysis test, which gives an understanding of the stability of ranking of risks.

Keywords: Supply Chain Management; Pharmaceutical Industry; Analytical Hierarchy Process; Delphi Method; Risks; Bangladesh.

1. Introduction

Risk is represented in terms of uncertain event, which possesses the probability of occurrence of unfavorable outcomes like late delivery, financial burdens, business loss etc. (Holton, 2004; Mangla et al., 2016; Hao et al., 2017). Risk exists in various fields of research like insurance, finance, manufacturing, health care, supply chain management, etc. (Kouvelis et al., 2006; Kleczyk, 2008; Mangla et al, 2015a; Vian et al., 2017). In today's scenario, organizations are becoming more vulnerable in their supply chain due to irregularities of material supply, product demand, skills and equipment requirements (Finch, 2004; Enyinda et al., 2009; Gandhi et al., 2016; Rishabh, 2017). Therefore, managing of risk has become important to tackle such kinds of disturbances from a supply chain context (Christopher and Lee, 2004; Tuncel and Alpan, 2010; Mangla et al., 2016). Managing risk can be a challenging part in pharmaceutical supply chain (PSC) due to its complex and dynamic network structure (Jaberidoost et al., 2013). PSC is responsible for a smooth flow of medicine to reach the customers (Manuj and Mentzer, 2008; Kaufmann et al., 2010; Jaberidoost et al., 2015). Being a significant element of the health scheme, PSC covers various activities like purchasing and procurement of raw materials, manufacturing, 3P (third party) for logistics and distribution, marketing, financing, sales and promotions (Wagner et al., 2011; Vian et al., 2017).

Pharmaceutical industry plays a significant role in providing medicines and saving human life. In this sense, any risk affecting the PSC could affect the efficiency of health system and disrupt the supply of medicines (Hung et al. 2005; Tazin, 2016). To deal with such vulnerabilities, it is important to examine the related risks and to reduce their occurrence to ensure the best practices in the PSC for quality ingredient of drug and flexibility in the business. An adequate understanding of risks can help pharmaceutical industries to minimize costs and liability, avoid waste, and thus, results in enhanced efficiency of the supply chain (Kwak and Dixon, 2008; Rogachev, 2008). Notably, over the past few years, researchers addressed the theme of risk assessment in pharmaceutical sector and the majority of studies conducted by considering a particular supply chain activity, such as outsourcing and off shoring (Enyinda et al., 2009; Mokrini et al. (2016a, b). This work aims to evaluate risks for the PSC by taking a holistic view. In addition, the present study aims to address the following questions:

- What are underlying supply chain risks in the PSC context?
- How the identified risks are modeled to know their priority?

This work is one of the initial contributions in the literature that focused on identifying and evaluating PSC risks in the context of Bangladesh. The first aim of this work is to select the most suitable risks in PSC in Bangladesh. The pharmaceutical industry plays a very important role in Bangladesh economy as the demand of medicine in its local market increased due to improved level of people awareness about health, higher income rate and increased governmental interventions (Ahamed, 2012). The second aim of this study is to evaluate the identified risks for determining their priority. For this purpose, AHP tool is used (Luthra et al., 2017b).

The rest of this article is structured as follows. Section 2 provides a comprehensive literature review. Section 3 illustrates the problem addressed in this research work. The solution methodology is provided in Section 4. Section 5 offers data analysis and results for the study. The sensitivity analysis is conducted in Section 6. Discussions of results and research implications are given in Section 7. Finally, Section 8 concludes the paper and provides limitations and scope for future work as well.

2. Literature review

This section present the literature related to PSC and risks in PSC context. At the end of this section, research gaps are provided.

2.1 Pharmaceutical supply chain

Supply chain involves movement of goods/information/money to satisfy customer requirements and consists of various entities - producers and suppliers, transporters, warehouses, retailers and stakeholders (Dubey and Kumar, 2007) . The pharmaceutical supply chain is somewhat different from the other supply chains of physical goods because of its urgency, importance, storage and transportation safety, regulation etc (Lin and Darling 1999; Bigdeli et al., 2013). PSC covers drug research and development, production, distribution and application through wide verities of healthcare facilities and additional businesses that help effective functioning of these different stages (Hulbert et al., 2008; Adam, 2013; Jaberidoost et al.,2015). Ricci (2007) stated the contribution of initiative of pharmaceutical industries in controlling the distribution function through improved communicating modes, which saves the human life from errors or defects occurred during repackaging or relabeling.

As the pharmaceutical commercial center goes up against overwhelming difficulties with different partners guaranteeing the pharmaceutical items on a reasonable prices, and thus, a strategic planning is important (Holdford, 2005). In addition, the boundary lines between an organization's inner and its outer operations, from the study of Graves *et al.* (2009) are becoming progressively fuzzy. Pharmaceutical products are relevant to human life that's why pharmaceutical supply chain is more important than any other supply chain network. Therefore, it needs proper execution in every branch of supply chain network to give better customer service and quality products. Chopra and Meindl (2014) pointed out that PSC should maintain regulatory compliance for ensuring better product quality. Moreover, this includes strong information sharing facility to facilitate more efficient supply chain network and fulfills the consumer's requirements. PSC network is unique due to the problems of data complexity and challenging supply chain adequacy, which needs careful attention to resolve these issues. Privett and Gonsalvez (2014) highlighted several challenges associated with the global PSC including inventory management, lacking demand information, human resource dependence, and warehouse management. In addition, Pharmaceutical companies have to manage its complex supply chains network due to involvement of many products, markets, processes and intermediaries in the network (Jaberidoost et al., 2013). A brief summary of recent contributions made by different scholars in area of PSC is provided in Table 1.

Table 1: Summarizing the recent contributions in area of PSC

Authors	**Contributions**	**Methodology/Context**
Enyinda et al., (2009)	Proposed a framework for assessing outsourcing risks in global pharmaceutical supply chains	AHP
Jaberidoost et al., (2015)	Developed risk assessment framework of Pharmaceutical supply chain in the context of Iran	AHP
Ouabouch and Amri, (2013)	Assessed logistics supply chain risks in Pharmaceutical Industry	A probability impact matrix based methodology
Aigbogun et al., (2014)	Developed a framework to enhance supply chain resilience in the context of Malaysian pharmaceutical industry	Conceptual model
Elleuch et al., (2014)	Proposed a combined descriptive and application based approach for risks in pharmaceutical	Combined descriptive and

	supply chain	application based approach
Mokrini et al. (2016a)	Proposed a risk assessment approach for outsourcing logistics in pharmaceutical supply chains	ELECTRE TRI
Mokrini et al. (2016b)	Evaluated the outsourcing risks in the pharmaceutical supply chain.	Fuzzy AHP-PROMETHEE
Lücker and Seifert (2017)	Focused on building resilience in pharmaceutical supply chains by considering inventory, capacity and dual sourcing aspects	A mathematical model
Pariazar et al., (2017)	Studied supply chain design issues to trade off and minimize risks in pharmaceutical and food supply chains	A two-stage stochastic programming model

For the pharmaceutical industry, it needs special attention because flow of medical products (i.e., medicine, medical components) are managed through the supply chain network in terms of delivery at right time, right place and to the right customers to meet their significant needs and requirements (Enyinda et al., 2009). A root cause of any inadequacy of PSC network is lack of coordination among supply chain members and stakeholders, which may lower the overall efficiency. Necessary measures should be taken to improve pharmaceutical based products delivery in regions that need it to make the global health challenge easier to take on and to save lives.

2.2 Risks in the context of pharmaceutical supply chain

Access to medicines is a human right, and one of the prime concerns of the healthcare systems. The supply chain connecting pharmaceutical industry is a prime part of the health care systems in distributing drugs to the community. Supply chain risks can waste resources as well as deteriorate PSC performance. Therefore, proper identification and analysis of risk are useful in formulating strategies to minimize the risks in the PSC (Adam, 2013; Hulbert et al., 2008; Jaberidoost et al., 2013). Risk management in the pharmaceutical industry context is getting increased attention. Because medicine products are profoundly controlled items and comes under the legitimacy of public regulatory authorities (Craighead et al., 2007; O'Connor et al. 2016). Moreover, supply of medicines involves higher more uncertainties and vulnerabilities due to economic, social and political instability in developing countries (Enyinda et al., 2009; Jaberidoost et al., 2015).

Managing risks in supply chains can lead to high performances and can reduce supply chain vulnerability and uncertainties through suitable plans and strategies (Breen, 2008; Mangla et al., 2015a). Researchers suggested that for risk management, organizations should follow a formal structure which helps them to identify supply chain risk, quantifying risk and finally reducing risk (Frosdick, 1997; Khan and Burnes, 2007; Mangla et al., 2016)

Based on previous studies, 16 risks in PSC context are selected. These risks were further confirmed through expert's feedback. In addition, the identified risks were divided into four main risks, given as supply related risks, operational related risks, financial related risks, and demand related risks. The simplified meaning of the identified risks along with their sources is provided in Table 2.

Table 2: Listed main and sub risks in PSC along with their sources

Main Risks	**Sub risks**	**References**
Supply related risks (S)	Fluctuation in imports arrival (S1)	Amin (2015), Mokrini et al. (2016a)
	Lack of information sharing (S2)	Jaberidoost et al. (2013),Yousefi (2015)
	Key supplier failure (S3)	Zsidisin et al. (2004), Blackhurst et al. (2008), Wagner et al. (2009)
	Non-availability of materials (S4)	Breen (2008), Mahendran et al. (2011), Ketkar (2012)
Operational related	Machine, equipment or facility failure (O1)	Mahendran et al. (2011), Finch, (2004)
	Quality risk (O2)	Mahendran et al. (2011), O'Connor et al.

risk (O)		(2016)
	Storage contamination risks (O3)	Mahendran et al. (2011), Brettler (2015)
	Power failure (O4)	Finch, (2004).
Financial related risks (F)	Increase in freight charges (F1)	Goff (2012)
	Dynamic foreign exchange rates (F2)	Blome and Schoenherr, (2011), Torabi et al., (2016)
	Bank interest rate fluctuation (F3)	Blackhurst et al., (2008), Blos et al. (2009), Tummala and Schoenherr, (2011)
	Financial restriction (F4)	Mangla et al. (2015a)
Demand related risk (D)	Demand forecasting errors (D1)	Breen (2008), Candan et al. (2014)
	Uncertainty in market (D2)	Enyinda et al. (2009), Mahendran et al. (2011)
	Bullwhip effects (D3)	Metters (1997), Craighead et al. (2007)
	Competitive risks (D4)	Mangla et al., (2015a)

2.3 Research gaps and problem definition for the research

PSCs has become imperative segments of the health system in drug supply, especially in nations where the principle medical products are given by nearby pharmaceutical organizations (Zhang et al., 2008; Rossetti et al., 2011; Uthayakumar and Priyan, 2013). The pharmaceutical industry is also facing tremendous uncertainty and fluctuations in demand, which may challenge its business sustainability in both local and international markets. The pharmaceutical industry are also facing various relevant supply chain issues, like shortage of raw materials, quality problem of the products, short product life cycle, sustainable supplier failure and seasonal demand of products (Craighead et al. 2007; O'Connor et al. 2016; Luthra et al., 2017b). Requirements of high technology is also an important issue being faced by organizations in a PSC context (Mahendran et al., 2011). Any problematic issue or disturbance influencing the pharmaceutical organizations' supply chain structure may not only hamper the supply of medicine products but also affect the efficiency of health system (Jaberidoost et al., 2015). Several works have been performed by different scholars in PSC area in recent years, specifically on understanding of idea, production and distribution system, availability/flow of medicines, and development of policies (Rossetti et al. 2011; Jaberidoost et al. 2013; Uthayakumar and Priyan, 2013; Abdallah, 2013). The present work is an original effort that examines the risks in PSC in the context of Bangladesh. In Bangladesh, the pharmaceutical industry has a major role in its economic growth. Bangladesh exports active pharmaceutical ingredients (APIs) along with a wide variety of pharmaceutical items to several countries, such as Myanmar, Sri Lanka and Kenya (Tazin, 2016). Besides, pharmaceutical companies are experiencing huge competition in

Bangladesh. Above all, pharmaceutical companies are facing supply chain disruptions due to technological revolution, organizational policy change, and uncertain market environment. Although, there is significant advancement in infrastructure, information and communication technology in pharmaceutical sector; yet, the industry is confronting different risks in supply chain (Jaberidoost et al. 2015). Therefore, managing risks in PSC has become a key focus of this industry (Yu et al., 2010). Analyzing risks is becoming a highly focused and increasingly adopted activity among organizations targeting to ensure a smooth and trouble free business (Mangla et al., 2015a). To deal with these research gaps and problem defined, the highlights of the contributions made by this research are given as:

- Identifying the key PSC risks in the context of Bangladesh using literature and expert's inputs under Delphi technique. This will give managers an understanding on the different risks existing in this sector.
- Evaluating the identified risks to know their priority using AHP. This will give an understanding on significant risks in managing the PSCs.

3. Solution methodology

In this research work, the Delphi and AHP techniques have been used as solution methodology. The reasons for combining Delphi and AHP are (Chuang et al., 2013; Kim et al., 2013)-

(i) The combined Delphi - AHP tool is a systematic method of decision making, which offers logical means to list the risks in PSC scenario.

(ii) The combined Delphi - AHP allows knowing the most significant risks in managing the risks in PSC scenario.

The flow chart of this research is presented in Fig. 1. The Delphi and AHP methods are detailed in the subsequent sub-sections.

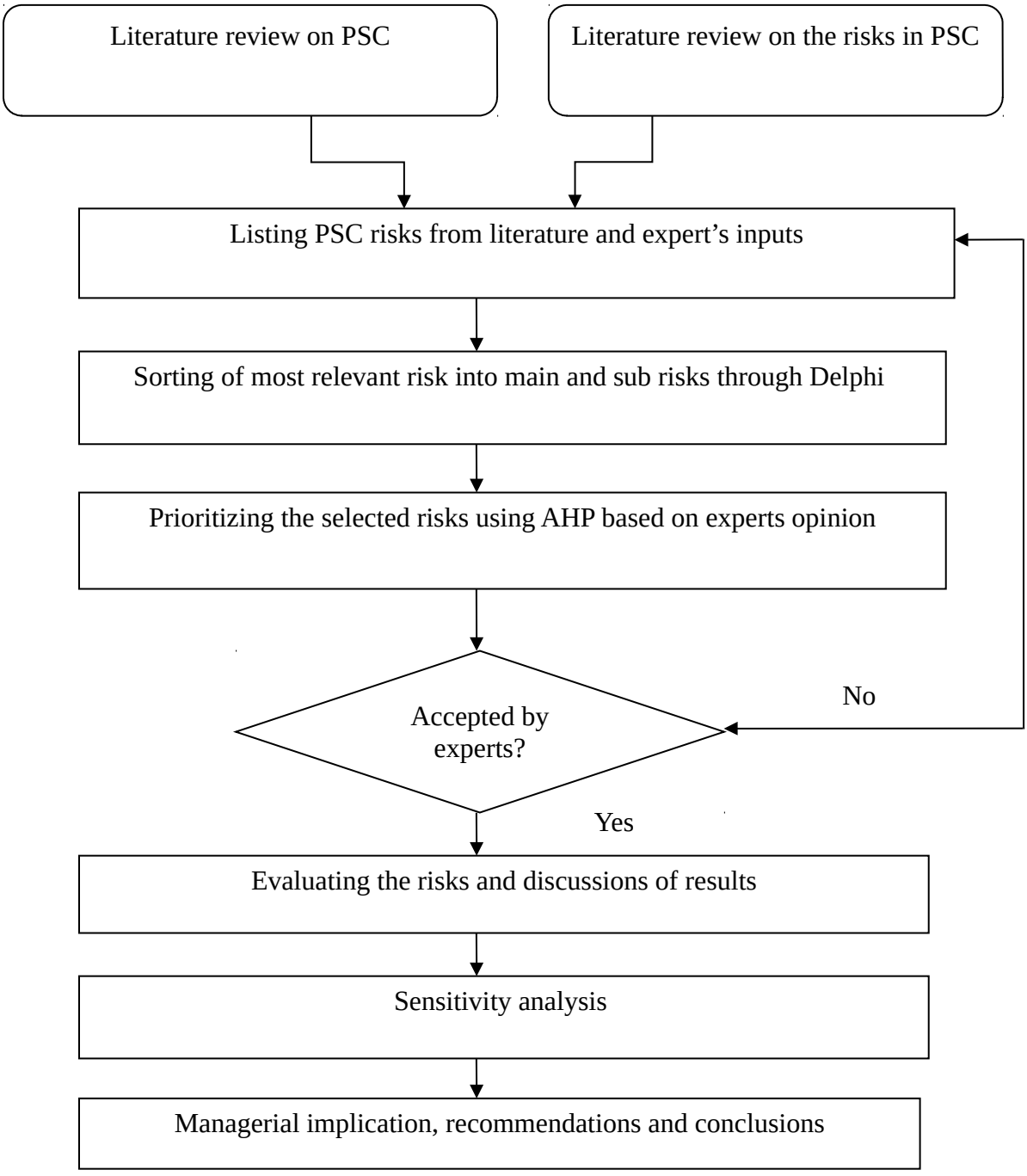
Literature review on PSC
Literature review on the risks in PSC
Listing PSC risks from literature and expert's inputs
Sorting of most relevant risk into main and sub risks through Delphi
Prioritizing the selected risks using AHP based on experts opinion
Accepted by experts?
No
Yes
Evaluating the risks and discussions of results
Sensitivity analysis
Managerial implication, recommendations and conclusions

Figure 1. The flow chart of the present research

3.1 Delphi method

The Delphi research method is a rational research technique in which data is collected from group of experts with the help of multiple sessions/questions (Chuang et al., 2013; Lummus et al., 2005; Jung-Erceg et al. 2007). It is very effective technique to evaluate data in which experts share their opinion, knowledge and experience until they reach to a mutual consent (Markmann et al., 2013; Nowack et al., 2011; Soon et al., 2012; Ilic et al., 2015; Ilic et al., 2017). This technique is one of the popular tools in identifying and evaluating issues related to the multi criteria decision making problems. In this work, Delphi method is used to finalize the most relevant risks in PSC. There is no specific limitation of considering experts to evaluate data. Normally, 10 to 30 experts opinion are suggested to be sufficient to ensure the best result by reaching a consensus among experts (Murry and Hammons, 1995; Okoli and Pawlowski 2004). In this research, we formed a group of 10 industrial and field experts to select PSC risks. Consequently, we utilized AHP technique to evaluate risks with the help of experts input.

3.2 AHP

AHP is a decision analysis tool proposed by Prof. Thomas L. Saaty in 1980 (Saaty, 1980). With the help of AHP, difficult problems are evaluated very easily (Luthra et al., 2015). The complex decision problems are converted into a hierarchical structure consisting of multiple levels, like goal, criteria, sub-criteria (Dey and Cheffi, 2013; Govindan et al., 2014; Madaan and Mangla, 2015a). AHP allows policy makers to have optimal decisions in an organizational context (Saaty, 1990). The input for the AHP can be picked from subjective assessment like review, interview and preference. AHP is used as a better decision making tools compared to ANP, TOPSIS, VIKOR, ELECTRE due to its wide acceptability and applicability, less pair wise comparisons, and simplicity in use (Topçu et al., 2011; Luthra et al., 2017a). However, AHP may

involve some small inconsistency in human judgment (Russo and Camanho, 2015). Hence, AHP has been criticized because it sometimes results in an unbalanced scale of judgment and ranking. In this research, we used AHP to evaluate PSC risks to know their priority. We also summarized the application of AHP in supply chain risk assessment in Table 3.

Table 3: Summary of application of AHP method in supply chain risk assessment

S. No.	Author	Contribution
1	Gaudenzi and Borghesi, (2006)	Overall managing risks in the supply chain
2	Wu et al. (2006)	Inbound supply risk analysis
3	Schoenherr et al., (2008)	Assessing supply chain risks for a US manufacturing company
4	Wang et al., (2010)	The risk research of ecological supply chain
5	Sharma and Bhat, (2012)	Assess the supply chain risk
6	Badea et al., (2014)	Investigating risk in collaborative supply chain
7	Dong and Cooper, (2016)	Supply chain risk assessment framework
8	Prostean et al., (2014)	Risk variables in wind power supply chain
9	Luthra et al., (2017b)	Prioritization and management of risks in sustainable supply chain

The basic steps of AHP (Schoenherr et al., 2008; Luthra et al., 2017a) are explained in below :

I. ***Fix the aim of present study****:* Evaluating the risks to examine their priority ranking in the PSC is fixed as the goal of this study.

II. ***Construct pairwise comparisons matrix:*** Pairwise comparison matrix is constructed with the help of expert's feedback from assigned pharmaceutical companies. The pair wise comparisons matrix (A) among the risk is constructed with the help of a nine-point Saaty's scale (Saaty, 1980)**.** The element a_{ij} of the matrix A is the relative importance of

i^{th} risk factor with respect to j^{th} risk factor. The representation is done like the following: A = [a_{ij}], Each entry in matrix A is positive ($a_{ij} > 0$) (Jaberidoost et al., 2015).

III. ***Calculation of the Eigen values and Eigen vectors and priority weights:*** The formulated pair-wise comparison matrices are then used to calculate the Eigen values and Eigen vector. Next, the priority weights of the listed risks are calculated.

IV. ***Computation of the consistency ratio:*** The consistency ratio (CR) checks the consistency of formulated pair wise comparisons matrices. CR is calculated with the help of following mathematical equation, CR = CI/RI, where, consistency index (CI) can be calculated by CI = $\frac{Maximum\,Eigen\,value - n}{n-1}$. The random consistency index (RI) value depends upon value of (n) as shown in Table 4.The value of CR should be less than 0.10 to have better level of consistency (Madaan and Mangla, 2015).

Table 4: Random consistency index value

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Data analysis and results

Data analysis and results are provided in the subsequent sections.

4.1 Data collection

In this research, data is collected through two phases: Phase 1, identification of most relevant PSC risks with the help of industrial and field experts and Phase 2, prioritizing the identified risks with the help of expert's inputs.

In this work, case companies were selected based on purposive sampling method rather than statistical sampling (Glaser and Strauss, 1967). In the purposive sampling method, the case companies are not selected randomly (Eisenhardt, 1989; Maalouf and Gammelgaard, 2016; Bai et al., 2017). The five pharmaceutical companies operating in Bangladesh were selected due to their immense interest to examine and manage the risks in their supply chain context. Next, ten industrial and field experts were selected from the listed five pharmaceutical companies. The selected experts are highly competent on Pharmaceutical supply chain and supply chain risk management. We collected expert's feedback through several rounds of personal interviews, e-

mail communication and telephonic discussion through questionnaire as provided in Annexure-A. An interview protocol was prepared based on a set of questionnaire with focusing several themes. The profile of experts along with the pharmaceutical company details contacted for data collection in this work is shown in Table 5.

Table 5: Profile of experts along with the pharmaceutical company

Professionals	**Years of experience**	**Name of Company, Products**	**Company size (Employees, Annual sales turnover for FY-2015)**
1. General Manager	18 years	XYZ1 Pharmaceutical, Medicine	Area: 22-acre, Employees-3000, Annual sales turnover- BDT 12,965.51 Million (January-December, 2015)
2. Supply chain executive	16 years		
3. General Manager	20 years	XYZ2 Pharmaceutical, Medicine	Area: 6.89-acre, Employees-3500, Annual sales turnover- BDT 12,965.51 Million
4. Supply chain executive	15 years		
5. General Manager	17 years	XYZ3 Pharmaceutical, Medicine	Number of Products- 738, Employees- 7,174, Annual sales turnover- BDT 41,678.78 Million (2015-2016)
6. Supply chain executive	15 years		
7. General Manager	19 years	XYZ4 Pharmaceutical, Medicine	Area: 8.03-acre, Employees-6000, Total Annual Sales, Volume Above US$100 Million.
8. Supply chain executive	17 years		
9. General Manager	18 years	XYZ5 Pharmaceutical, Medicine	Area: 9.03-acre, Employees-4,334, Annual sales turnover-BDT 12,880.9 Million (During January-December, 2015)
10. Supply chain executive	16 years		

Next step was to collect the data needed for addressing the goals of this work. The two phased data collection is explained as follows:

4.2 Finalizing ***of the most relevant PSC risks using Delphi method***

Total 16 risks falling into four main risks were primarily identified through the literature review. To approve the identified risks, the industrial and field experts were requested for their feedback and asked to include or erase any risk relevant to the existing PSC in the context of Bangladesh. The responses from experts were gathered to finalize the risks. The experts agreed that the four main risks and 16 sub-risks are most relevant for PSC in Bangladesh. The simplified meaning of listed risks is also provided upon discussion with experts as given in Annexure-B.

4.3 Evaluation of the PSC risks by determining their priority using AHP

In this step, the finalized risks were prioritized using AHP with the help of expert's inputs. A hierarchical structural is constructed using expert inputs (Fig. 2).

This hierarchical structural figure comprises of three different levels: evaluating the supply chain risks in pharmaceutical sector (Level-1), four main risks (Level-2) and sixteen sub risks (Level-3).

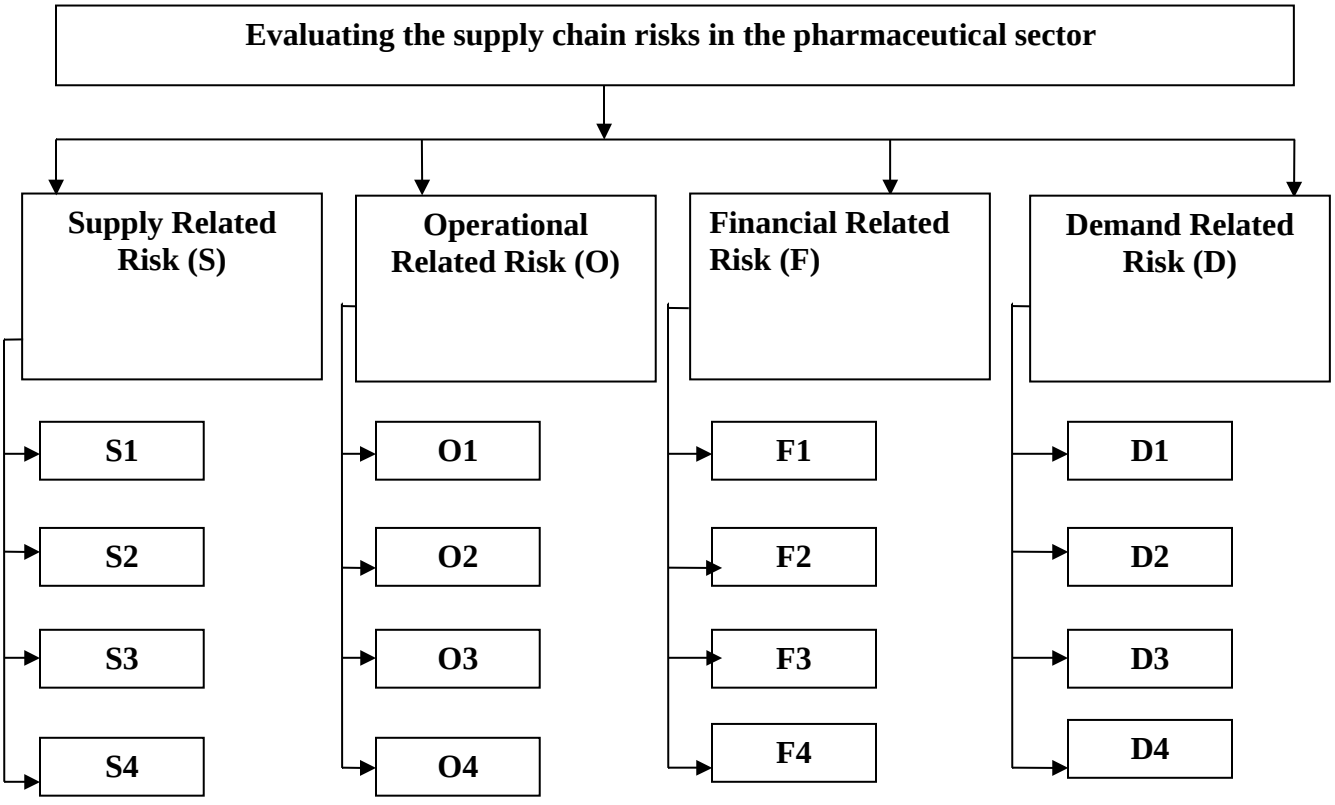

Figure 1. Hierarchical structure of evaluation of PSC risk

The pair wise comparisons relation matrices are formed for both the major risks and the sub-risks using experts' inputs through provided Saaty scale. With the help of experts feedback, at first pair wise comparison relation matrix for the main risks is formulated and then we calculated the priority weights and ranking for each risk (see Table 6).

Table 6: Pair wise comparison relation matrix for main PSC risks

Risks	S	O	F	D	Relative weight	Rank
S	1	1	2	3	0.3618	1
O	1	1	2	2	0.3270	2
F	1/2	1/2	1	1	0.1635	3
D	1/3	1/2	1	1	0.1477	4

Maximum Eigen Value =4.0210; C.I. =0.0070

Likewise, the pair-wise comparison relation matrices for sub-risks under each main risks are formulated and their corresponding priority weights are calculated (for details see Annexure-C).

The pair wise comparison matrices are used to determine the relative importance of weights and global importance of weights and their rank are evaluated in Table 7. Global weights are computed by multiplying relative weights of main risks with relative weights of sub-risks and then global ranking is determined accordingly.

Table 7: Weights and ranking of main risks and sub risks in PSC

Main risks	Relative weights	Sub risks		Relative weights	Relative rank	Global weights	Global rank
Supply related risk (S)	0.3618	S1	Fluctuation in imports arrival	0.4262	1	0.1542	2
		S2	Lack of information sharing	0.1740	3	0.0630	6
		S3	Key supplier failure	0.1463	4	0.0529	8
		S4	Non-availability of materials	0.2534	2	0.0917	4
Operational risk (O)	0.3270	O1	Machine, equipment or facility failure	0.5166	1	0.1689	1
		O2	Quality risk	0.2830	2	0.0925	3
		O3	Storage contamination risks	0.1174	3	0.0384	10
		O4	Power failure	0.0830	4	0.0271	14
Financial risks (F)	0.1635	F1	Increase in freight charges	0.3561	1	0.0582	7
		F2	Fluctuation in the foreign exchange rates	0.2117	3	0.0346	11
		F3	Bank interest rate fluctuation	0.3217	2	0.0526	9
		F4	Financial restriction	0.1105	4	0.0181	15
Demand related risk (D)	0.1477	D1	Demand forecasting errors	0.4883	1	0.0721	5
		D2	Uncertainty in market	0.2142	2	0.0316	12
		D3	Bullwhip effects	0.1040	4	0.0154	16
		D4	Competitive risks	0.1935	3	0.0286	13

Based on Table 7, it is clear that supply related risk obtained the highest priority, which is followed by operational risk, financial risk and demand related risk. In this research work, the sub risk “machine, equipment or facility failure (O1)” has got the top priority in risk assessment. Bullwhip effects under the category of demand related risk gets the last position in evaluation of supply chain risk.

4 Discussions of findings

According to Table 7, the ranking of main risks of PSC is as follows: Supply risks > organizational risks > Financial risks > Demand risks. The global ranking of sub-risks is also established based on their respective global weights (see Table 7). In this research work, supply related risk holds the first priority in ranking and thus indicates that this risk should be addressed with highest priority. Supply related risk can be explained as the risk which occurs during supplying the materials (Amin 2015; Mokrini et al. 2016a; Mangla et al., 2015b). In this main risk, there are four sub-risks which are fluctuation in imports arrival, lack of information sharing, key supplier failure and non-availability of materials. According to findings, fluctuation in imports arrival gets the first rank in their ranking. The delay or fluctuations of imports arrival heavily hamper the supply chain process as the regular flow gets disrupted if the raw materials and other components which are exported from outside the country. Therefore, pharmaceutical companies need to concentrate in this issue. Non-availability of materials risk holds the second position thus indicates non-availability of materials can hamper the regular production rate. So decision maker should give attention to ensure materials for regular production. Lack of information sharing and key supplier failure carry third and fourth position subsequently in their ranking.

Operational related risk comes next to Supply risks. Operational risk occurred due to machine, equipment or facility failure, quality risk, storage contamination risks and power failure. Therefore, top management should give attention to minimize such risks to improve the performance. The highest priority stands for machine, equipment or facility failure. Smooth operations ensure the profitability of pharmaceutical industry. Quality risk gets the second position. Quality is an important issue for pharmaceutical products as it is directly related to human life. Other risks like storage contamination risk, power failure gets the third and fourth position in their priority ranking. These two risks can reduce the supply chain performance so it’s not negligible during supply chain risk management.

Financial related risk obtains third position in priority rank and plays a vital role in adopting proactive action against PSC risk. Decision makers should aware about financial risk and must keep multiple options to recover such risks. In this main risk, there are four risks such as increase in freight charges, fluctuation in the foreign exchange rates, bank interest rate fluctuation, and financial restriction. Increase in freight charges gets the first position. The increase in government taxes can raise the cost of production by adding to the cost of supplier’s raw materials and finished goods. Next, bank interest rate fluctuation gets the second position.

Managers should conscious about this issue because it may affect the supply chain performance as well as hamper the regular business activity of pharmaceutical companies. The risk Dynamic foreign exchange rates hold the third position. Fluctuation in the foreign exchange rates is always unanticipated to predict the conditions. It is indicated as an important risk in pharmaceutical company due to unpredictable exchange rates. It is not predictable that the new business or the new products will be profitable or not (Rao and Holt, 2005; Tang, 2006); thus, manager needs to address this risk effectively. Financial restriction gets the fourth position. Decision makers should give priority to this risk because poor financial plan can hamper the efficiency of supply chain network.

Demand related risk obtains the last rank in the priority ranking. Variations in demand of pharmaceutical products can affect the business. In this, four risks are involved - demand forecasting errors, uncertainty in market, bullwhip effects and competitive risks. Demand forecasting errors take the first place in ranking. Demand forecasting is one of the important issues for any kinds of business. Forecasting errors can aggravate the demand unpredictability. Thus, top management should conscious about this risk. Increase in demand of supplies, bullwhip effects and competitive risks take the second, fourth and third rank in priority ranking. Due to the rapid increase of pharmaceutical companies in the country, the demand for common supplies is getting higher. Therefore, increase in demand of supplies risk is taking importance in priority risk. The bullwhip effect can be clarified as an event identified by the supply chain network where orders sent to the manufacturer and supplier make larger change than the sales to the end customer (Chen et al., 2000; Geary et al., 2006; Hussain and Drake, 2011). Bullwhip effects indicate demand information distortion within the supply chain. It creates difficult for the companies to estimate accurate products demand and results in decrease operational performance. Pharmaceutical industries are facing high supply chain risks due to exceptional competition in the local and international market of their products. In this manner, competitor approach and strategy make the new products more uncertain in the market. In Bangladesh, there are lots of pharmaceutical companies are present in market, which creates more competition among them. This competition may bring market failure or quality failure (Mangla et al., 2015a) of pharmaceutical products.

5 Sensitivity analysis

In this research, among four main risks, supply related risk holds the utmost priority weight. Moreover, multi criteria decision analysis method cannot deal perfectly to prioritize risk due to human judgment. Mangla et al. (2015a) proposed that small change in relative weights of risks may show the large change in final ranking. Therefore, it is necessary to investigate the ranking for stability of result (Chang et al., 2007). A sensitivity analysis was performed by changing weight from 0.1 to 0.9 with 0.1 as incremental value to supply related risk to examine the changes in ranking of supply chain risks. At the same time, corresponding changes in the weights of other risks are also examined. Sensitivity analysis results show that maximum change occurred in the operational risks (O) weights (see Table 8).

Table 8: Main risk values when increasing supply related risks value from 0.1 to 0.9.

Main risks	**Priority weights for main risks**									
S	0.3618	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
O	0.3270	0.4611	0.4099	0.3587	0.3074	0.2562	0.2049	0.1537	0.1025	0.0512
F	0.1635	0.2306	0.2050	0.1793	0.1537	0.1281	0.1025	0.0769	0.0512	0.0256
D	0.1477	0.2083	0.1851	0.162	0.1389	0.1157	0.0926	0.0694	0.0463	0.0232
Total	1	1	1	1	1	1	1	1	1	1

Due to changes in main risks weights, sub risks weights and their ranking are also changed. In this study, at 0.1 value of supply related risk, specific risk O1 takes the top rank whereas S2, S3, S4 take the lowest rank. Risk O1 holds the highest rank until the value 0.3 of supply related risk. From value 02 to 0.9, the lowest rank was obtained by risk D3. From varying supply risk weights values (from .4 to .9), the sub risk S1 obtained the top rank whereas O1 hold the second rank for the weights (.4 and .5) and after that S4 takes second rank up to .9 weights. At the same time,

ranking of other risk was also investigated. Global weights of sub risks when “Supply Related Risk” value increased from 0.1 to 0.9 are provided in Table 9.

Table 9: Global weights for sub risks when “Supply Related Risk” value increases from 0.1 to 0.9

Sub Risks	Normal	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
S1	0.1542	0.0426	0.0852	0.1279	0.1705	0.2131	0.2557	0.2984	0.3409	0.3836
S2	0.0631	0.0174	0.0348	0.0522	0.0696	0.0870	0.1044	0.1218	0.1392	0.1566
S3	0.0529	0.0146	0.0293	0.0439	0.0585	0.0732	0.0878	0.1024	0.1171	0.1317
S4	0.0917	0.0254	0.0507	0.0760	0.1014	0.1267	0.1521	0.1774	0.2028	0.2281
O1	0.1689	0.2382	0.2118	0.1853	0.1588	0.1324	0.1059	0.0794	0.0530	0.0265
O2	0.0925	0.1305	0.1160	0.1015	0.0870	0.0725	0.0580	0.0435	0.0290	0.0145
O3	0.0384	0.0541	0.0481	0.0421	0.0361	0.0301	0.0241	0.0180	0.0120	0.0060
O4	0.0271	0.0383	0.0340	0.0298	0.0255	0.0213	0.0170	0.0128	0.0085	0.0043
F1	0.0582	0.0821	0.0730	0.0638	0.0547	0.0456	0.0365	0.0274	0.0182	0.0091
F2	0.0346	0.0488	0.0434	0.0380	0.0325	0.0271	0.0217	0.0163	0.0108	0.0054
F3	0.0526	0.0742	0.0660	0.0577	0.0495	0.0412	0.0330	0.0247	0.0165	0.0082
F4	0.0181	0.0255	0.0227	0.0198	0.0170	0.0141	0.0113	0.0085	0.0057	0.0028
D1	0.0721	0.1017	0.0904	0.0791	0.0678	0.0565	0.0452	0.0339	0.0226	0.0113
D2	0.0316	0.0446	0.0396	0.0347	0.0298	0.0248	0.0198	0.0149	0.0099	0.0050
D3	0.0154	0.0217	0.0192	0.0168	0.0144	0.0120	0.0096	0.0072	0.0048	0.0024
D4	0.0286	0.0403	0.0358	0.0314	0.0269	0.0224	0.0179	0.0134	0.009	0.0045
Total	1	1	1	1	1	1	1	1	1	1

Ranking for sub risks by sensitivity analysis when “supply related risk” value increases from 0.1 to 0.9 is shown in Table 10.

Table 10: Ranking for sub risks by sensitivity analysis when “supply related risk” value increases from 0.1 to 0.9.

Sub Risks	Normal	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
S1	2	9	4	2	1	1	1	1	1	1
S2	6	15	12	8	5	4	4	3	3	3
S3	8	16	14	9	7	5	5	4	4	4
S4	4	13	7	5	3	3	2	2	2	2
O1	1	1	1	1	2	2	3	5	5	5
O2	3	2	2	3	4	6	6	6	6	6
O3	10	6	8	10	10	10	10	10	10	10
O4	14	11	13	14	14	14	14	14	14	14
F1	7	4	5	6	8	8	8	8	8	8
F2	11	7	9	11	11	11	11	11	11	11
F3	9	5	6	7	9	9	9	9	9	9
F4	15	12	15	15	15	15	15	15	15	15
D1	5	3	3	4	6	7	7	7	7	7
D2	12	8	10	12	12	12	12	12	12	12
D3	16	14	16	16	16	16	16	16	16	16
D4	13	10	11	13	13	13	13	13	13	13

Graphical illustrations for global weights of sub risks and priority ranking for sub risks based on sensitivity analysis are shown in Fig. 3 and Fig. 4.

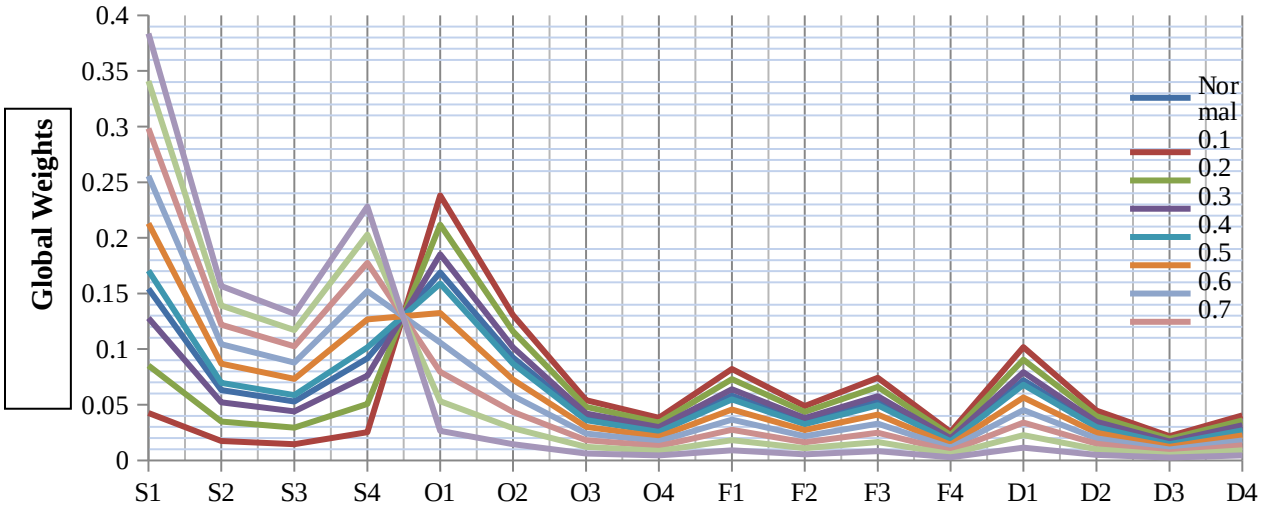

Figure 3. Sensitivity analysis of risks of PSC (by global weights)

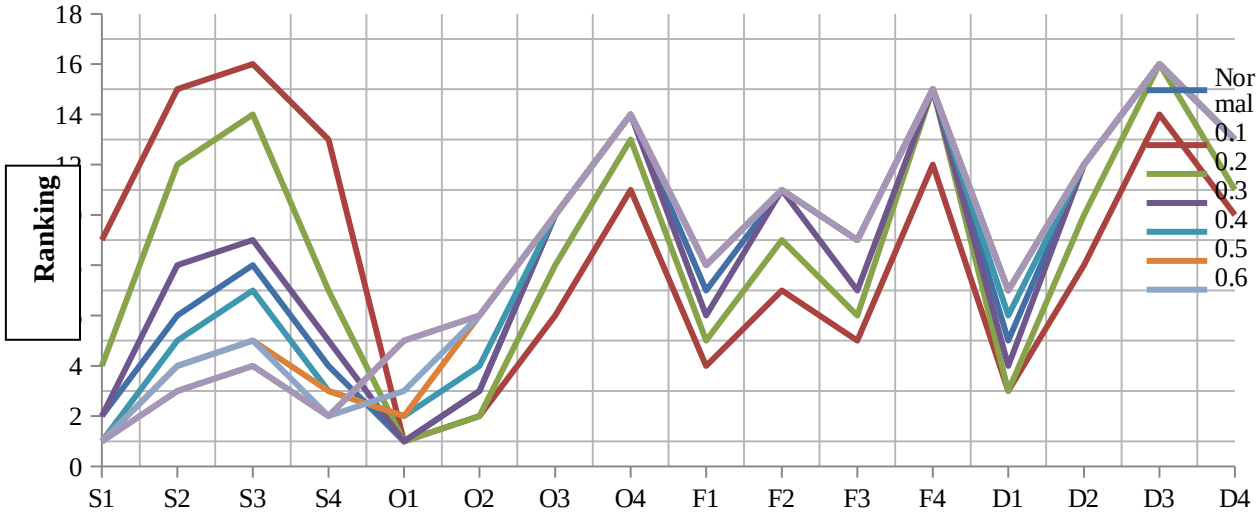

Figure 4. Sensitivity analysis of risks of PSC (by rank)

At the end, it can be stated that supply related risk is more important than other risks. Thus, minimizing supply chain risk is significant for managers to improve the effectiveness of PSCs.

6 Managerial and practical implications

The major contribution of this work is the identification and prioritization of PSC risk, which are significant to mitigate the risks as well as to improve overall performance. After realizing basic knowledge on the relevant supply chain risks and vulnerabilities, the industrial manager will be able to minimize supply chain risks by taking proactive policies in the PSCs sector. This study will assists decision makers to identify the most important risks and to suggest means to minimize the risks in PSCs. Some of the policies are also recommended for helping managers in reducing the occurrence of the risks in PSC in Bangladesh, given as below:

- Realizing the actual nature of risk is a pre-requisite to mitigate the risk. This research can be useful to managers for introducing risk mitigation strategies. The managers should set some proactive and reactive strategy to overcome the supply related risk, which has received the highest weight in the priority rank.
- Managers in the pharmaceutical sectors must develop resilience capabilities to improve PSC system performance and effectiveness. They need a proper understanding of the existing supply chain risks in the first place to develop resilience capabilities of their

supply chains. This research can guide them in formulating decision strategies. As quality of pharmaceutical products are vital to human lives, and compromising quality can cause severe reputational and financial loss to pharmaceutical companies. Therefore, operational risks should take into consideration to overcome the quality defects of pharmaceutical products. Decision makers should develop sound operational procedure as well as enhance operational and infrastructure resilience to mitigate operational risks. PSC managers must monitor every activity in the supply chain to ensure quality of pharmaceutical products.

- Since the supply chain depends majorly on the production of the commodities, to maintain the proper flow of it, it is to be made sure that the production process faces no disruption. The interruption in production affects the entire PSC. In this sense, failure of machines/equipment should be reduced. The machineries involved in production are required to function without error for increasing PSC effectiveness.
- As the pharmaceutical sector involves some degree of emergency or essentiality than any other industry, therefore, supplying of necessary materials related to pharmaceuticals should be efficient. This will make sure the delivery of necessary medical service to the society.
- From a managerial context, proper storage and handling is suggested in pharmaceutical materials to minimize loss due to expiry of the purchased or produced materials.

7 Conclusions and recommendations for future research

Supply of medicine is a significant priority as a strategic product in any healthcare system. Pharmaceutical organizations, a significant player of the medicine supply chain, are subjected to multiple risks. Therefore, it is necessary to examine the risks to take proactive action for their mitigation. This study proposes an AHP based model for evaluating the risks in the PSC context. This work is one of the initial contributions in the literature that focused on identifying and evaluating PSC risks in the context of Bangladesh. The most relevant four main risks and sixteen sub-risks were identified through the existing literature review and expert’s feedback through Delphi analysis. The AHP was used to prioritize these risks for determining their priority. Results show that the priority of main risks is as follows: Supply risks > Organizational risks > Financial risks > Demand risks. According to the findings, the “supply related risks” carries the top rank.

Therefore, it requires significant managerial attention in increasing PSC effectiveness. The results obtained from this present study may assist to other developing countries to analyze the probable risks in PSC. This work is significant for pharmaceutical industries to deal with their specific vulnerabilities and obstacles faced in their respective supply chains.

This research also carries some limitations. In this study, only four main risks and sixteen sub risks relevant to PSCs are taken into considered. The identification of the risks may be challenging in any case. Further, Delphi-AHP based model depends on expert feedback, which may be biased. In the future work, a fuzzy based AHP tool might be used to avoid the human bias. Also, the proposed Delphi-AHP based model can be applied in different industry like construction, manufacturing, service etc for evaluating the risks, however expert's feedback may vary with industry. Further, the causal relations may be identified between listed risks in future studies.

Annexure-A

Questionnaires survey covering the process of data collection

Phase 1, Identification of most relevant PSC risks in context of Bangladesh

Q.1 What is your designation and experience/role in pharmaceutical industry?

Q.2 Are the listed risks relevant to pharmaceutical supply chains?

Please write Yes if you think the mentioned risk is relevant to pharmaceutical supply chain, otherwise write No. You are also free to add/delete any of the risks mentioned in the list. Table A1: Response sheet for respondents

Main risks	**Sub risks**	**Response (*Yes/No*)**
Supply related risks (S)	Fluctuation in imports arrival (S1)	
	Lack of information sharing (S2)	
	Key supplier failure (S3)	
	Non-availability of materials (S4)	
Operational related risk (O)	Machine, equipment or facility failure (O1)	
	Quality risk (O2)	
	Storage contamination risks (O3)	
	Power failure (O4)	
Financial related risks (F)	Increase in freight charges (F1)	
	Dynamic foreign exchange rates (F2)	
	Bank interest rate fluctuation (F3)	
	Financial restriction (F4)	
Demand related risk (D)	Demand forecasting errors (D1)	
	Uncertainty in market (D2)	
	Bullwhip effects (D3)	
	Competitive risks (D4)	
Please mention any other main risk in this column.	*Please mention any other sub risk in this column.*	

Phase 2, prioritizing the identified risks with the help of expert's inputs.

Q.3 Are you realize the assessment scale which we provided to assess the selected risks?

Table A1: Scale to be used for making pair wise comparison (Saaty 1980)

Importance intensity	**Preference judgments**
1	Risks *i* and *j* are both equally important
3	Risk *i* is moderately important to risk *j*
5	Risk *i* is strongly important to risk *j*
7	Risk *i* is extremely important to risk *j*
9	Risk *i* is extremely more important to risk *j*
2, 4, 6, 8	Intermediate values between adjacent scale values

Q.4 Please fill the following comparison matrices using above mentioned scale

Table A3: Pair wise comparison relation matrix for main PSC risks

Risks	**S**	**O**	**F**	**D**
S	1			
O		1		
F			1	
D				1

In the same way, please also fill the pair wise relation matrix for the sub risks.

Table A4: Pair wise comparison relation matrix for sub-risks

S	**S1**	**S2**	**S3**	**S4**
S1	1			
S2		1		
S3			1	
S4				1

Annexure-B

Table B.1: Main risks and Sub risks in PSC along with their sources

Main Risks	**Sub risks**	**Simplified Meanings**	**References**
Supply related risks (S)	Fluctuation in imports arrival (S1)	The imported raw materials of the medical products are subjected to various fluctuations, which includes delay in the arrival of the shipping, delay in customs/movement of freights. This will affect the overall efficiency of PSC in turn.	Amin (2015), Mokrini et al. (2016a)
	Lack of information sharing (S2)	Information is the foremost requirement for doing any activity. Lack of information sharing can affect the regular activity of PSC process, I terms of supplying of medicines, pricing etc.	Jaberidoost et al. (2013),Yousefi (2015)
	Key supplier failure (S3)	Failure of any key supplier will disturb the functioning of a PSC in an organizational context	Zsidisin et al. (2004), Blackhurst et al. (2008), Wagner et al. (2009)
	Non-availability of materials (S4)	Sudden disruption may bring non-availability in supply of raw materials. This may add to the disturbances to production function in PSC context.	Breen (2008), Mahendran et al. (2011), Ketkar (2012)
Operational related risk (O)	Machine, equipment or facility failure (O1)	Failure of any machines/equipment/facility leads to disruptions in the manufacturing process of pharmaceutical products.	Mahendran et al. (2011), Finch, (2004)
	Quality risk (O2)	Lack of quality products can threaten human life in case of pharmaceutical products. It is important to produce the pharmaceutical products with highest quality as their tendencies to directly affect the health of the patient.	Mahendran et al. (2011), O'Connor et al. (2016)
	Storage contamination risks (O3)	Industries are facing issues related to storage contamination during storage of raw materials and finished goods, as pharmaceutical products needs to be maintained at prescribed conditions, such as specified temperature and humidity.	Mahendran et al. (2011), Brettler (2015)

	Power failure (O4)	Power failure is a common problem in developing economies, like Bangladesh. Power failures will disturb the production activity and hence lower the overall efficiency of PSC.	Finch, (2004).
Financial related risks (F)	Increase in freight charges (F1)	From a pharmaceutical organizational context, increase in freight charges will have a significant impact on profit margins. The freight charges are generally influenced by fuel prices.	Goff (2012)
	Dynamic foreign exchange rates (F2)	Fluctuation in the foreign exchange rates can affect in profit margin of the pharmaceutical products. This risk is unpredictable.	Blome and Schoenherr, (2011), Torabi et al., (2016)
	Bank interest rate fluctuation (F3)	Bank interest rate fluctuations may affect the PSC performance as well as hamper the regular business activity of pharmaceutical companies	Blackhurst et al., (2008), Blos et al. (2009), Tummala and Schoenherr, (2011)
	Financial restriction (F4)	Poor financial plans and/or financial restrictions can hamper the smooth functioning of PSC.	Mangla et al. (2015a)
Demand related risk (D)	Demand forecasting errors (D1)	Inaccurate demand forecasts will result in poor supply chain planning and may even create in gap demand and supply of products in a PSC context	Breen (2008), Candan et al. (2014)
	Uncertainty in market (D2)	The demand for common supplies is getting uncertain in market, thus, it is becoming difficult to achieve in a PSC context.	Enyinda et al. (2009), Mahendran et al. (2011)
	Bullwhip effects (D3)	The bullwhip effect makes hard for pharmaceutical companies to anticipate exact demand, which may reduce the business performance.	Metters (1997), Craighead et al. (2007)
	Competitive risks (D4)	There is a tremendous competition in the local and international market of pharmaceutical products. Thus, pharmaceutical industries are under huge risks due to competitor approach and strategy in introducing new products with improved performance levels.	Mangla et al., (2015a)

Annexure-C

Pair-wise comparison relation matrices for sub-risks under each main risk

Table C1: Pair-wise comparison relation matrix for supply related risks in the PSC

Risks	S1	S2	S3	S4	Relative weight	Rank
S1	1	3	2	2	0.4262	1
S2	1/3	1	1	1	0.1740	3
S3	1/2	1	1	1/3	0.1463	4
S4	1/2	1	3	1	0.2534	2

Maximum Eigen Value =4.1610; C.I. =0.0537

Table C2: Pair wise comparison matrix for operational risks in PSC

Risks	O1	O2	O3	O4	Relative weight	Rank
O1	1	2	5	5	0.5166	1
O2	1/2	1	3	3	0.2830	2
O3	1/5	1/3	1	2	0.1174	3
O4	1/5	1/3	1/2	1	0.0830	4

Maximum Eigen Value =4.0476; C.I. =0.0158

Table C3: Pair-wise comparison matrix for financial risks in pharmaceutical supply chain

Risks	F1	F2	F3	F4	Relative weight	Rank
F1	1	2	1	3	0.356	1
F2	½	1	1/2	3	0.212	3
F3	1	2	1	2	0.322	2

F4	1/3	1/3	1/2	1	0.110	4

Maximum Eigen Value =4.0974; C.I. = 0.0325

Table C4: Pair wise comparison matrix for demand related risks in pharmaceutical supply chain

Risks	**D1**	**D2**	**D3**	**D4**	**Relative weight**	**Rank**
D1	1	3	3	3	0.4883	1
D2	1/3	1	3	1	0.2142	2
D3	1/3	1/3	1	1/2	0.1040	4
D4	1/3	1	2	1	0.1935	3

Maximum Eigen Value = 4.1193; C.I. = 0.0398

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