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Research Article

Green Supply Chain Risk Network Management and Performance Analysis: Bayesian Belief Network Modeling

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Abstract
With the increase in environmental awareness, competitions and government policies, implementation of green supply chain management activities to sustain production and conserve resources is becoming more necessary for different organizations. However, it is difficult to successfully implement green supply chain (GSC) activities because of the risks involved. These risks alongside their resources disrupt the normal functioning of the GSC and affect its environmental and economic performance. The pharmaceutical industry in particular, is crucial to providing life-saving products and services to the society. The products and services provided in this industry, have several impacts on the environment in different ways. These include expired or unused medicines, inappropriate distribution by pharmacies or drug companies, disposal of surplus medicines in household sewage and improper disposal of pills or capsules by patients. This study represents a GSC risk network model that considers the interrelationships between risks in order to achieve an optimal level of performance measures defined in the supply chain by Bayesian Belief Networks (BBN). The model is empirically implemented through a case study conducted in Imam Reza hospital of Mashhad medicine supply chain involving structured and semi-structured interviews and workshop sessions with experts. This work uses a literature review and a causal map BBN approach in finalizing the risks and also uses the BBN inference system and scenario analysis for prioritization and analysis of the risks through the network under probability conditions. According to the findings, inefficient logistics network design, supplier quality issues and green raw material supply disruption are highly prioritized.

Keywords: Green supply chain, Bayesian belief network model, Medicine supply chain risks, Interacting risks, Supply chain performance.

Introduction

Risk management in Supply Networks (SN) has been a growing area of research in operations, supply chain and management science. A major challenge facing supply chain management is that many recent strategies and approaches to SN design, which aim to increase supply chain efficiency, actually tend to make the SN more vulnerable and exposed to risks.

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While climate change is of global concern, it has only been relatively recently that researchers have sought to determine whether the implementation of climate change or green initiatives have a positive impact on overall supply chain performance (Younis et al., 2019). In the modernized world, Supply Chain Management (SCM) is regarded as being one of the key elements to improve the efficiency of business (Mohtashami et al., 2020). In addition to this, SCM is considered as a potentially important candidate for the implementation of the green or environmental aspects (Iqbal et al., 2020). To accomplish the environmental responsibilities at an industrial standpoint, the perception of Green Supply Chain (GSC), and Green Supply Chain Management (GSCM) has been evolved. In the recent two decades researches has been growing dramatically in this field, especially since 2008 (Asgharizadeh et al., 2019). Green supply chain management can reduce wastes, costs and also improve the relationships between the commercial partners and their leader companies. As a result of the increase in customer's demand, higher rate of production requires more transportation fleet in the network, which causes more environmental effects (Aziziankohan et al., 2017). Environmental effects refer to different concepts such as pollution, noise, traffic congestion, etc. (Ahi and Searcy, 2013; Rodrigue et al., 2016). In practice, a green supply chain may exhibit a relatively high production cost as a result of its adoption of new and cleaner technology; however, manufacturing or retailing capacity restrictions impede the realization of the scale effect.

Medicines are produced, transported and used in the pharmaceutical industries. Therefore, such industries differ from the usual physical goods supply chains due to the importance, manner of maintenance, transportation, as well as laws and regulations (Settanni et al., 2017; Moktadir et al., 2018). The main purpose of the pharmaceutical SC is to build the necessary backup to supply the right medicines to health systems at the right time (Settanni et al., 2017).

The pharmaceutical industry is growing rapidly in terms of enhancing research and design within the industry; however, proper execution of supply chain activities in this sector generates huge pharmaceutical waste, which is harmful to the environment and has a direct impact on human health (Faisal, 2016). In the last few decades, the consciousness of people about the environment has increased and regulatory bodies have also started to focus on world environmental issues such as scarcity of resources, global warming and carbon emissions (Xie and Breen, 2012; Tseng and Chiu, 2013). To help industries mitigate environmental impacts, managers and decision makers recommend applying the principles of greening in the supply chain network (Dehdari Ebrahimi et al., 2017). Increasing global and regional pressures on environmental, economic and safety issues have forced pharmaceutical industry activists to implement green supply chain activities in their businesses (Kumar et al., 2019). Risks to GSC, such as the disruption in material supply, quality related concerns, increased environmental impacts and decreased competitive gains, may significantly affect pharmaceutical industry's green sourcing decisions (Mangla et al., 2015). As far as gaining a new perspective on this work is concerned, to improve performance and to manage GSC initiatives (considering a holistic picture of GSC), the concept of risks to GSC needs to be addressed (Mangla et al., 2015).

The pharmaceutical industry has grown exponentially in countries with developing economies like Iran. The Iranian pharmaceutical industry has the potential to reach one thousand trillion Rials by 1398. Notably, about 450 tons of waste is generated by healthcare facilities in Iran per day; this includes expired medications, contaminated products and drugs which are unused or obsolete. (Molla Mahmoodi et al., 2019).

It is not yet fully understood what is causing the failure to implement green activities in the supply chain (Wasim Syed et al., 2019). It is mainly due to the fact that greening activities in various dimensions face several problems. (Ma et al., 2012). Consequently, there arise different risks and risk factors in implementing different GSC initiatives in business, which would certainly affect the overall performance (Wang et al., 2012). Therefore, to effectively manage the activities associated with the green supply chain, it is necessary to identify and understand the risks involved (Ma et al., 2012). Risks in the green supply chain can be extracted from two sources of expert comments and literature. Besides, different industries face different risks and difficulties to green their supply chains. (Mangla et al., 2015). Similar risks in a particular industry are not equally important given their source and effects. The overviews of literature on green supply chain risk management in different industries can be found in Srivastava (2007), Rostami et al. (2013) and Wu et al. (2019). Furthermore, Sarkis et al. (2011) and Petljak, et al. (2018) review the organizational theory and modeling research on green supply chain management, respectively. Eskandarpour et al. (2015) review the design of sustainable supply chain networks. Other interesting research covers the performance evaluation of green supply chain management in practice (Varsei and Polyakovskiy, 2017). However, only a few researchers study green supply chain management through mathematical models, while these could help us to identify the optimal strategy for green supply chain performance. The prime contributions made by this research are listed as follow:

- Listing the important risks in adoption of GSC in Mashhad pharmaceutical industry and medicine supply chain using extensive literature review and expert inputs using interviews. This will give a proper understanding to managers about potential interacting risks. Thirty-one risks are listed in this study with the help of literature and expert feedback.
- Develop and operationalize a green supply chain risk network process that captures the interdependencies between risks and multiple performance measures helping to prioritize risks specific to each decision maker. In addition, it demonstrates its application through a case study.
- The finalized risks were analyzed for their probability and impact using the BBN approach. This analysis will help industry managers to understand their relative significance in managing GSC activities in the pharmaceutical industry.
- Scenario analysis via BBN approach used for analyzing the combination of risks in the supply chain, which aids in preparing the mitigating plans and improving the reliability of the system supply chain.
- The managerial implications are provided based on the research outcomes to help managers and the officials to achieve sustainable development goals in the pharmaceutical sector.

Literature review

This section presents the literature on the GSC and GSCM, the risks in GSC, and the BBN used in GSC and GSCM.

GSC risks & GSC risk management

From a supply chain perspective, risk is defined as the deviation from defined goals and the events that cause the supply chain to fail. (Hora and Klassen, 2013). It can reduce the efficiency and effectiveness of activities (Gurnani et al., 2012) and processes through a supply chain (Sodhi et al., 2012). Furthermore, in industrial and commercial organizations, supply chain management is known as a management approach that examines the flow of materials, goods, and resources throughout the product life cycle. (Chopra and Meindl, 2007). In contrast, the GSCM adds environmental dimensions into the traditional supply chain. (Ahi and Searcy, 2013). In the case of GSC, risk can be understood as an occurrence of unforeseen events that might affect the green material movement, and even disrupt the proposed flow of ecofriendly materials and finished green products from their point of origin to the point of consumption (Mangla et al., 2015). Few of them include raw material supply disruptions, scarcity of skilled labor, supplier failures, management policy failures, information disorder, customer risks, technology risks, etc. (Ma et al., 2012; Wang et al., 2012; Mangla et al., 2015). The results of the risk can be delays in delivery, financial problems, damage to goods and other performance problems.

Pharmaceutical products are specifically linked to society (Narayana et al., 2014). Thus, the supply chain plays a crucial role in distributing medicines or materials to stakeholders in the pharmaceutical industry (Moktadir et al., 2018). Implementing the concepts of GSC in any industry makes it an environmentally friendly and a socially responsible industry (Patil et al., 2016). The concepts in the GSC also include the optimal use of resources that were overlooked in traditional supply chain activities. However, the existence of different risks can waste resources and influence decisions about whether to implement the GSC concepts (Mangla et al., 2016). Some negative effects of GSC risks include supply failure, disruptions in the workflow, and quality issues, thereby disturbing ecological balance and causing a decline in business sales (Jaberidoost et al., 2015; Samvedi et al., 2013). If managers and decision makers fail to identify and manage these risks at the right time, the results can be devastating (Ma et al., 2012). Greening the pharmaceutical supply network can help in increasing revenue and improving its commitment toward the environment and society. GSC means optimal utilization of resources with minimal wastage, which, accordingly, produces maximum output and ecological efficiency (Mangla et al., 2015; Dubey et al., 2017). Operational managers of the pharmaceutical industry have realized that implementing GSC activities not only has a positive impact on the environment but also affects the overall performance of the chain participants. (Jaberidoost et al., 2015). The integration of GSC may also include several risks (Sreedevi et al., 2017; Mangla et al., 2014) in the industry context. These risks need to be identified and analyzed to ensure the proper functioning and optimal use of resources in the operations of the pharmaceutical industry. (Kumar et al., 2019; Olson and Wu, 2011; Mangla et al., 2016). Furthermore, Research on risk analysis of GSC implementation in the pharmaceutical industry compared to other industries such as automotive, textile and food is still immature. (Olson and Wu, 2011; Mangla et al., 2015; Seker and Zavadskas, 2017). Therefore, this study is conducted to fill this research gap in the GSC agenda in the pharmaceutical sector.

In this context, this work lists 31 potential risks to GSC in the pharmaceutical industry through a literature review and expert opinions. The listed risks were confirmed through expert feedback in the case study of Mashhad medicine supply chain of Imam Reza Hospital. A brief description of literature supported risks is given in Table 1.

Bayesian Belief Networks in supply chain risk management (SCRM)

The beginnings of research on SCRM date back to the early years of the 21st century (Christopher and Peck, 2004; Manuj and Mentzer, 2008). There is an extensive literature on SCRM that considers conceptual theory building facets as well as empirical investigations of best practice in managing risks. This literature has been well-considered in numerous literature reviews (Jüttner et al., 2003; Heckmann et al., 2015; Dong and Cooper, 2016). There are two major research gaps that necessitate immediate attention: first, the existing SCRM processes or frameworks ignored the interdependency modeling of risks (Garvey et al., 2015; Qazi et al., 2018) and second, a decision maker's need to analyze risks is not explicitly taken into consideration in general when the risks are not prioritized and evaluated (Heckmann et al., 2015). In addition, there is a lack of research measuring the correlations between risk factors and corresponding risk types, or the probability of the occurrence of particular risks associated with their factors (Ho et al., 2015).

Table 1. List of risks related to GSC in the pharmaceutical industry

1.	Lack of skilled labour	Lack of workers with good understanding of GSC concepts	Olson and Wu (2011); Mangla et al. (2015); Govindan et al (2017)
2.	Level of green technology	Risks related to bringing or making suitable technology for implementing the GSC activities.	Expert's comment
3.	Cost effective development	Risks related to adoption in more expensive green activities.	Wang et al. (2012); Rostamzadeh et al. (2018)
4.	Equipment failure	Risk related to machine or equipment for implementing the GSC process.	Jaberidoost et al. (2013); Olson and Wu (2011); Govindan et al. (2017)
5.	Procurement cost risk (R5)	Failure to procure ecofriendly raw materials.	Mangla et al. (2015); Lintukangas et al. (2016)
6.	Financial restriction	Poor financial plans which definitely disturb the GSC functioning	Expert's comment
7.	Supplier quality issues	Raw materials and services supplied will affect the quality of the green products.	Mangla et al. (2015)
8.	Green raw material disruptions	Failure in supplying green raw material which may disrupt entire GSC.	Expert's comment
9.	Lack of collaborative Relationships	Risks related to issues in mutual understandings among stakeholders.	Lintukangas et al. (2016); Brusset and Teller (2017); Kumar et al. (2019)
10.	Supplier failures	Risk related to at least one supplier failure in a GSC context.	Lintukangas et al. (2016); Kumar et al. (2019)
11.	Reverse logistics design risk	Any flaw in designing the reverse logistics process	Lintukangas et al. (2016); Weraikat et al. (2016)
12.	Uncertainty in recovery of medicines	Drugs recovered may be tampered with, and thus become unsuitable for consumption	Narayana et al. (2014); Govindan et al (2017)
13.	Capacity and inventory related disruptions	Inventory & capacity issues in recovering pharmaceutical products.	Mangla et al. (2015); Rostamzadeh et al. (2018); Lücker et al. (2018)
14.	Inventory costing issues	This implies that high expenditure is needed as higher inventory is required in the healthcare sector.	Seker and Zavadskas (2017)
15.	Shortage of lifesaving drugs	Failure to supply lifesaving medicines required in emergencies	Expert's comment
16.	Market dynamics	Market changes in supply and demand which affect GCS performance	Jaberidoost et al. (2013); Rostamzadeh et al. (2018)
17.	Product life cycle risks	Risk related to sensitivity of pharmaceutical products because of their life cycle and impacts	Mishra et al. (2012); Rostamzadeh et al. (2018)
18.	Lack in enterprise strategic goals	Improper strategy planning and less priority given by higher management in adopting GSC concepts in pharmaceutical industry	Expert's comment
19.	Management policy failures	Failure to manage policies which may disrupt the adoption of pharmaceutical GSC concepts	Olson and Wu (2011); Brusset and Teller (2017); Rostamzadeh et al. (2018)
20.	insufficient inventory levels	Risk occurred due to insufficient inventory levels in adopting pharmaceutical GSC activities.	Jaberidoost et al. (2015); Mehralian et al. (2012); Mangla et al. (2015)

Table 2. Continued

21. Inefficient process planning and scheduling	Risk occurred due to inefficient process planning and scheduling in adopting GSC concepts in pharmaceutical industry.	Luthra et al. (2011); Mishra et al. (2012)
22. Insurance risk	Risk related to high insurance and risk coverage	Mangla et al. (2016); Mandal and Jha (2018)
23. Infrastructure failure	Represents failure in infrastructure such as equipment or machines in adopting GSC concepts in pharmaceutical industry	Luthra et al. (2011); Xie and Breen (2012)
24. Uneven capacity district	Districts in the pharmaceutical supply network may have different capacities for storing drugs	Mangla et al. (2015); Mandal and Jha (2018)
25. Natural calamities	Represents the occurrence of natural calamities in pharmaceutical supply network	Mishra et al. (2012); Govindan et al. (2017)
26. Inadequacy in waste management system	Risks related to inefficiency in managing the waste in pharmaceutical industry.	Olson and Wu (2011); Samvedi et al. (2013); Wee and Aris (2017)
27. Inefficient use of materials and Energy	Inefficient use of material and energy may create severe ecological and social problems in healthcare sector.	Olson and Wu (2011); Wee and Aris (2017)
28. Legal risk	Risk about breach of contract, terms of cooperation and settlement accounts	Seker and Zavadskas (2017)
29. IT infrastructure risks	Risks related to IT infrastructure such as data centers, hardware, software and related equipment.	Modgil and Sharma (2017); Rostamzadeh et al. (2018)
30. Inefficient logistics network design	Represents inefficiency in logistics activities of green materials in pharmaceutical industry.	Luthra et al. (2018); Mangla et al. (2015); Weraikat et al. (2016)
31. Partnership risks	Problems between the participants of SC	Experts comment

Bayesian belief networks (BBN) is a graphical framework for modeling uncertainty. BBNs were first introduced in the 1980s for dealing with uncertainty in knowledge-based systems and have their background in statistics and artificial intelligence (Sigurdsson et al., 2001). They have been successfully used in addressing problems related to a number of diverse specialties including reliability modeling, medical diagnosis, geographical information systems, and aviation safety management among others. For understanding the mechanics and modeling of BBNs, interested readers may consult Nadkarni and Shenoy (2004); Jensen and Nielsen (2007). A BBN consists of the following elements:

- A set of variables (each having a finite set of mutually exclusive events) and a set of directed edges between variables forming a directed acyclic graph; a directed graph is acyclic if there is no directed path $X_1 \rightarrow \ldots \rightarrow X_n$ so that $X_1 = X_n$; furthermore, the directed edges represent statistical relations if the BBN is constructed from the data whereas they represent causal relations if they have been gathered from experts' comment, and
- A conditional probability table $P = (X|Y_1; \ldots Y_n)$ attached to each variable X with parents $Y_1; \ldots; Y_n$.

Take a Bayesian network specified with $X = X_1; \ldots; X_n$. The structure of a BBN implies that the value of a particular node is conditional only on the values of its parent nodes. Therefore, the unique joint probability distribution $P(X)$ representing the product of all conditional probability tables is given as follows:

$$P(X) = \prod_{i=1}^{n} P(Xi)|Pa(Xi)\ \mathrm{P(X)} \quad (1)$$

where $Pa(Xi)$ are the parents of Xi.

BBNs offer a unique feature of modeling risks combining both the statistical data and subjective judgment in the case of non-availability of data (Sigurdsson et al. 2001). Although BBNs have been extensively used in the field of risk management (Norrington et al. 2018), their application to the field of SCRM is mainly focused on addressing specific problems involving supplier selection, supplier assessment and ranking of suppliers. Recently, a few models have been proposed to capture the supply network-wide chain of risks. However, existing approaches have not considered framing and operationalizing a comprehensive risk management process integrating suitable techniques across all stages of the process. Furthermore, the challenges involved in implementing such a framework remain unexplored.

BBNs present a useful technique for capturing interdependency between supply chain risks (Badurdeen et al. 2014). Another advantage of using BBNs for modeling supply chain risks is their ability of back propagation that helps in determining the probability of an event that may not be observed directly. They provide a clear graphical structure that is comprehensible to most people. Besides, it becomes possible to make a flexible inference based on partial observations, which allows reasoning. Another important feature of using BBNs is to conduct what-if scenarios. There are certain problems associated with the use of BBNs: along with the increase in the number of nodes representing uncertain variables, a considerable amount of data is required in populating the network with (conditional) probability values; similarly, there are also computational challenges associated with the increase in the number of nodes.

Research methods

This section presents the description of the methods utilized to achieve the aim of this study. There are many studies in the literature with exclusive focus on the impact of supply chain risks on performance measures (Jüttner et al., 2003; Zhao et al. 2013). However, the main limitation of these studies is modeling risks in silo, where the focus is on modeling a risk network and evaluating its comprehensive effect on performance measures. Cause-effect relation is selected as the main type of relationship to capture interactions among risks by the BBN SC risk model. The consequence of risk is identified by SC performance in the effect area by linking intermediate and root cause variables. The last element is the mitigating strategy used in the mitigating area. Mitigating actions are generally of two types: reducing the probability of risk (in the cause area) or reducing negative impact on SC performance by different actions (Khan and Burnes, 2008). Therefore, the provided framework by Jüttner et al. (2003) is modified to explain the comprehensive impact of a supply chain risk network on supply chain performance measures as shown in Figure 1.

Based on the critical review of literature and expert opinions, the risks and their resources in GSC context have been identified. These risks were evaluated using industry expert comments. To analyze the risk consequences measured in supply performance measures, a Bayesian network-based approach was used. The process of this research is illustrated in Figure 2 shown below.

Description of the case study

One of the important objectives of this research is to evaluate the proposed model through a case study in order to represent the application of the model and provide the benefits and challenges associated with its implementation. The empirical evaluation of the model involved establishing the context of a specific organization (case) and developing a model based on how the decision makers perceived the interdependencies between risks and why certain risks and performance measures were given due importance (study). For this reason, a case study method is an appropriate choice for making investigations.

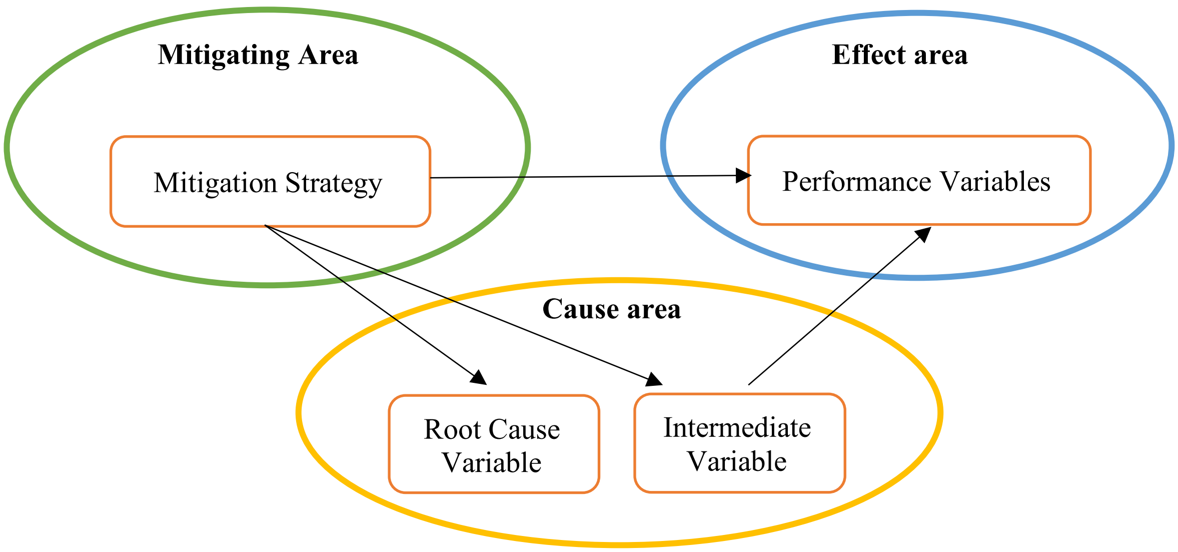

Figure 1. Supply chain risk analysis framework for network of interacting risks and performance measures

Disruption or low performance of the medicine SC is very important. Therefore, if BBN SC risk model can be applied in this scope as a typical case, other similar cases should also be able to implement this model. For this reason, the medicine supply chain of Imam Reza Hospital of Mashhad, which is one of the largest and most important hospitals in the city, is selected for the empirical evaluation of the model. This SC includes drug manufacturer and wholesalers and the medicine distribution center. This hospital currently has more than 1,000 inpatients and 300 emergency patients per day, all of which attest to its significance. This is an educational and research hospital which has the best medical university professors in Iran as well as highly experienced staff. The respondents were selected on the basis of their expertise in supply chain risk management in general and the green concept of production and distribution in particular. A total of seven semi-structured detailed interviews were conducted with the experts. Each interview lasted for about 50 minutes on average. A total of two workshop sessions were also held involving the development and validation of the model and communication of the results with each session lasting for 80 minutes on average.

Model development and results

Five performance objectives (namely environmental, time, operational, economic performance and sustainability) were identified during the interviews. Generally, the modeling scope was defined upon agreeing with the decision maker. To identify the relationships between risks, all experts were interviewed individually and asked to develop individual Causal Maps of risks in their working area. Then, the primary BBN GSC risk model was developed and presented to the expert panel in the workshop (qualitative BBN). The final qualitative part of the model is shown in Figure 3. The agreed model structure was prepared for quantification. Structured interviews, arranged in the expert working place were conducted to quantify the model. The numbers obtained from the individual experts were put into the model using GeNIe software, and the results were analyzed. The last workshop was arranged to show the results of the analysis to the expert panel. This way, feedback on the main developing processes and the model results were obtained from the expert panel and subsequently used to evaluate the BBN SC risk model.

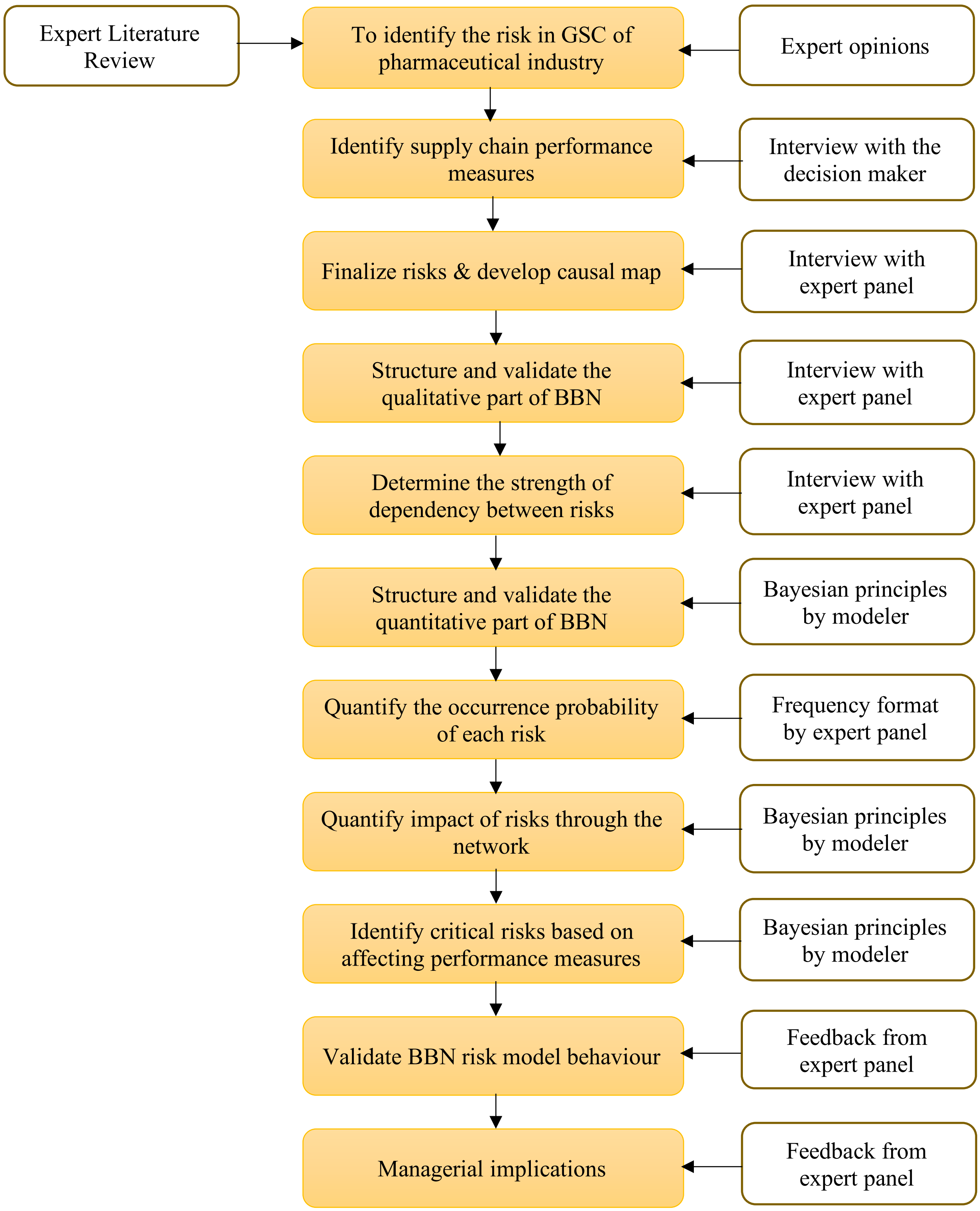

Figure 2. Research steps

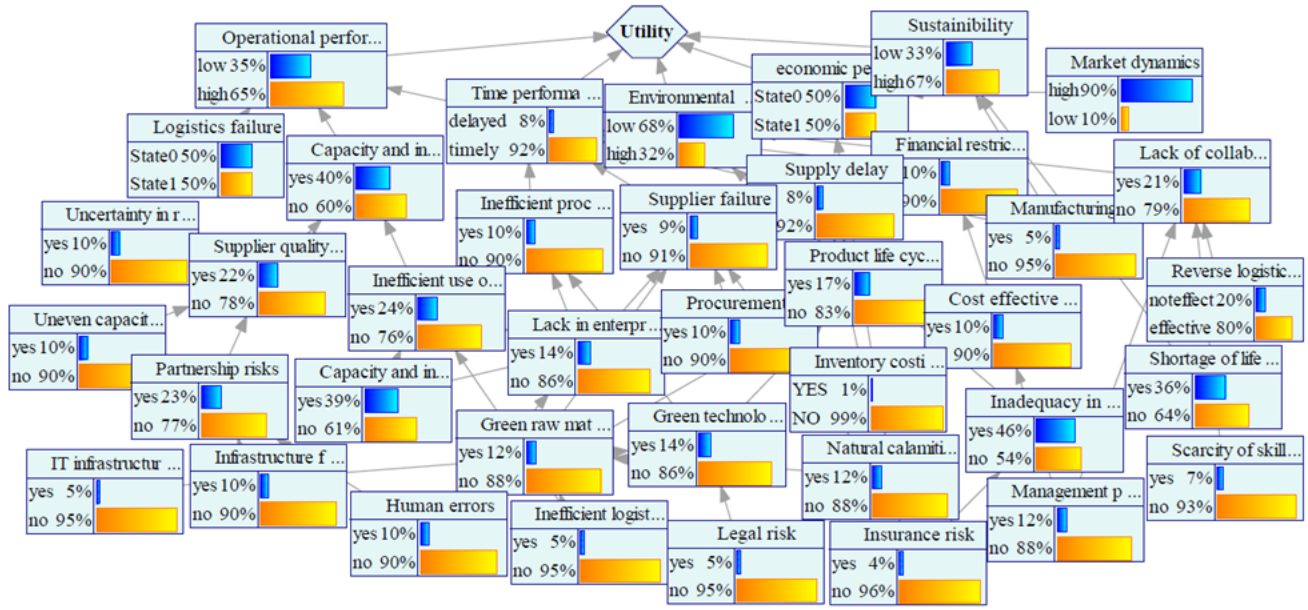

Figure 3. BBN model of interacting risks

The aim of analyzing the BBN SC risk model is to improve the current understanding of the existing risks within the selected supply chain. Standard BBN analysis is implemented generally to address three questions that are important to decision makers:

1. What is the probability of a particular risk occurring?

The chance of a particular risk occurring can be shown by a marginal probability called "current probability", which refers to the probability of individual risks occurring at the present time, is as follows:

$$P(Y) = \sum P(Y|X)\, P(X) \qquad (2)$$

The proportion format estimates more accurately when presenting information in a frequency format (numbers per one hundred or per one thousand) rather than in absolute number format between 0 and 1 (Oakley, 2010). Therefore, a self-answering format of a questionnaire is designed for probability elicitation, using the frequency format, for two types of variables: root cause and effect.

2. What are the main risks that cause performance failure?

Many risks have been identified and it is impossible to mitigate all of them due to the constraints on resources (such as numbers of staff, time, and budget). Therefore, risk prioritization can help the decision maker identify the major risks to be managed under the limited resources and help to manage the risks effectively. The Normalized Likelihood (NL) is the index proposed for measuring the impact of (causal) risks on the focus variable. The adjusted probability of individual risks is diagnosed by calculating marginal posterior probability, which is the probability given the observed performance event.

$$P(X|Y) = \frac{P(Y|X)\, P(X)}{P\ (Y)} \qquad (3)$$

$$NL = \frac{P(\varepsilon|Y)}{P\ (\varepsilon)} = \frac{P(Y,\varepsilon)/P(Y)}{P\ (\varepsilon)} = \frac{P(Y,\varepsilon)/P\ (\varepsilon)}{P(Y)} = \frac{P(Y|\varepsilon)}{P(Y)} \qquad (4)$$

Table 2 shows the crucial risks prioritized by NL, which is the ratio of adjusted probability, provided the performance event is observed, to the current probability.

Table 3. Crucial risks prioritized by NL which is the ratio of adjusted probability given the utility and current probability

Risks	Current probability	Adjusted probability	Normal likelihood
Inefficient logistics network design	0.2702	0.9683	3.584
Supplier quality issues	0.2505	0.6267	2.529
Green raw material supply disruption	0.4102	0.8134	1.922
Infrastructure failure	0.1844	0.4619	2.511
Scarcity of skilled labour	0.1622	0.5677	3.498
Green technology issue	0.1084	0.2201	2.032
Equipment failure	0.0922	0.2405	2.766
Inefficient use of materials and energy	0.0533	0.1391	2.383
Insurance risk	0.0461	0.0989	2.431
Procurement cost risks	0.0631	0.0792	1.178
Reverse logistics design risk	0.0521	0.0904	1.847
Management policy failures	0.0723	0.0865	1.196
Capacity and inventory related disruptions	0.0671	0.1683	2.612
Natural calamities	0.0257	0.0749	2.754
Product life cycle risks	0.0712	0.1893	2.658
Market dynamics	0.0611	0.1449	2.428
Inadequacy in waste management system	0.0671	0.2683	3.998

When the NL of a variable is 4, the possibility of the variable occurring increases four-fold compared with its current probability of occurrence when the performance of the supply chain is observed. The current probability and NL are used to represent the probability and consequence of the individual risk by dividing the graph into four quadrants similar to a matrix; see Figure 4 which categorizes high or low probability and consequence.

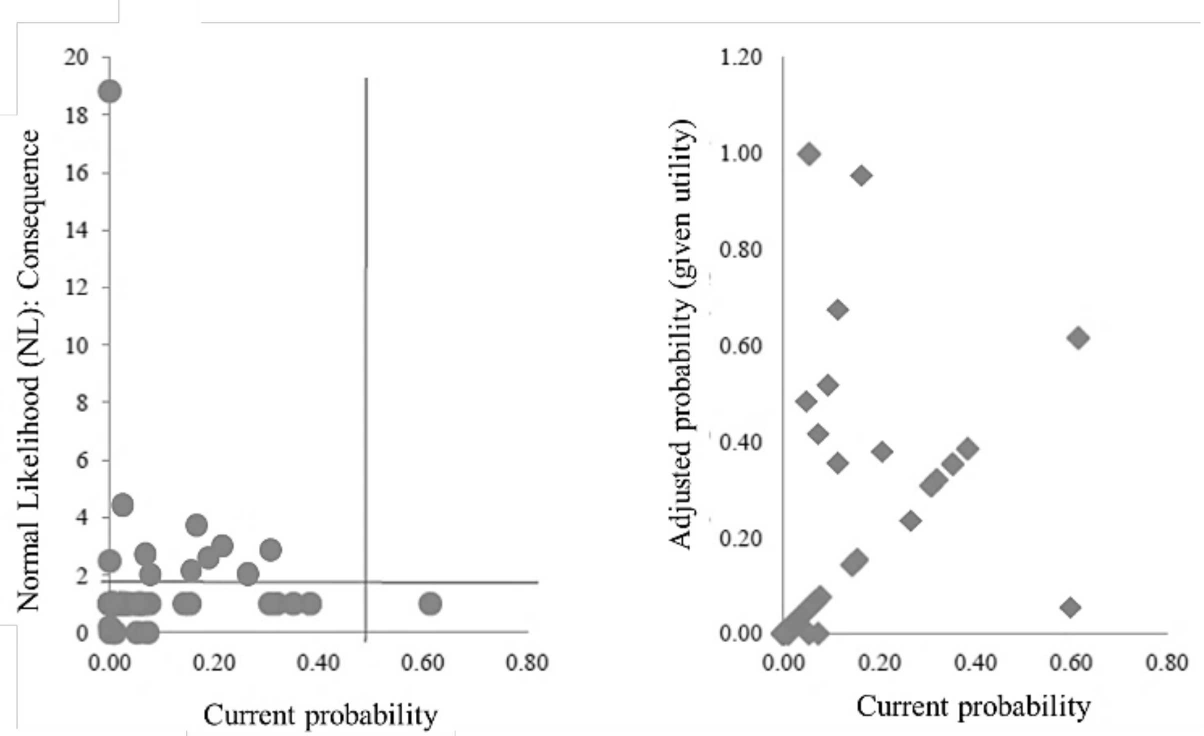

Figure 4. Risks categorized by current probability and consequence to the utility represented by NL

3. What is the impact of (combinations of) risks on supply through the chain?

Exploring joint risks can improve the understanding of possible effects when risks happen simultaneously and the scenario analysis can be used to support risk management. This aids in preparing the mitigating plans and/or improving the reliability of the GSC. The effects of scenarios can be measured using focus variables by comparing the adjusted probability (marginal posterior probability) to show the effects of setting scenarios with current probability (marginal probability). For example, the occurrence of Inefficient logistics network design can generate problems in logistics in the defined medicine GSC. Therefore, these risks can lead to six focus variables shown in radar map of figure 5.

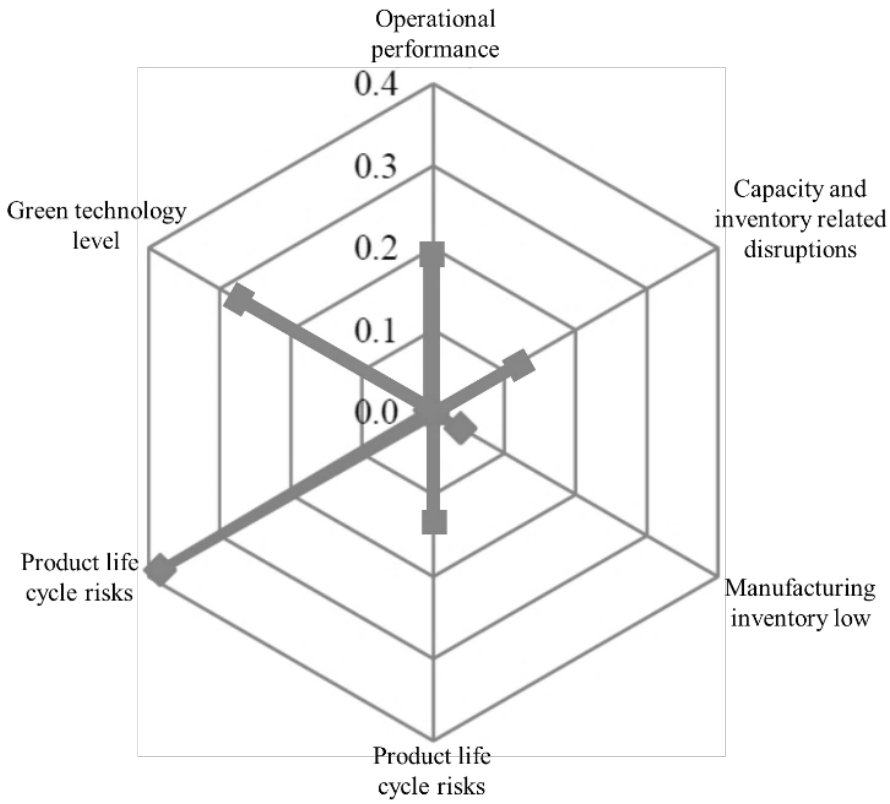

Figure 5. Radar map of difference between adjusted probability if Inefficient logistics network design happens, and current probability of the focus variables

Sensitivity Analysis

Sensitivity analysis is carried out to evaluate the impact of individual risks on each performance measure and ascertain whether the results make sense and conform to the perception of the participants. In the case of any discrepancy, the quantitative model is revisited and amendments are incorporated until the sensitivity results are agreed upon. Evidence sensitivity analysis is used in this thesis to depict the effect that changing input cause variables in the network has on the performance variables. The sensitivity analysis is depicted by the Tornado graph. The length of a bar is the range of difference between the effects of the two extreme states of a cause variable on the specific state of the effect variable. There are two defined possible states for each performance variable. The sensitivity analysis will show the top ten cause variables which can impact the individual performance variables as shown in Figure 6.

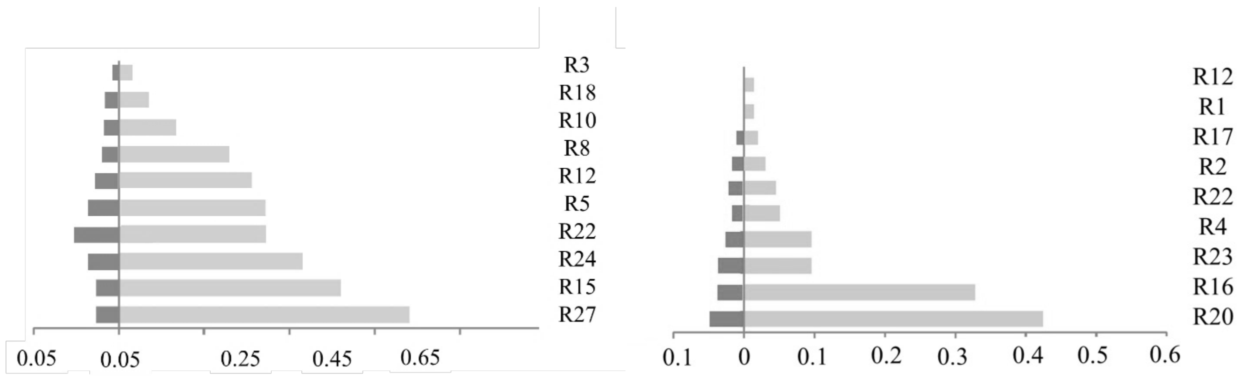

Figure 6. Result of sensitivity analysis given two performance variables

Discussion and implications

GSCM has become an important subject of research for the academicians and practitioners in recent years. Owing to customer pressure, market demand and governmental policies, the organizations are making sure green practices are implemented in network design (Mathiyazhagan et al., 2014). This will help the industrial sector to adopt sustainability practices and will eventually contribute to the preservation of resources. However, the successful accomplishment of different business activities in the green supply chain context is comparatively difficult, as several risks and risk factors are associated with the GSC. The listed risks as well as the specific risks would certainly assist managers in understanding the theory of risk in GSC. The pharmaceutical industry is specially very important in the delivery of life-saving products or services to society. There are many ways for pharmaceutical based products or services to influence the environment; these include improper disposal of pills or tablets by patients, expired and unused medications, expulsion of pesticides and molecular farming waste, improper release of drugs by pharmacies, household sewage mixed with surplus drugs, etc. This leads to a higher negative environmental impact, possibly posing a question about the sustainability of the pharmaceutical industry, particularly in a developing economy like Iran. In order to improve the environmental efficiency of pharmaceutical supply activities, the present work seeks to integrate GSC concepts in the pharmaceutical sector.

Interacting risk can be modeled to capture interrelationships between risk events with BBN being proposed as the suitable model for this research to capture these characteristics since it can fulfill the requirements of SC risk analysis such as risk prioritization, scenario and sensitivity analyses. BBN can capture different types of uncertainty in SC, using the probability language and logical structure which the risk management team can understand. The most complex relationship, non-deterministic dependence, can be captured by the model and it follows that it will also be able to capture lower levels of relationship complexity. Furthermore, the visual display of the BBN (a natural logic represented by arrows) encourages discussion and participation by the risk management team and also others to improve understanding of risks in the SC. Thus, BBN can be used as an interactive tool to support risk communication.

With respect to interdependency modeling, there are a number of approaches applied to other application areas including, but not limited to, project risk management (Qazi et al., 2018), enterprise resource planning (Mamoghli et al., 2018) and reliability of engineering systems (Ashrafi et al., 2015). In many of articles just title of risks were found and no detail about them mentioned and some of them reported risks in detail (Jaberidoost et al., 2015) and in some others weigh of risks were measured (Mehralian et al., 2012) but none of them consider interrelationships between risks. On the other hand, in some articles mitigation strategies were discussed; but impact of each risks within the whole network and other functions were not mentioned. Furthermore, measures in this study can be used to solve problems of previous models such as newsvendor and other inventory models (Panja and Mondal., 2019), transportation problems involving risk (Li et al., 2016), network configuration and facility location (Zetterholm et al., 2018) and many more (Fahimnia et al., 2015). They also could be used to develop mitigation and contingency plans that will increase a supply chain's resiliency efforts (Hu et al., 2013) by performing scenario analysis and integrating measures in existing petri net models (Zegordi and Davarzani, 2012).

Using the unique features of BBNs, the proposed model captures probabilistic interdependency between risks. The risk network provides an effective visual tool to help managers prioritize risks on the basis of relative probability and propagation impact values, thereby considering a holistic view of multiple factors including the position of a risk within the network, its influence on the key performance measures identified, and its probability of occurrence. Instead of following the conventional risk classification schemes, the process introduces the development of a risk and performance network where performance measures (objectives) are identified initially followed by linking risks to these measures. Adopting such a technique (similar to BBN) helps in modeling not only basic risks but also common cause failures. The participants involved in developing the risk network were able to identify around 46 connections within the network.

Finally, the identified risks were analyzed by priority, sensitivity and scenario analysis using the Bayesian network approach. The analysis of data by BBN will assist managers to overcome the problem of human subjectivity in analyzing the GSC risks. It will help to provide a measure determining the relative concerns of recognized specific risks in GSC.

The results highlight the importance of temperature and pollution-controlled technology for storage and transportation of drugs in the pharmaceutical context. This is very important in the pharmaceutical industry since manufacturers deal with sensitive products. Overcoming these risks demands high expenditure and capital, it is hardly surprising that capital-intensive infrastructure is one of the most significant issues in Iran. Warehouses and vehicles for storage and transportation of drugs need to have an intricate temperature and pollution-controlled environment (Lintukangas et al., 2016).

In GSC implementation, it is highly important to consider the high insurance premiums. The main goal of organizations is to provide proper materials that meet the customers' expectations. Hence, both financial and ecological advantages will be acquired (Mohanty and Prakash, 2014). The supplier selection process needs to be done carefully. This process should aim a close supplier-customer relationship which results in a facilitated green material supply (Rostamzadeh et al., 2018). Procurement costs as a large portion of costs, need to be carefully managed in developing countries. Moreover, pharmaceutical companies should also collaborate with suppliers to deliver eco-friendly raw material to minimize its environmental impact. In that sense, supply chain managers in pharmaceutical industry need to consider two important factors: being cost-effective and selecting green suppliers. In developing countries like Iran, green supply chain is a rather raw concept which makes sourcing state of the art machinery and equipment more challenging. Hence, green technology level become more important followed by equipment failure. The managers in the pharmaceutical industry have to be always ready to answer to the customer needs. Regarding the risk of the scarcity of skilled labour, continuous education and well-being have to be provided. Returning the used products by customers for recycling, should be strategized and facilitated by pharmaceutical companies. So, a considerable value gained from those products will improve the GSC performance.

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