Bayesian Belief Network Approach for Supply Risk Modelling

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ABSTRACT

Today's global and complex world increases the vulnerability to risks exponentially, and organizations are compelled to develop effective risk management strategies for mitigation. The prime focus of the research is to design a supply risk model using Bayesian belief network bearing in mind the tie-in of risk factors (i.e., objective and subjective) critical to a supply chain network. The proposed model can be re-engineered as per new information available at disclosure, so risk analysis will be current and relevant along the timeline as the situation is strained. The top three factors which influenced profitability were transportation risk and price risks. Netica is the platform used for designing and running simultaneous simulations on the Bayesian network. The proposed methodology is demonstrated through a case study conducted in an Indian manufacturing supply chain taking inputs from supply chain/risk management experts.

KEYWORDS

Bayesian Belief Network, Modelling, Supplier's Performance, Supply Chain Risk

1. INTRODUCTION

In today's competitive world running a commercial manufacturing organization smoothly and profitably is a daunting task due to presence of uncertainties at various locations of its supply chain network (SCN). Supply chain network of a manufacturing unit consists of activities such as procurement of raw material, transportation, converting into final product, packaging and supplying. It starts with procurement of raw material from a supplier anditcan have one or more than one suppliers. With the increase in competition and decrease in profit margins, organizations needs to implement policies such as globalized supply chain, higher capacity utilization, lower-inventories and just-in-time (Adhitya, Srinivasan, & Karimi, 2009). These policies favours single supplier, as a single supplier reduces complexity of supply network and therefore results in reduction of supply chain cost (Sadgrove, 2005). But a single supplier makesthe supply chain more vulnerable to disruptive risks.

Disruptions not only decrease the supply chain performance but without proper mitigation strategies, supply chain will take long time to recover (Sheffi & Rice Jr, 2005). To prevent supply

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chain networks from disruptions or halt, mitigation strategies have to be made by manager, that's why the use of supply chain risk management is inevitable. Supply-chain risk management (SCRM) in various literatures is defined as implementing the strategies to manage risk in the form of material, financial or information in supply chain with continuous risk assessment and rectification, with the aim of reducing vulnerability and ensuring proper working. Therefore supply chain risk management is a field of growing importance and is aimed at developing approaches for the identification, assessment, analysis and treatment of areas of vulnerability and risk in supply chains"(Neiger, Rotaru, & Churilov, 2009). Iwan et al. (2009) reviewed the Supply-chain risk management (SCRM) literature published from 2000 to 2007. There are four stages in SCRM, first is assessing the sources of risk for the supply chain, and then identifying the drivers of risk. After finding the drivers of risk, define the consequences of the risks on the supply chain and in the last stage development of mitigating strategies for supply chain risk so that it can operate smoothly and efficiently.

This paper has identified the possible sources of risks and their drivers coming from supplier side in automobile sector, and develops strategies to mitigate the consequences of risks. With these sources of risk and their drivers a model is developed using Bayesian belief network. The model is further tested with scenario analysis and sensitivity analysis to propose the risk mitigation strategies. The next section provides the literature on supply chain risk management, supplier selection and Bayesian belief network. The literature review is based on papers published on relevant topics from last 15 years. Section 3 provides the methodology of the present work, with the flowchart showing the steps required for solving the problem. After it, section 4 provides the results and discussion. The last section provides the conclusions and future scope of work.

2. LITERATURE REVIEW

The first step in supply chain risk management is to identify the risks associated with supply chain network from supplier end and to find their possible drivers. Therefore to identify the possible sources of risks in supply chain network a through literature review of the published papers is done and summarised in Table 1.

From the above literature review eight possible sources of risk were identified. But after discussion with the expert, these sources of risk are reduced to four which are very important and also include effect of other sources. After assessing possible source of risk the next step is to look for their possible drivers from the literature survey. Doing this risk model I came up with two possible drivers for each source of risk as explained below and shown in Table 2.

1. **Total Cost:** Total cost of a product includes all the expenses that have been incurred by an organization from ordering a product till it get consumed. It consists of price of a product, transportation cost, inventory cost and other indirect expenses. It is one of the main sources of risk that can enter into the supply chain of the organization, making the final product less competitive in market in term of cost. Total cost had been used by (Mulyati, 2015), (Khodakarami & Abdi, 2014), (Acebes, et al., 2014) in their risk model. Total cost of a product increases when cost of any one of its components increases as given below:
    a. **Price inflation:** It can increase when supplier increases its profit margin or there is shortage of supply with respect to demand or increase in raw material used by supplier or financial instability of supplier.
    b. **Transportation cost:** The main reason for variation in transportation cost is fluctuating fuel price but other reasons can also contribute in its increment such as non-availability of proper transportation mode, transportation union strike or change in government transportation policies etc.

Table 1. Literature review on SCRM

S. No.	Title	Authors and Year	Country	Remarks
1.	A Bayesian network framework for Project cost, benefit and risk analysis with an agricultural development case-study	(Yet, et al., 2016)	Turkey, U.K., Kenya	**Risk**: Political instability, Extreme climate impact, Intuitional efficacy, Cost. **Method**: Bayesian network modelling.
2.	A framework for measuring the performance of supply chain management.	(Cho, Lee, Ahn, & Hwang, 2012)	South Korea	**Risk**: Service-reliability, Responsiveness, Order Process management, Flexibility. **Method**: Fuzzy analytic hierarchy processes.
3.	A new approach for project control under uncertainty. Going back to basics	(Acebes, Pajares, Galán, & López-Paredes, 2014)	Spain	**Risk**: cost. **Method**: Earned Value Methodology and Monte-Carlo simulation.
4.	A review of modeling approach for sustainable supply chain management.	(Seuring, 2013)	Germany	**Risk**: Economic, Environmental, Social. **Method:** Multi- criteria decision making (MCDM), Analytic Hierarchy Processes (AHP).
5.	Supply chain Risk management study of the Indonesian seaweed industry.	(Mulyati, 2015)	Indonesia	**Risk**: Demand, Cost, quality, delivery reliability. **Method**: Multi- criteria decision making (MCDM).
6.	Identify risk issues and research advancements in supply chain risk management	(O. Tang & Musa, 2011)	Sweden, Malaysia, China	**Risk:** Material flow risk, Flexibility, Supply capacity, product flexibility. **Method**: Decision tree based optimizing model, Multivariate analysis.
7.	Mathematical programming model for supply chain production and transport planning	(Mula, Peidro, Díaz-Madroñero, & Vicens, 2010)	Spain	**Risk**: Transportation, Flexibility. **Method**: mathematical modelling.
8.	Purchasing and Supply: An investigation of risk management performance.	(Hallikas & Lintukangas, 2016)	Finland	**Risk:** Price fluctuation, Quality, Accuracy of deliveries, lead time. **Method**: Regression analysis.
9.	Supplier risk management: An economic model of P-chart considered due date and quality risks.	(Sun, Matsui, & Yin, 2012)	Japan, China	**Risk**: Quality, Delay, Cost. **Method:** P- chart Solution model.
10.	Towards an evidence based probabilistic risk model for ship grounding accidents	(Mazaheri, Montewka, & Kujala, 2016)	Finland, Poland.	**Risk:** Ship grounding accidents. **Method:** Evidence based and expert supported probabilistic model.
11.	Risk management processes in supplier networks.	(Hallikas, Karvonen, Pulkkinen, Virolainen, & Tuominen, 2004)	Finland	**Risk:** Delivery reliability, Cost, Flexibility. **Method**: Analytic hierarchy processes (AHP).
12.	The performance evaluation of SCOR sourcing processes- The case study of Taiwan's TFT-LCD industry.	(Hwang, Lin, & Lyu Jr, 2008)	Taiwan	**Risk**: Procurement. **Method:** Supply chain operation reference (SCOR).
13.	Project Cost risk analysis: A Bayesian networks approach for modelling dependencies between cost items.	(Khodakarami & Abdi, 2014)	Iran	**Risk**: Cost. **Method**: Bayesian Network.
14.	Parameterisation and evaluation of a Bayesian network for use in an ecological risk assessment.	(Pollino, Woodberry, Nicholson, Korb, & Hart, 2007)	Australia	**Risk**: Environmental. **Method**: Bayesian network.
15.	A new approach for supply chain Risk Management: Mapping SCOR into Bayesian network.	(Abolghasemi, Khodakarami, & Tehranifard, 2015)	Iran	**Risk:** Cost, Quality, Flexibility, Responsiveness, Asset management efficiency. **Method**: SCOR and Bayesian network.
16.	Supply chain risk identification using a HAZoP-Based approach.	(Adhitya, et al., 2009)	Singapore	**Risk:** Quality, Quantity, Due date. **Method**: HAZard and Operability (HAZoP) analysis.

continued on following page

Table 1. Continued

S. No.	Title	Authors and Year	Country	Remarks
17.	Bayesian belief network-based framework for sourcing risk analysis during supplier selection.	(Nepal & Yadav, 2015)	USA	**Risk**: Port congestion, custom inspection, incorrect bill of landing, price inflation, currency inflation, quality. **Method:** Bayesian network.
18.	Managing Risk to avoid Supply chain Break-down	(Chopra & Sodhi, 2004)	USA	**Risk:** Delays, Systems, Disruptions, Intellectual Property, Inventory. **Method**: Stress testing method.
19.	Perspectives in supply chain risk management.	(C. S. Tang, 2006)	USA	**Risk:** Environmental, demand price, lead time, capacity. **Method**: Probabilistic model.
20.	Reducing the risk of supply chain disruptions.	(Chopra & Sodhi, 2014)	USA	**Risk**: Disruption **Method**: Probabilistic model.
21.	Supplier selection in automobile industry: A mixed balanced scorecard–fuzzy AHP approach.	(Galankashi, Helmi, & Hashemzahi, 2016)	Malaysia	**Risk**: Quality, cost, service and delivery, distance, flexibility, standards consideration. **Method**: Fuzzy and AHP.
22.	Supplier selection using AHP methodology extended by D numbers.	(Deng, Hu, Deng, & Mahadevan, 2014)	China	**Risk:** Cost, quality, service performance, supplier's profile. **Method**: D-AHP.
23.	Analysing risks in supply networks to facilitate outsourcing decisions.	(Lockamy III & McCormack, 2010)	USA	**Risk:** Cost, quality, service performance, natural disasters, leadership change. **Method**: Bayesian Networks.
24.	A fuzzy-Bayesian model for supplier selection	(Ferreira & Borenstein, 2012)	Brazil	**Risk**: Cost, compliance with quality, compliance with due date, lead time. **Method**: Fuzzy-Bayesian approach.
25.	A Model Proposal for supplier selection in Automotive Industry.	(Beşkese & Şakra, 2010)	Turkey	**Risk**: Quality, cost, delivery and service, financial stability. **Method:** Fuzzy-AHP.

Table 2. Sources of Risk and Possible Drivers

Source of Risk	Possible Driver of Risk
Total cost	• Transportation cost • Price inflation
Quality	• Quality certification • Inspection
Flexibility	• Volume flexibility • Product flexibility
Delivery reliability	• Lead time • Order completeness and filling order accuracy

2. **Quality:** Quality of a product is another important source of risk which was used by many researchers for developing their risk models such as (Abolghasemi, et al., 2015), (Beşkese & Şakra, 2010) and many more. This type of risks occurs when a product fails to perform its function during its use. To asses quality risk two of its drivers are discussed below:
    a. **Quality certification:** International organization for standardization is an international organization whose function is to set standards for organizations across the globe (Guide, Harrison, & Wassenhove, 2003). They give quality certification in the fields of management

(ISO 9001), environmental (ISO 14001), social responsibility (ISO 26000) and many more. An organization having these certifications is considered to deliver high quality products.

b. **Inspection:** A product needs to pass through a number of quality checks/inspection tests before being delivered to end customer. If significant number or volume of products fails to pass these quality checksthen there are chances that quality of consignment is poor.

3. **Flexibility:** Flexibility is a trait of an organization which represents its ability to adopt different conditions of market fluctuation in demand and supply. It is very important parameter for measuring performance of any organization and it had been considered by many researchers to measure the supplier's performance like (Galankashi, et al., 2016), (Lockamy III & McCormack, 2010)and (C. S. Tang, 2006). Flexibility can be of two types:
   a. **Product Flexibility:** Means ability to deliver different products; and
   b. **Volume Flexibility:** Refers to ability to deliver products with variable quantity.
4. **Delivery Reliability:** Delivery reliability had been used by many authors for assessing the supplier's performance like (Nepal & Yadav, 2015), (Hallikas & Lintukangas, 2016), (Ferreira & Borenstein, 2012). It represents the quality of a supplier to deliver the products without any delay, deliver correct product and in required quantity. It can be measure by lead time, filling order accuracy or order consistency.

From the above literature review, it is observed that only a few researchers have applied BBN for the analysis of supply chain risk. (Qazi, Quigley, Dickson, & Ekici, 2017) proposed a comprehensive supply chain risk management technique based on Bayesian Belief Networks (BBN), showing causal dependency among risks and risk drivers. (Hegde, Utne, Schjølberg, & Thorkildsen, 2018) used Bayesian Belief Network to model the risk affecting autonomous subsea IMR (Inspection, Maintenance and Repair) operations. The nodes of the BBN model were based upon three main risk categories, i.e. technical, organizational, and operational. (Nepal & Yadav, 2015) presented a paper on supplier selection by taking into account the cost and risk factors. Failure modes effects analysis (FMEA) and Bayesian belief networks were used for quantifying the risks from each factor. The supplier selection decision was based on the total cost of a product which includes purchase costs and the risk-related costs. Their proposed methodology provides a clear picture for supply chain risk managers to see how cost and risks are distributed across the different factors and to calculate expected value of a supplier's performance to avoid a certain risk.

Lawrence et al. (2020) identified potential factors for pharmaceutical supply chain disruption in U.S. under severe weather conditions. (Daultani, Goswami, Vaidya, & Kumar, 2019) focuses on Bayesian network modelling the enterprise level risks from the perspective of an original equipment manufacturer. (Zimon & Madzík, 2019) determined the impact of standardized management systems (ISO 9001, ISO 14001, ISO 22000 and ISO 28000) on minimizing selected aspects of risk in the supply chain. (Kros, Falasca, Dellana, & Rowe, 2019) adopted a contingency theory from a quality perspective to develop a model for assessing the impact of counterfeit prevention efforts on supply chain performance. (Wiengarten, Humphreys, Gimenez, & McIvor, 2016) tried to explore the importance of risk management practices in the successful running of an organization in respect of cost and innovation. They applied relational view technique and found that organizations can strengthen the performance of the supplier through supply chain risk management practices in competitive environment. (Yet, et al., 2016) developed a model based on Bayesian Belief Network for calculating costs, benefits and return on investment of a project over a given time period and accounting for dynamic situations of market. Their BBN model consists of both discrete and continuous random variables and it was used as a basis for many project management assessments. (Sumeet, Mark, Robert, Fanwen, & Miti, 2014) attempted to bring out a schema for analyzing supply chain risks faced by the firm and develop a risk management action framework. (Rajesh Kr, 2014) identified major factors responsible for coordination in the food supply chain and developed a framework to quantify the effectiveness of coordination in the food supply chain.

After studying the literature, it is observed that extensive work had been done on modelling risks by different techniques for various sectors and conditions but none of them explored the possibility of developing the risk model for automobile industry based on Bayesian Belief Network technique for assessing a supplier's performance. In this paper, we try to develop such risk model based upon BBN which can be used by mangers for assessing the four fundamental risks i.e. Total Cost, Quality, Flexibility and Delivery Reliability for their organization and able to develop mitigation actions for reducing the negative consequences on their network.

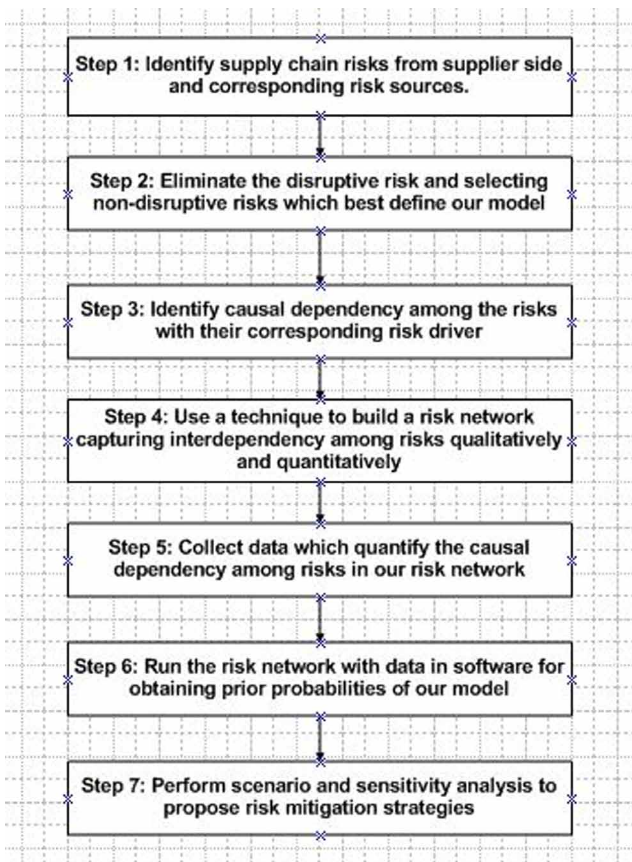
3. METHODOLOGY

Figure 1 shows the step by step procedure to propose the mitigation strategies for averting the negative consequences of non-disruptive risks coming from supplier side for an automobile industry.

3.1 Selection of Risks and Their Drivers

First step is to select non-disruptive risks suitable for an automobile industry. From the literature review on supplier selection for an automobile industry and discussing with industry experts four categories of risks and their drivers are selected as shown in Table 1.

Figure 1. Methodology



3.2 Bayesian Belief Network

A Bayesian belief network is the representation of joint probability distribution of a set of random variables with possible mutual causal relationship. The Bayesian belief network consists of nodes representing the random variables, edges between pairs of nodes representing the causal relationship of these nodes and a conditional probability distribution tablefor each of the nodes. The primary objective of the method is to obtain the posterior conditional probability distribution of the outcome (often causal) variable(s) after entering new evidence in the model (Horny, 2014). Bayesian belief networks are the concept of probabilistic inference. Inference refers to the fact that we have prior beliefs of the world around us structured in the form of Bayesian belief network. When we assume that a particular event in our network has occurred, we must update all our beliefs that are dependent on that event which we assume to occur; this leads to a posterior belief (Garvey, Carnovale, & Yeniyurt, 2015).

BBN are graphical probabilistic models based on Bayes' theorem; Bayes' theorem expresses the relation between the dependent variables. When we have a prior belief (prior probability) about an event and observe some evidence about this event, we can revise our belief by using Bayes's theorem. Mathematically Bayes theorem can be stated by equation (i) as follows:

$$P\left(\frac{A}{X}\right) = \frac{\mathrm{P}\left(\mathrm{X} / \mathrm{A}\right) * \mathrm{P}\left(\mathrm{A}\right)}{\mathrm{P}\left(\mathrm{X} / \mathrm{A}\right) * \mathrm{P}\left(\mathrm{A}\right) + \mathrm{P}\left(\mathrm{X} / \text{not A}\right) * \mathrm{P}\left(\text{not A}\right)} \quad (1)$$

where P (A), the prior, is the initial degree of belief in A, P(A | X) denotes the "posterior," is the degree of belief having accounted for X, P(X/A) is conditional probability, the likelihood of occurrence of X given event A occur.

BBN consists of a graphical representation of variables and a set of probabilistic parameters. The graphical network of BBN is a directed cyclic graph. But the cycles are not allowed among the nodes. If there is an arc from node X to Y, it means node X is parent of node Y, and node Y is child of node X. The parameters of a BBN are tabulated in Node Probability Tables (NPT). Each node has an assigned NPT that defines the conditional probability distribution of that node based on its parents. Each event can take two possible states i.e. True or False.

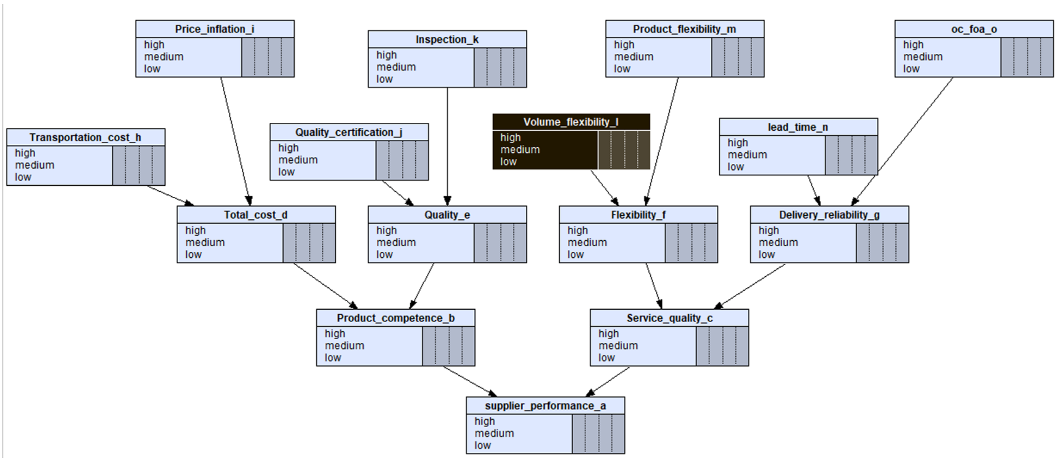
The advantage of using BBN for analysing the risks in a supply chain network is that if any change occurs at any variable, its effect will be reflected on other variables which depends on it, either upstream or downstream. Bayesian belief network vividly captures this causal dependency among variables and also able to calculate mathematically the changes that will occur at various variables due to change occurring at a single variable. The advantages of using Bayesian belief network over other techniques for analysing a probabilistic risk model are as follows:

1. It shows a vivid and clear representation of joint probability distributions and causal dependency among random variables.
2. It offers a powerful way of making probabilistic inferences and learning.
3. They can be used for updating prior probabilities based upon experts experience or evidence for obtaining post probabilities.

4. CONCEPTUAL MODEL

Now we will construct the graphical representation of risk model using Bayesian belief technique. For building and analysis of Bayesian belief network many software's are available such as GeNIe, Netica, Agena risk and many more. Netica is used in the present work. Bayesian belief model using Netica is given in Figure 2.

Figure 2. Bayesian belief network model in Netica



In the proposed BBN causal model, three states i.e. High, Medium & Low are proposed at each node. Reason for choosing three states depend on the trade-off between model accuracy and complexity. The description of each node is given in the Table 3.

The next step is to collect data for node probability table for each node, for which, a questionnaire was constructed for each primary risk driver. This questionnaire along with definition of states and node probability tables was shared with the mangers of automobile industry. The data obtained is known as prior probabilities of model. After receiving the data, the model was solved using Netica software and the results obtained, are discussed in the next section.

5. RESULTS AND DISCUSSION

Figure 3 shows prior probabilities for each node obtained from Bayesian belief risk model with the data obtained from experts. The last node of the model shows the performance of supplier by high, medium and low states of probabilities. The prior probabilities of last node are shown in Table 4.

Now two types of analysis are done on Bayesian belief risk model, to investigate that how risks can propagate in a network or how much is the negative impact on supplier's performance when any risk in the model is set to 100%. Scenario analysis is used for aforementioned purpose. Sensitivity analysis is also done on the model to see its robustness with respect to its parameters.

5.1 Scenario Analysis

The proposed model is investigated under different scenarios, i.e. how the posterior probabilities of the supplier's performance change when there is a change in the states of other nodes. In this analysis the state of one of the node is changed to High or Low keeping other nodes at their prior probabilities and observed the change that will occur at supplier's performance node. We did this for 12 different scenarios using Netica, and the results are tabulated in the Table 5.

Scenario analysis shows that if Price inflation, Transportation Cost or Total Cost is kept at H=100%, it will reduce the high performance of the supplier performance. And the impact of Total Cost is maximum on supplier performance, which reduces it by 5.3 points. Similarly if

Quality certification, inspection, quality, volume flexibility, product flexibility, flexibility, lead time, OC & FOA or delivery reliability is kept at L=100% it also reduces the supplier high performance and the impact of Quality is maximum which reduces the supplier performance by 8.3 points.

Table 3. Description of states at each node

S.No.	Risk	Description
1.	Transportation Cost	H:- If % increase greater than 10%. M:- If % is between 10% to 5%. L:- If % increase less than 5%.
2.	Price inflation	H:- If % increase in base price greater than 10%. M:- If % increase in base price in between 10% to 5%. L:- If % increase less than 5%.
3.	Quality Certification	H:- Supplier has ISO 9001:2010/2015 and ISO 14000. M:- Supplier has ISO 9001:2010/2015. L: Supplier has no quality certification.
4.	Inspection	H:- Material rejection is less than 1%. M:- Material rejection is between 1% to 3%. L:- material rejection is greater than 3%.
5.	Volume flexibility	H:- Supplier able to provide greater than 1.75 times of previous quantity. M:- Supplier able to provide between1.25 to 1.75 times of previous quantity. L:- Supplier able to provide less than 1.25 times of previous quantity.
6.	Product flexibility	H: Supplier able to provide more than 10 different products. M:- Supplier able to provide between 5 to 10 different products L: Supplier able to provide less than 5 different products.
7.	Lead time	H:- Delay less than 5 days. M:- Delay in between 5 to 10 days. L:- delay greater than 10 days.
8.	Order completeness and filling order accuracy (OC and FOA)	H:- Delivery is 100% accurate. M:- Delivery has accuracy between 95% to <100%. L:- Delivery has accuracy less than 95%.
9.	Total cost	H:- Total increase in cost is greater than 10% M:- Total increase in cost is in between 5% to 10% L:- Total increase in cost is less than 5%
10.	Quality	H:- Material rejection during processing is less than 1% M:- Material rejection is in between 1% to 3% L:- Material rejection is greater than 3%
11.	Flexibility	H:- If state is H in both volume and product flexibility. M:-If state is H in any one of them. L:- If state is not H in any one of them
12.	Delivery reliability	H:- If state is H in both lead time and OC & FOA M:- If state is H in any one of them L:- If state is not H in any one of them
13.	Product competence	H:- If state is H in both total cost and quality M:- If state is H in only one of them L:- If state is not H in any one of them
14.	Service Capability	H:- If state is H in both flexibility and delivery reliability M:- If state is H in only one of them L:- If state is not H in any of them
15.	Supplier's performance	H:- If state is H in both product competence and service. M:- If state is H in only one of them L:- If state is not H in any one of them

5.2 Entropy and Mutual Information

The entropy of a random variable is a function which is used to quantify the unpredictability or uncertainty of a random variable. Entropy is not just about the number of possible outcomes but it is also about their frequency.

Entropy has a precise mathematical definition. In particular, if a random variable X takes on values in a set € ={a,b,c,d,…….z} and is denoted by a probability distribution P(X), then entropy of the random variable is given by:

Figure 3. Prior probabilities of the model in Netica

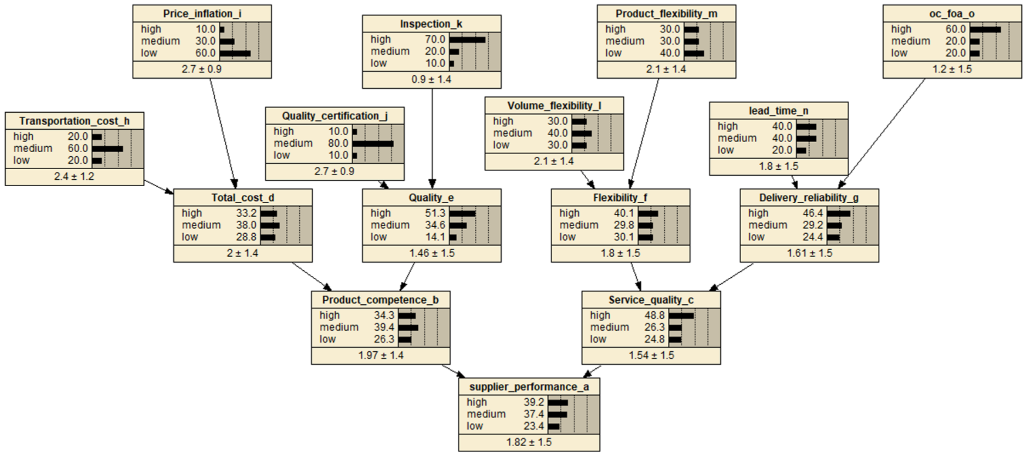


Table 4. Prior probabilities of supplier's performance from Netica

S.No.	Prior Probabilities of Supplier's Performance	
1.	High	39.2%
2.	Medium	37.4%
3.	Low	23.4%

$$H(X) = -\sum P(x) \cdot \log P(x) \quad (2)$$

If the log in the above equation is taken to be to the base 2, then the entropy is expressed in bits. If the log is taken to be the natural log, then the entropy is expressed in nats. More commonly, entropy is expressed in bits, and unless otherwise noted, we will assume a logarithm with base 2. The entropy at each of the 15 nodes in the proposed Bayes network is calculated using Netica and its results is tabulated below in Table 6.

From the Table 6 we can see that Quality Certification has least amount of unpredictability and Total Cost has the highest amount of unpredictability.

Mutual information is a concept that calculates a relationship between two random variables that are sampled simultaneously. It measures how much information is communicated, on average, from one random variable about another. Intuitively, it tells, how much does one random variable tell us about another?

The mathematical definition of the mutual information of two random variables X and Y, whose joint distribution is defined by P(Q; R) is given by:

$$P\left(Q;R\right) = \sum\sum P\left(q,r\right) log\left(P\left(q,r\right) / P\left(q\right) * P\left(r\right)\right) \quad (3)$$

In this definition, P(Q) and P(R) are the marginal distributions of Q and R.

Table 5. Scenario analysis

S.No.	Scenario	% Change in Supplier's performance (Netica)	Difference
1.	Price inflation H = 100%	H - 39.2 to 36.4	-2.8
		M - 37.4 to 38.1	0.7
		L - 23.4 to 25.5	2.1
2.	Transportation Cost H = 100%	H – 39.2 to 37.9	-1.3
		M - 37.4 to 37.9	0.5
		L - 23.4 to 24.2	0.8
3.	Total Cost H = 100%	H - 39.2 to 33.9	-5.3
		M - 37.4 to 38.7	1.3
		L - 23.4 to 27.4	3
4.	Quality certification L = 100%	H - 39.2 to 37.6	-1.6
		M - 37.4 to 37.8	0.4
		L - 23.4 to 24.5	1.1
5.	Inspection L = 100%	H - 39.2 to 36.0	-3.2
		M - 37.4 to 38.2	.8
		L - 23.4 to 25.8	2.4
6.	Quality L = 100%	H - 39.2 to 30.9	-8.3
		M - 37.4 to 39.1	1.7
		L - 23.4 to 30.0	6.6
7.	Volume flexibility L = 100%	H - 39.2 to 36.8	-2.4
		M - 37.4 to 38.4	1
		L - 23.4 to 24.8	1.4
8.	Product flexibility L = 100%	H - 39.2 to 37.1	-2.1
		M - 37.4 to 38.3	0.9
		L - 23.4 to 24.6	1.2
9.	Flexibility L = 100%	H - 39.2 to 31.8	-7.4
		M - 37.4 to 40.0	2.6
		L - 23.4 to 28.2	4.8
10.	Lead time L = 100%	H - 39.2 to 36.3	-2.9
		M - 37.4 to 38.5	1.1
		L - 23.4 to 25.1	1.7
11.	OC & FOA L = 100%	H - 39.2 to 37.0	-2.2
		M - 37.4 to 38.3	0.9
		L - 23.4 to 24.8	1.4
12.	Delivery reliability L = 100%	H - 39.2 to 31.0	-7.2
		M - 37.4 to40.2	2.8
		L - 23.4 to 28.8	5.4

Table 6. Entropy at each node using Netica

S.No.	Risk driver	Entropy
1.	Transportation cost	1.37095
2.	Price inflation	1.29546
3.	Quality certification	0.92193
4.	Inspection	1.15678
5.	Volume flexibility	1.57095
6.	Product flexibility	1.57095
7.	Lead time	1.52193
8.	OC&FOA	1.37095
9.	Total cost	1.57579
10.	Quality	1.42228
11.	Flexibility	1.57052
12.	Delivery reliability	1.52915
13.	Product competences	1.56589
14.	Service reliability	1.51110
15.	Supplier's performance	1.55039

Using this equation the mutual information of all nodes w.r.t. supplier's performance is calculated and shown in Table 7. From Table 7 we can see that product competences have maximum effect and Quality certification has least effect on supplier's performance.

5.3 Sensitivity to Parameters Analysis

In sensitivity analysis, the effect of change in states of input parameters on supplier's performances evaluated. The state of every node in the model is varied between the predefined limits. The purpose of sensitivity analysis is to measure the robustness of the model for the changes in its parameters.

Table 7. Mutual Information of supplier's performance

S.No.	Node	Mutual Information
1.	Transportation cost	0.00018
2.	Price inflation	0.00117
3.	Quality certification	0.00011
4.	Inspection	0.00048
5.	Volume flexibility	0.00100
6.	Product flexibility	0.00060
7.	Lead time	0.00119
8.	OC and FOA	0.00045
9.	Total cost	0.00612
10.	Quality	0.00585
11.	Flexibility	0.00980
12.	Delivery reliability	0.00936
13.	Product competences	0.11060
14.	Service reliability	0.09500

In this analysis first set the High state of supplier's performance as the target node and run the sensitivity analysis of parameters. The results are shown in the tornado graph shown below Figure 4. Changes in the probabilities of all states of other nodes were kept between 10% and investigated how much change occurred in the probability of high state of supplier's performance. The initial probability of supplier's performance in high state, before any change, is 0.384395. By changing the other parameters 10%, this probability value can be changed between 0.370065 and 0.398624. In other words, this variable is not sensitive to changes in other variables. The model developers can assess the robustness of their model and sequence the most sensitive variables so that they can define more accurate values for their parameters.

Tornado graph shows the relative importance of parameters on outcome variables. The outcome variable "supplier performance" is impacted by the different parameters like inflation and price variations etc. Sensitivity analysis shows % change in outcome variable with % change in various parameters. Bar length shows the relative importance of all the parameters.

6. CONCLUSION AND FUTURE SCOPE OF RESEARCH

In this paper, Bayesian belief network is used to build probabilistic decision support model based on expert knowledge. BBN had been used in many areas of research such as medical science, economics, engineering etc. but its use in risk management for a business organization is presently scarcely. Due to its unique ability to capture the causal dependency among random variables and compute probabilities efficiently makes it a good choice for analysing risks that may be inducted from a supplier side. The research has shown that total cost and quality along with transport risk and price risk (raw materials and commodities) are most significant factors affecting supplier performance. Two different analyses are done on risk network using BBN, i.e.scenario analysis and sensitivity analysis. In scenario analysis posterior probabilities of supplier's performance are obtained after entering evidence at other nodes. If High state of supplier's performance node is greater than 33% then the supplier is performing well and if it is less than 33% then it means there are chances of risk in the supply chain network in any form of total cost, quality, flexibility or delivery reliability. The reason to choose 33% for high state is that, there are three states in total for a node, so high state should be at least one third of the total.

Figure 4. Tornado graph of the model

From scenario analysis it is observed thatby changing High state of Total cost node and Low state of nodes Quality, Flexibility and Delivery reliability to 100%, the high state of supplier's performance goes below 33%. If we change state of primary risk driver nodes either High or Low to 100%, the supplier's performance is above 33% but if more than one primary node fails then supplier's performance may go below, thereby indicating the entering of risks into supply chain network. The mangers must look into the matter and try to find out the reason for it; they must talk to the supplier and try to resolve the problem. If High state is going down below 33% frequently, then the managers must look for another supplier.

The inability to include all relevant risks into the model could limit its efficiency in representing a more accurate riskmodel. It can be improved by adding more states to each node but it will make the model too complicate to solve and also data set required will increases exponentially. The developed model accuracy can be measured by comparing its results with actual risk scenarios happening. This can be validated in future by keeping two sets of data, analysis sample and validation sample. A similar model can be developed for other sectors, which have high interdependencies and may have an impact on the economy in a major way.

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