System dynamics approach for risk assessment in foodgrains supply chain

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Abstract

The unexpected risk event can have a negative effect on the operations of foodgrains supply chain (FSC). In this regard, this paper aims to model the complex interactions and dynamic risk effects on the performance of a FSC. This paper suggests a novel modeling and simulation process to elaborate the dynamic risk impact on the FSC. This research helps the researchers to critically examine the effects of important risks on foodgrains supply chain system. Based on the outcome of the simulation, risk mitigation policies can be suggested. This can help in improving the effectiveness of the FSC system.

Keywords: Foodgrains supply chain, System dynamics, and Risk management

Introduction

Foodgrains supply chain (FSC) involves several stages such as procurement, storage, movement, quality control and delivery of foodgrains in the different states of a country. As per the CAG report (2013), annually 50% of foodgrains are wasted in India. This is due to inadequate storage facility, poor packaging, in transit loss and communication failure. India is a highly populated country, and it is a severe challenge to transport the adequate amount of foodgrains to satisfy the demand of the needy people. To ensure the availability of the foodgrains government has formalized the public distribution systems (PDS) for distributing the foodgrains at reasonable prices to beneficiaries. The PDS is run mutually by central and state governments. While the duty of the central government (through FCI) is to procure, store, and transport foodgrains from procurement center to central FCI godowns located all over the country. The duty of state government is to transport foodgrains to FCI owned/hired warehouse of states and distribute to the needy people through the fair price shops.

In India, the FSC is extremely complex, and it includes a substantial number of stages in the distribution process. Unforeseen or risky events can have a negative impact on the overall FSC operations which could affect the performance of the system. In view of this, supply chain managers need to incorporate the strategies which could help to manage FSC to improve the efficiency and effectiveness of the SC operations.

In the current state-of-the-art literature, supply chain risk management has gained substantial attention which will be helpful for managing hazardous events (Ghadge et al., 2012; Boadi et al., 2015; Dong and Cooper, 2016). Risk in FSC faces severe challenges owing to inadequate storage facility, malfunctioning, poor packaging and preservation, unavailability of storage, and natural disaster. All these issues negatively affect the smooth flow of foodgrains. In order to maintain the smooth flow of foodgrains, it is essential to investigate the risk scenarios to accommodate the hazardous and risky events in FSC. To evaluate the dynamic risk event, system dynamics (SD) simulation approach is used in this research.

The key advantage of adopting an SD simulation approach is that it can incorporate many complexities and intricacies of a system with moderate amount of information. Other traditional simulation approaches such as Monte Carlo simulation, discrete event simulation are not enough to capture such scenarios efficiently. SD can help to understand the real situation mimicking the actual scenario, and it is easy to observe the dynamic impact of the risks during time period. Hence, SD can help to decision makers and managers to improve the FSC performance (Fisher et al., 2000).

The remaining paper is structured as follows. Section 2 describes the literature review. Section 3 includes the development of SD model which involves the creating of causal loop diagram by building a stock and flow diagram using Vensim software. Section 4 highlights the results of the SD simulation approach. Managerial implications will be discussed in Section 5. Section 6 concludes the paper.

Literature Review

Risk management in food supply chain has been addressed by several researchers (Assefa et al., 2016; Barker et al., 2010; Fredriksson and Liljestrand, 2015). For analyzing the supply chain approaches for perishable foods, Dreyer et al. (2016) recommended an analytical framework. Similarly, Ackerley et al. (2010) divided the risk factors into several categories for food transportation safety problem in the case of developed country. However, most of the existing researchers are not able to capture the dynamic feedback effects and complex interactions of the important factors. These effects can deteriorate the reliability of the risk management system. The government of India has taken necessary measures and direction for the quality and safety of the foodgrains (Zhou and Wan, 2006). All these measures are crucial for avoiding the risk scenarios related with inadequate storage facility, poor packaging, in transit loss and communication failure (Dong and Cooper, 2016; CAG report, 2015). The current state-of-the-art literature addresses the adequate efforts while reporting the risk management in several areas such as chemical transportation, construction project, electronics industry, etc. (Assaf and Al-Hejji, 2006; Li et al., 2016; Sodhi and Lee, 2007). For the perishable food supply chain, Prakash et al. (2017) recommended the risk mitigation strategy. Chaudhuri et al. (2016) suggested the risk drivers that can have an adverse effect on the food processing chain and proposed the risk mitigation approaches. Diabat et al. (2012) recognized and ranked the several risks that can affect the FSC. However, the literature highlighted a very limited attention in modeling of risks in the domain foodgrains supply chain. Hence, it is necessary to investigate the risk scenarios which can analyze the hazardous and disruptive actions in FSC.

In this research, SD is used for modeling and analysing of dynamic risk impact for FSC. SD is developed by the Forrester (1961) for predicting the dynamic behavior of the system and to evaluate the effectiveness of decision-making capability using simulation. SD method is most widely used in many industries for analyzing the risks (Bouloiz et al., 2013; Chen et al., 2002; Ehlen et al., 2014). For a non-perishable food product, Kumar and Nigmatullin (2011) implemented the SD approach to examine the behavior and relationship. Minegishi and Thiel (2000) analyzed how the SD can help to improve the complex behaviour of the logistics of the food product. Georgiadis et al. (2005) adopted the SD approach to handle the strategic problems for FSC. Other simulation techniques can be used for generating the risk scenarios. In this study, SD approach is used to deal with the FSC risk because it can address the dynamic risk effect which can governed by the feedback effect (Li et al., 2016).

The objective of this paper is not only to use the SD approach for calculation the dynamic risk impact, but also it investigates to develop key managerial insight for the practitioner and managers. This study provides few valuable insights into the present body of knowledge. First, the risks in FSC have acquired inadequate consideration in the existing research. Second, this paper highlights how the dynamic risks can affect the food supply system in a developing country like India, an area which has not received considerable attention in the existing literature.

Research Methodology

This study applies the SD simulation approach to study the effect of risks in FSC in India. SD modeling and simulation process involves several steps. The steps include the describing the problem, which involves the problem background, contextual settings, and system boundary. Depending upon the problem, key variables are identified in the second step. In this step, interaction of the key variables is defined. In third step, we develop a causal loop diagram. Generation of stock and flow diagram is done in step four. In step five, set of various risks are inserted in the developed model. In step six, we standardize the system performance with consideration of the risks which permits us to analyze and measure the adverse risk in FSC.

System Dynamics model structure- Causal loop diagram

In India, foodgrains are procured from the farmers at minimum support price, and it is kept at central FCI warehouse and based on the demand of state government, foodgrains are distributed through suitable mode of transport (train or trucks). Actual inventory level can be measured based on the procured quantity, capacity of warehouse and amount transported. Figure 1 (a) represents the causal loop diagram of FSC system. This diagram depicts the different feedback loops who govern the changes in the FSC system. Backlogged order will be generated if a particular warehouse fails to fulfil the demand of the subsequent warehouse. Labor availability for loading and unloading of the foodgrains is also considered which depends upon the procurement quantity and labor force. The '+' and '-'sign represents the causality of the two factors. The source of the arrow defines the causal factors and point of the arrow defines the effect factors. If the cause and effect factors have the same tendency, then it follows the '+' sign, and for opposite tendency, it follows the '-'sign.

System Dynamics model structure- Stock and flow diagram

In the next section, causal loop diagram is converted into a stock and flow diagram. Vensim software is used for the construction of stock and flow diagram, causal loop diagram. Figure 1 (b) represents the stock and flow diagram. Stock is represented in blocks. Stocks describe the state of the system and deliver the basis for actions. Flow is used to pass the information in the system, and it governs the change of the system. A flow variable is calculated over the period of time. So, the flow is measured per unit of time. In this study, actual inventory level and labor availability are considered as stock, and it demonstrates the accumulation of inventory and the labor respectively.

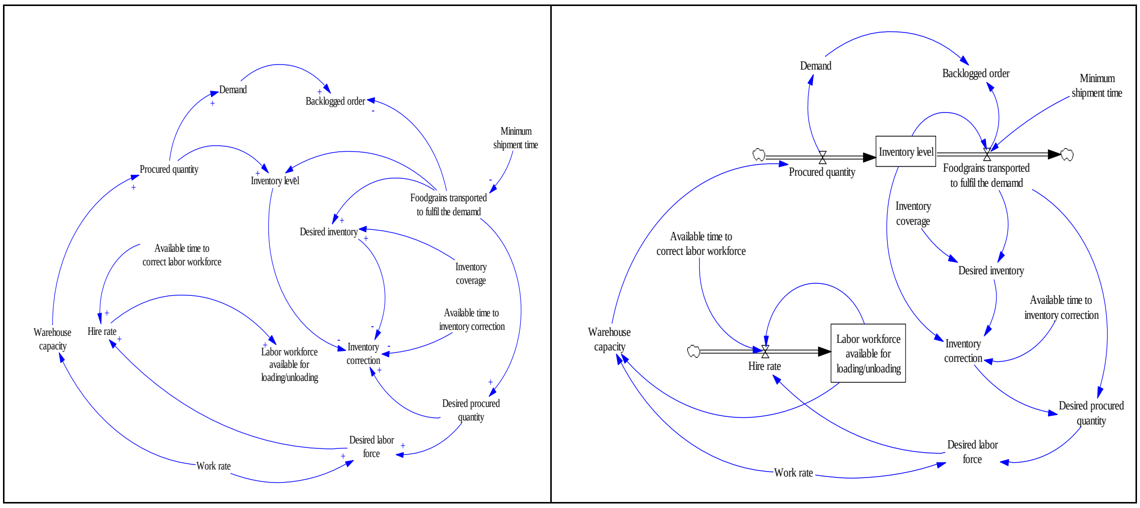

Figure 1 – (a) Causal loop diagram (b) Stock and flow diagram of FSC system

The developed FSC model is a system that allows for the occurrence of major hazardous or risky events. This event disrupts the FSC system and affects the efficacy of the system. With the help of SD simulation, behaviour of the system is obtained while generating the risk scenarios, which delivers the qualitative information of the system. Table 1 highlights the key variables used for the formation of SD model.

Table 1 – Description of the key variables used in SD model

Variable name	Type	Unit	Equations
Inventory level	Stock	Metric tonne (MT)	INTEG (Procured quantity-Foodgrains transported to fulfil the demand,0)
Labor workforce available for loading/unloading	Stock	Person	INTEG (Hire rate,3000)
Backlogged order	Flow	MT/Week	IF THEN ELSE(Demand> Foodgrains transported to fulfil the demand, Demand-Foodgrains transported to fulfil the demand,0)
Procured quantity	Flow	MT/Week	MIN(Warehouse capacity, Demand)
Foodgrains transported to fulfil the demand	Flow	MT/Week	Inventory level/Minimum shipment time
Desired inventory level	Flow	MT	Foodgrains transported to fulfil the demand*Inventory coverage
Labor hire rate	Flow	Person/ Week	((Desired labor force-“ Labor workforce available for loading/unloading ”)/Available time to correct labor workforce)

Inventory correction	Flow	MT/Week	(Desired inventory level-Inventory level)/Available time to correct inventory
Desired labor force	Flow	Person	Desired procurement quantity/Work rate

Initial operating condition

For each factors such as inventory level, procured quantity, demand, labor work force, etc., we set their initial values. For this study, time period is set to 1 year. This initial condition is termed as reference condition. Based on these conditions, we run the simulation model. The obtained results are highlighted in Figure 2. Foodgrains transported quantity is varied between 1600 MT/Week and 2100 MT/Week. The inventory level varies between 2700 MT and 4100 MT. Similarly, backlogged order is varied between 0 MT and 1870 MT. This performance of the FSC system is considered as a base line and characterized as initial operating condition for calculating the risk scenarios simulation.

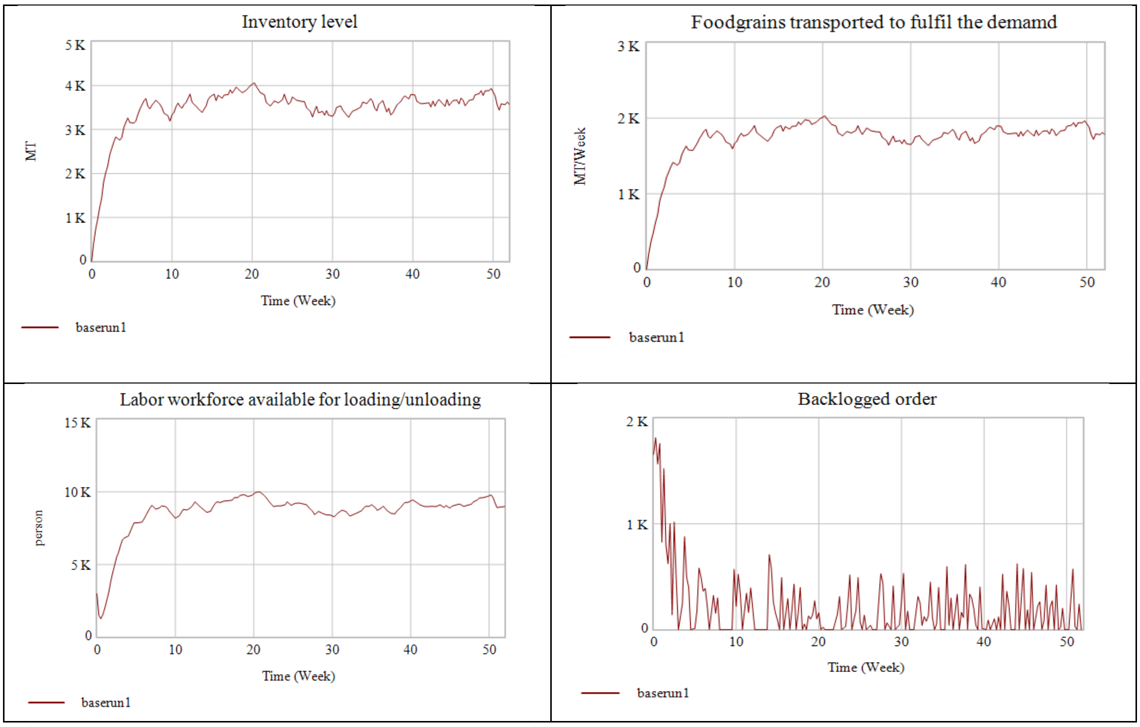

Figure 2 – Initial operating condition of FSC system

Integration of risk in the existing SD model

In this study, seven major risks are considered for generating the risk scenarios. The risk contains availability issues of storage, poor packaging and preservation, malfunctioning in PDS, labour strike, inadequate capacity, forecasting error and communication failure. In this section, the risks are considered as an auxiliary variable and it is incorporated in the developed model. We calculated the parameter index value based on the developed grey-AHP and grey-TOPSIS framework (Rathore et al., 2017). This value is considered as input for the developed SD model. Values of parameter index along with factors values used for constructing SD model are presented in the Table 2. Figure 3 demonstrates the integration of risk in the existing SD model. For each risk, we developed separate risk scenario simulations and checked how the FSC behaves when some hazardous event occurs.

Table 2 –Description of the key variable used in developing SD model

Type of variable	Variables	Initial value	Unit
Constants	Minimum shipment time	2	Weeks
	Available time for inventory correction	1	Weeks
	Warehouse capacity	3500	MT
	Available time to correct labor workforce	1	Weeks
Parameter index values of risks	Availability of Storage- Warehouse (R1)	0.7446	-
	Poor packaging and preservation (R2)	0.7359	-
	Malfunctioning in PDS (R3)	0.4123	-
	Labour strike (R4)	0.6802	-
	Inadequate capacity (R5)	0.8799	-
	Forecasting error (R6)	0.1846	-
	Communication failure (R7)	0.8630	-
Level variables	Inventory level	0	MT
	Backlogged order	0	MT
	Labor workforce available for loading/unloading	3000	Persons

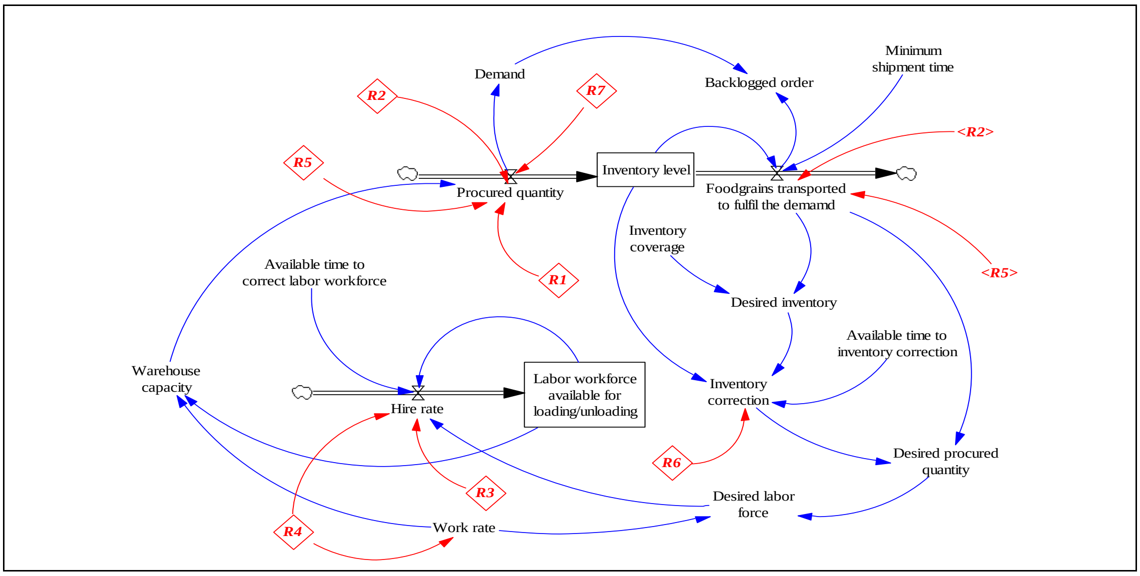

Figure 3 – SD model with integrated risks

Findings

In the developed model, the analysis is done considering the time horizon of one year (52 months). Model input and information have been collected from the available literature and interviews conducted with the officials of FCI. In this work, seven major risks are considered. Based on these risks seven risk scenarios are generated. Table 3 shows the system behaviour under the presence of different risks. It represents the effects of the several risks, and delivers the quantitative facts to screen out the substantial risks. For generating the meaningful insights, Table 4 is extracted from Table 3. For the first risk "*Availability of Storage- Warehouse*", it can be anticipated that the average inventory level has increased by approximately 16.06% from the initial value. Due to occurrence of the risk, warehouse fails to satisfy the demand, which shows the reduction in order fulfilment rate which is termed as backlogged order. It has been observed from Table 4 that there is 18.01% reduction in backlogged order during the simulation period. In the considered foodgrains supply chain system, the major sources of risks are availability of storage- warehouse, malfunctioning in PDS and labor strike.

The result obtained from this study could help the policy-makers and managers to design a better and responsive FSC system. Based on the outcomes of the simulation, risk mitigations strategy can be suggested. For increasing the storage capacity, FCI can tie up with a third party. Use of modern technology such as GPS technology for tractability, development of online PDS, inclusion of steel silos and silo bags, computerized allocation to FPS, web based portal, etc. can help to lessen the possibility of malfunctioning.

Table 3 - The description of SD simulation results of different risk scenarios

	Inventory level		Labor workforce available for loading/unloading		Backlogged order	
Availability of Storage-Warehouse	Max	186.29	Max	2294	Max	3000
	Min	0	Min	465	Min	942
	Avg	184.6	Avg	485	Avg	1713.12
Poor packaging and preservation	Max	194.54	Max	2489	Max	3000
	Min	0	Min	446	Min	0
	Avg	194.4	Avg	777	Avg	1796.54
Malfunctioning in PDS	Max	868.6	Max	2034	Max	4666.65
	Min	0	Min	569	Min	0
	Avg	708.6	Avg	876	Avg	1997.54
Labour strike	Max	601.3	Max	2411	Max	3813.3
	Min	0	Min	187	Min	987
	Avg	493.1	Avg	1286	Avg	1234.6
Inadequate capacity	Max	675.17	Max	2914	Max	3000
	Min	0	Min	435	Min	678
	Avg	569.168	Avg	445	Avg	1796.54
Forecasting error	Max	775.17	Max	2204	Max	3000
	Min	0	Min	461	Min	942
	Avg	369.168	Avg	482	Avg	1713.12
Communication failure	Max	786.29	Max	2094	Max	3813.3
	Min	0	Min	405	Min	987
	Avg	584.6	Avg	405	Avg	1734.6

Table 4 -The comparison of the risk scenario simulation with initial operating situation

	Inventory level (%)	Labor workforce available for loading/unloading (%)	Backlogged order (%)
Availability of Storage-Warehouse	16.06	18.1	-14.63
Poor packaging and preservation	8.1	12.7	-14.19
Malfunctioning in PDS	10.5	16.2	-13.47
Labour strike	14.01	16.7	-14.22
Inadequate capacity	10.8	11.9	-14.62
Forecasting error	9.7	12.71	-14.33
Communication failure	2.45	1.097	-8.8

Practical implications

This research helps the researchers and practitioners to critically examine the effects of important risks on overall foodgrains supply chain system. Based on the outcome of the simulation, risk mitigation strategy is suggested. This strategy can help in improving the effectiveness of the foodgrains supply chain system. One of the significant advantages of the developed system dynamics model is that practitioners and managers can detect and investigate how the existence of the risks would affect the performance of the system over a given period of time. Furthermore, the developed SD model is intuitive, easy and convenient for managers to implement. Developing an effective risk management for efficient FSC system is important. From the present literature, it has been observed that dynamic risk impact on supply chain and interrelationship of the risk for managing the risks are absent. This study tries to narrow this gap by presenting a SD model for FSC and it represents how the dynamic risk impacts the existing FSC. This research found that there is a significant difference between system performance while considering the risk interaction and without risk interaction. Particularly, while consideration of the risk, average inventory level increases up to 10.23% and order fulfillment rate which is termed as average backlogged order is decreased up to 13.46%. The findings of this research suggest that it is necessary to consider the impact of the dynamic risk on the FSC system to understand and enhance the performance of the system.

Conclusion and future scope

This research has investigated how the dynamic risk can impact the performance of the FSC. This study exposed that three major risks availability of storage- warehouse, malfunctioning in PDS and labor strike critically affect the FSC system. The outcome of this study will help to adopt the various risk mitigations measures. The proposed approach is considered as an intermediary approach among the frequently used approaches like empirical study and mathematical modeling. The classification of the risks is done based on the expert comments who is working as managers in FCI and the available literature. The parameter index value is calculated based on the risk assessment framework which is based on the Grey-AHP and Grey-TOPSIS.

This research explains the causality between the factors, dynamic behavior of the risks and its implication to FSC. This can help the FCI managers to understand the system performance with and without the risk which can ultimately help in suggesting the risk mitigation strategies. For making strategic, and tactical level decisions, FCI can implement the proposed SD modeling approach and recommendations for improving the food safety during the supply to different channels.

Generation of risk scenario simulation is done by inserting parameter index value of the risk, and the calculation of this value is based on expert comments. It has been observed that the nature of feedback from expert might be a source of bias. For validating the existing research, it needs to be verified by using a comparative analysis which includes statistical approach.

In this study, we did not consider cost parameter, vehicle, and transportation capacity factors. These factors could be considered for future research. In the developed model, economic aspect is also missing which can also be considered while developing the model. Integration of this factors could help in analyzing the FSC system more critically and helps to enhance the effectiveness of the system performance.

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