Risk Probability Assessment Model Based on PLM's Perspective Using Modified Markov Process

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Abstract. The management of the supply chain in presence of uncertainty is a challenge task. This paper proposes a stochastic model for modeling both the structure and the operation of the supply chain. Existing approaches for this task are either deterministic or single level structure which might not be appropriate to capture the essences of the supply chain. The proposed method employs the Markov chain model as the foundation and incorporate the concept of multi-level. The levels are used to model both the internal events and the external events. In the proposed method, the product life cycle management is used as a guiding principle to identify each component of the supply chain.

Keywords: Product life cycle management; supply chain uncertainty; modified Markov process; stochastic process; risk assessment.

1   Introduction

Dealing with such complex and uncertain environments, especially when you are the company within a large supply chain, it is a very difficult task and it is also hardly foreseeable for what would be coming onward every day. Today, supply chains or companies have to deal with several types of uncertainty and of course, several kinds of risk. Complex growth of supply networks, economic systems, globalization or natural disasters for instance, have brought up new types of uncertainty that could put supply chains or companies at risk. Several companies are put an effort to deal with the undesirable effects due to uncertainties by minimizing risks. The tool such as stochastic model has been widely used to maximize profit and minimize risk [4]. For example, Markov process, which is the one of stochastic modeling that use to model and analyze supply chain, is used to develop discrete event dynamic systems (DEDS) to analyze the flow of physical entities or resource traveling within manufacturing line with changing attributes such as queues, destinations, inventory buffers, manufacturing speed, and customer demands. The discrete nature of event-based processes are captured. However, due to interlace occurrences of unforeseen disruptions in the real world (e.g. accidents, sick workers, natural disasters, machine breakdown) and changing of others parameter value, verisimilitude of using any optimization technique could be in questioned [7].

Since Markov model is capable of model the systems consist of multiple state (like manufacturing systems, supply chain network), it's also used to study the dynamics of systems based on probability of discrete time or continuous time events [13]. Two types of Markov process, which are Markov chain and hidden Markov chain, have been widely used in several analytics of dynamic systems including supply chain. However, the presences of Markov chain applications shows limitations of using both Markov chain and hidden Markov chain. Although Markov chain has visibility of the entire processes through state transitions, it cannot handle all possible observations. For hidden Markov chain, the output of each state might conditionally independence, but the processes ruled by hidden Markov chain are not entirely observe. The conditional independence is not always justified [3]. For example, the observed variables in the real world have both direct and indirect interactions between each other and the states in these model could have interactions interlacedly which would lead to one output. This instance would require all possible observations and not a single process to justify the output. In order to evaluate the output of the stochastic process such as uncertainties in the more realistic way, this article has proposed the new method to evaluate the uncertainty in supply chain using modified Markov chain. The method shall cover the advantages of both Markov chain and hidden Markov chain. In this paper we focus merely on downside risks due to changing of environment.

2 Literature Review

This section divided into two parts, the first part has presented the importance of product life cycle management and its relationship to the supply chain management. The second part is focus on applications of stochastic process in supply chain risk management.

2.1 Product Life Cycle Management and Supply Chain Management

Today, business environment and supply chain have grown complicatedly, the companies themselves are inevitably in such surroundings. Due to an increasing of environment's complexity in which the products were developed, the Product Lifecycle Management (PLM) concept emerged to cope with such complex environments by guiding the firms through proper management over each period of product's life. But to be able to create a more effective management system such PLM, it's necessary to understand how the environment would change overtime during the life cycle of the products. As the competitive success of the firms are rely on the success of their products, PLM aims to coordinate the right information in the context at the right time to the related processes through life cycle of the product and it's all about "knowledge management" [2]. Knowing how to manage supply chain in important, but knowing how to manage change is even more essential. Supply chain is rather dynamic than static, environmental changes also affect ordinary functions of supply chain and they have associated uncertainties and risks [9]. PLM has opened new management dimensions in quite a dynamic way by managing products from the first idea until they disposed, this give the company to take control both products and supply chain

processes involved. Several supply chain management model using PLM are based on information management. For example of a product information modeling framework [11], it's extended to support full range of information along product life cycle in order to gain full access product's description and design rationale. The other objective of this framework is to create a bridge for the future computer aided system, e.g. CAD, CAE, and CAM, and to capture product's development trajectory. According to the objectives, these could lead to further development of efficient supply and production planning, and collaborations of others supply chain activity involved throughout product's life cycle. However, involvement of complicated processes, systems and stakeholder, such as automotive assembly which requires dynamic participations of several discrete systems, might risk malfunctioning of product due to uncertainty and diversity of operations and environments [12]. Thus, intelligent prognosis system is recommended in order to oversee the complex operations and systems throughout product life cycle and supply chain management. The prognosis system shall also include monitoring, analyzing, and diagnosis capability that would help provide critical information when abnormal events occur along life cycle of product or even at real-time supply chain operations.

Product life cycle management and supply chain management are both clearly a complex task. They constitute of several complex participations of processes and involving systems which latent uncertainties and risks lie under. Thus, they need more than just static management but rather dynamic way to cope with such changing environments.

2.2 Stochastic Model and Supply Chain Risks Management

The modern supply chain management paradigm, such as PLM, has been enabling key technological and organizational approaches for effective managements [1]. However, real industrial operations always involve changing of product environment, dynamic systems and processes. Risk factors affecting management of product throughout its life and management of supply chain can be found in both external sources and internal sources [9]. Any risks associated with environmental changes along product lifecycle and supply chain process are considered to be a stochastic process which state of environmental or process changes are assumed to occupy only one state at present time to evolve to another state without effect of past history [10]. The examples of stochastic process associated with supply chain risks such as, demand risk, exchange rate risk, natural disasters, supply risk, and etc. [4], these risks capable of disrupting normal operations of supply chain which represents transition of state from normal condition to abnormal condition instantaneously. To represent such behavior of the system, stochastic model is widely used for describing transition of state in mathematical approach. Several applications of stochastic process have appeared in supply chain management, it is frequently uses in risk management and optimization issue. For instance of exchange rate risk hedging for multinational supply chain operations, a stochastic dynamic programming is used to determine optimal operation option for multi-product, and multi-stage supply chain. The results are operational flexibility that could reduce financial risk and demand risk due to market and location changes [5]. Another example of stochastic modeling found in application for risk minimization – profit maximization problem for multi stage supply chain [4] by providing general

formulation of mathematical model for large scale supply chain network. The model incorporate several kinds of supply chain risks, such as supply risk, demand risk, exchange rate, and others disruption. In micro level application such as inventory control system [6], stochastic model also used to determine material order policy based on required stock level for multi-product and multi-production site of Hewlett-Packard Company (HP). The model specifically attempted to achieve highest service level for a pull-type, periodic, order-up-to inventory system which the operation associated with uncertainties due to dynamic conditions, such as, change in market demand, change in supply network structure, changes in production capacity.

In conclusion, PLM has shown benefits to supply chain management by providing a more effective way. The PLM takes all of the factors of each process in the product life cycle into consideration. Despite the advantage of the PLM, there are some problems existed, risk and uncertainty. The stochastic process is a well-known tool that is widely used to handle the problem. As a consequence, the further development of stochastic modeling for uncertainty and risk assessment based on the PLM could enhance product management capability.

3.   Proposed Method

In this section, we endeavor to present a framework of stochastic model of a global supply network using modified Markov Chain, consisting of as numerous uncertainties as possible. The goal is to illustrate the idea of new methodology in an evaluation of supply chain uncertainty, to predict the possible changing situations based on giving circumstances. The idea of the proposed method and also the inceptive model definition are presented.

3.1   Concept of the Proposed Method

The characteristics of dynamic and interlace environments in supply chains are often not restricted to deterministic system because they are quite uncertain and consist of several forms of risks [8]. Furthermore, the changing in actual business can be instantaneously, which is means that changing of the system from one state to another require zero time, and we've called it the "Transition of state". The system could evolve overtime and the future state depends on only its current state without its past history involved. Such a system can be represented by a "Markov Process" which can be found the same property in several actual systems such as the business, engineering, biological, physics, and social science [10]. In this paper, the proposed method could be divided into three part. First, we use scope of PLM concept as the guideline for identifying uncertainties in each phase of product life cycle management. Each phase of product life cycle shall be clarified into sub-processes from manufacturer's perspectives; that would be easier to identify uncertainties and risks related to those sub-processes. Second, Uncertain environments shall be identified and defined as a set of uncertain environments regarding activities of product life cycle. Third, after the clarifications of uncertainties and risks are completed, Markov process is getting involve, the transition probability matrix of uncertainties and the transition probability matrix of all possible risks under each state of uncertainty are identified. This step requires the definition of relationship between uncertainties and risks which would

leading to deployment of multilevel transition probability matrix. The 3 steps of proposed methodology is concluded in Fig.1. and the conceptual framework of proposed method of risk's probability assessment model based on PLM using Markov process are shown in Fig. 2.
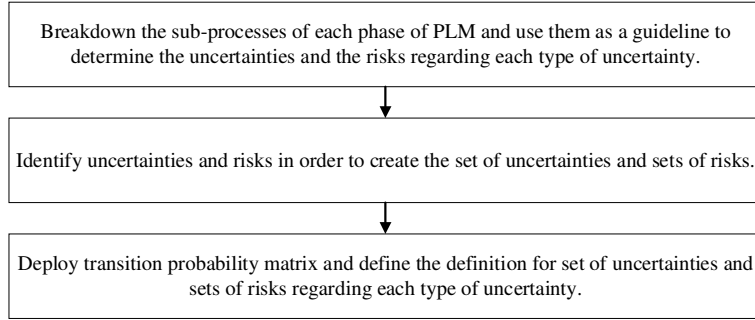

| Breakdown the sub-processes of each phase of PLM and use them as a guideline to determine the uncertainties and the risks regarding each type of uncertainty. |

| Identify uncertainties and risks in order to create the set of uncertainties and sets of risks. |

| Deploy transition probability matrix and define the definition for set of uncertainties and sets of risks regarding each type of uncertainty. |

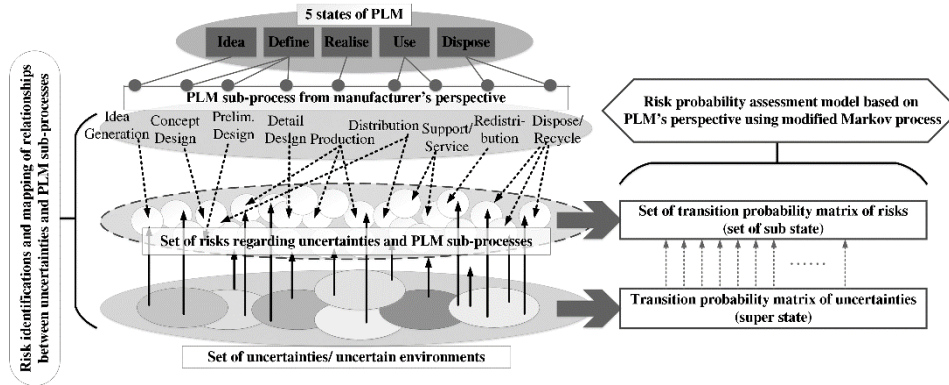**Fig. 1.** Proposed methodology for risk's probability assessment based on PLM.

Fig. 2. Conceptual framework of proposed method of risk's probability assessment model based on PLM using Markov process.

3.2 Model Definition

Unlike traditional Markov process, this proposed adapted Markov process using in the research consists of multi-level Markov process, called Modified Markov Chain (MMC). This is a memory-less, multi-level, stochastic process. The MMC employs the downward causation to simulate the chain of events. In other word, the transition matrix of the chain won't be changed. Similar to the traditional model of Markov chain, the MMC has a number of finite states,

$$S = \{s_1, s_2, \ldots, s_n\} \tag{1}$$

Moreover, the states of the model is separated into *levels*

$$L = L_1 \cup L_2 \cup \ldots \cup L_m \qquad (2)$$

where
$$L_1, L_2, \ldots, L_m \subseteq S \qquad (3)$$

Since the MMC has multi-level, the transition process of MMC has to be specified in induction style. As a consequence, there are 2 types of transition process.

The first type of the transition process is the same as traditional Markov chain model. This type is dedicated to the highest level of the model which change the states without the influence of the other state except the previous one. Therefore, the transition process is given by p_{ij} where j denotes the state at time t, i denotes the state at time $t-1$ where

$$p_{ij} = P\left(X_t = j \mid X_{t-1} = i\right) \qquad (4)$$

The second type of the transition process is for the states that has a higher state which will be referred as *super state*. The lower state will be referred as *sub state*. In other word, this type of transition process is for the state resided in the level that is not the highest level. The transition of state of this type can be assigned by $p_{ij,k}$ where j denotes the state at time t, i denotes the state at time $t-1$ and k denotes the state of the super state (which current level is l),

$$p_{ij,k} = P\left(X_{t+1} = j \mid X_t = i, X_{l+1} = k\right) \qquad (5)$$

Normally, the states in the lowest level is the estimated event and the state in the higher level is the environment. For example, the manufacturing is a process in the production. Thus, it is the state in the lowest level. On the other hand, the reduction of currency value is the environmental factor. As a consequence, it should be modeled as a state in the level beside the lowest level.

4. Discussion and Conclusion

In this paper, the MMC has been proposed by extending conventional Markov modeling to support a more complex changing of state. Inspired by interlaced changing environment in the real world, MMC supports multi-level characteristics of state transitions found in supply chain, product life cycle or any other dynamic systems which incur downside risks capable of disrupting the systems in both direct and indirect ways. Each level of MMC can be easily described as the level of events, from the highest level which represents main causes of uncertainties (e.g. natural disasters, economic crisis, or political crisis) and the lower levels which are caused by higher

state (e.g. destruction of facility, company bankruptcy or worker strike). These can be formulated into transition of states of each level and the transition probability matrix shall be able to develop regarding the relationship between each level of uncertainty and PLM sub-process. To illustrate the multi-level uncertainty, suppose that the laptop manufacturer has ordered parts form its supplier located within another continent. The parts will be delivered by sea freight across Pacific Ocean. Unfortunately, there is great hurricane formed in Pacific Ocean and the ship that responsible for parts delivery has to be delayed for at least 1 week. This instance has caused the aggregate production plan of the company delays for at least 3 weeks and product launching delays for a month. Given example has illustrate the interlacement of changing environments which aren't directly caused negative impacts on supply chain or production cycle but the impacts are caused by the collateral damages from those changing environments to the process of production within phase of product realize of product life cycle. For products with a short life cycle such as electronic devices, delaying in product launching, especially not a day but a month, could have made the company risk losing a huge amount of sale revenue, or even worse. MMC could add up both relevant and irrelevant issues regarding PLM context into the model along with their relationships based on probability of occurrence which would lead to manufacture of transition probability matrix. Future research will adopt this MMC into decision support system for predicting risks caused by uncertainties. Possible outcomes shall be able to estimate time until any risk occurs. Decision support system with MMC integrated shall provide information that helps the company to foresee possible uncertainties and risks before they occur.

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