Operational Efficiency of Perishable Product Supply Chain Using Petri Net Technique

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Abstract

This paper discuss the operational efficiency of Perishable Product Supply Chain (PPSC) in context of Petri Net (PN) modeling technique. The operational efficiency is classified into: inventory management, logistics, information sharing and supply chain risk among different stages of supply chain with coordination and monitoring through traceability and PPSC risk management. This classification of operational efficiency will allow the industrial practitioners and academicians to decide on the suitable petri net technique for the problem identified. This paper discuss the research directions of application of Petri Net in PPSC (operational efficiency). In addition, paper provides future directions for operational efficiency in PPSC and are as follows: 1) modelling PPSC with uncertainty, 2) reducing complexity in PPSC, 3) integration of PN modelling with emerging technology, 4) PN involvement in information flow and traceability and 5) application of PN modelling in decision making.

Keywords
Supply chain, Perishable Product Supply Chain, Petri Net, Supply Chain Risk

1. Introduction

Supply Chain Management is defined as the coordination or integration of different stages such as procuring, production and planning, logistics, inventory management, information sharing, manufacturing, retailer and finally to end-consumer, Vishwanadham & Raghavan, 2000; Dong & Chen, 2001. Supply chain is a process oriented approach where main objective is value deliver process, Vishwanadham & Raghavan, 2000. Quality is the main constraint with optimized price in delivery of products. There are several reasons why so much perishable food is lost which lowers the operational efficiency of supply chain: Biswas, 2014, MOFPI, 2018, fig.1

Perishable products are short life-cycle products, such as fruits, vegetables, grains, meat, canned products, blood etc. These products have uncertain behaviour, such as late deliveries, order cancellation, exploitation of products, unnecessary slack time, demand of products, market change, natural hazard etc. Supply chain for perishable products are complex and inefficient in nature, thus there is increase in deteriorate rate of perishable products. Modelling of PPSC is necessary to increase the performance and reliability. The modelling leads to less deterioration rate of perishable products. At operational management and control level design variables are required such as time, accuracy, quality pf product and quality of information flow, Van der Vorst, 2000.

Supply chain are regarded as discrete event dynamic system Vishwanandham & Raghavan, 2000; Arns et al., 2002. These system considers time as a factor for determining various discrete events such as product arrival at supplier, logistics, transportation, flow of material through stages of supply chain. The state of supply chain changes at discrete time, Vishwanadham & Raghavan, 2000.

Figure.1. Reasons for Inefficient Supply Chain of Perishable Products

In this paper, PPSC is considered as a discrete event dynamic system, where different state such inventory, production and planning, logistics and information flow are discrete events. These events are characterized as asynchronous, concurrent, non-deterministic, and stochastic and distributed. Modelling and analysis of such supply chain is difficult. Existing literature has discussed about mathematical, simulation and network based modelling on supply chain. Various mathematical modelling technique has been applied on PPSC such as mixed integer linear programming, Abedi & Zhu 2017; Agustina et al., 2014; Rong, et al., 2011; Lacomme, 2018; Hu et al., 2018, multi-objective non-linear programming, Amorim et al., 2012, dynamic programming, Rajurkar & Jain, 2011; Gigler, 2002 and stochastic programming, Lin 2013, have been used. The challenges which in mathematical modelling lies in its complexity. It introduces large number of variables and constraints which are difficult to maintain and increases complexity of the problem. This reduces the operational efficiency of the supply chain. Petri Net modelling technique has been selected as an appropriate tool to reduce the complexity and increase the operational efficiency of supply chain. Petri Net captures the dynamic behaviour of supply chain and understands the supply chain process mathematically and graphically Petri net modelling tool is being discussed, which develops a strong mathematical foundation to describe the behaviour of the system and include easy to understand graphical feature. As less literature us being focused on PPSC using Petri Net modelling technique. This paper provides an overview of Petri Net modelling in PPSC followed by discussion on operational efficiency of PPSC using Petri Net modelling technique, which provides the inference for increase in performance evaluation and reliability of supply chain. Finally with implication and conclusion of the paper

2. Application of Petri Nets in Perishable Product Supply Chain

1.1 Definition and Adoption of PN in PPSC

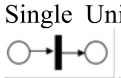
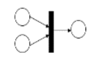
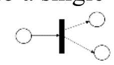
Petri net is a bipartite, directed and multiway graph. Petri Net is divided into structural components such as places, transitions and arc. Petri Net is a five-tuple set, PN = {P, T ,F ,W, M_0}, where

P = {P_1, P_2… P_m}, represent state of the system, shown by circles,
T= {T_1,◯… T_n}, represent action to be taken in the system modelled, shown by bar ▮ or boxes □

P and T are finite set of elements, non-empty and disjoint set $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$, m>0, n>0 , m and n are integers
F is defined as the flow of arc with input and output function

- Input function: defined as flow of tokens from transition to places, I: $T \rightarrow P$
- Output function: defined as flow tokens from places to transitions, O: $T \rightarrow P$

F = (P X T) U (T X P), defined as set of arcs which transmits information from places to transitions and transitions to places.
W, represents the weight associated with each arc. Based on the weight function, transition node is enabled.
M0, represents the marking, it denotes the number of tokens in a place, ready to make a transition enable.
Arc representation has been categorized to:

- Single Unidirectional Arc: Directed arc which connects place to transition and vice-versa. Shown by,  . These arcs transmits the information. The transition is enables, if at the defined place token is placed. Information is transmitted from input place to output place when transition occurs through arc, A = $\{A_1, A_2 ....A_t\}$, t>0, t is an integer.
- Multi Unidirectional Arc: The information is transmitted from multiple places and merges to a single output place or information transmitted from single place to multiple places. Shown by,  ,  . A = {{ A_1, A_2….At} , … { Ap, Ap+1…. At+p}}, t>0, p>0, t, p are integers

For illustration, Van der Vorst et al., 2000, model is adopted and presented. Fig.2, displays a generic food supply chain, where the food product is moved from producer to manufacturer, manufacturer to distribution centre and finally to outlet to the end-consumer. The PN model represented in fig. 3., represents time colored PN model for food supply chain. This model concerns with delivery of product to retail outlet. Shipment (p1) of product from distribution centre to retail outlet. The transition enabled (t1), shows the discrete event that transform the shipment from receipt_of_good to delivered_goods (p2). At transition (t3), when retail outlet becomes is free and start of filling of shelves (t2). Place (p3), represents the inventory and is updated.

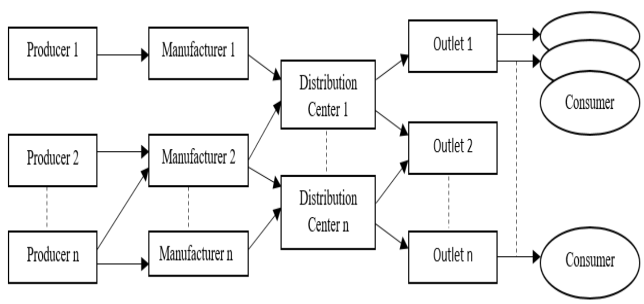


Fig. 2. Generic food supply chain (adapted from Van der Vorst et al., 2000)

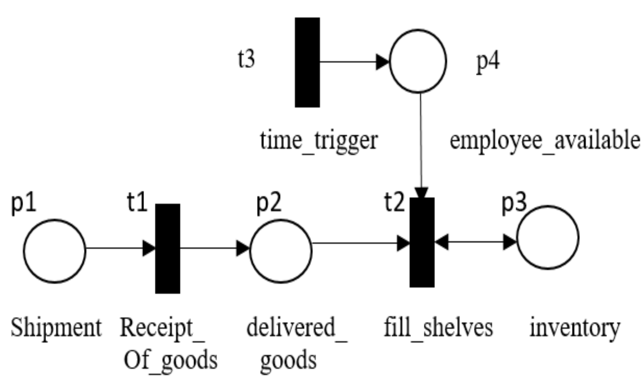


Fig. 3. Petri net model for PPSC (adapted from Van der Vorst et al., 2000)

The adapted PPSC model (Van der Vorst et al., 2000), represents the discrete events, capture the dynamic behaviour of the supply chain, increased the performance evaluation of supply chain, operational efficiency is increased in terms of logistical performance and improved decision-making based on discrete events.

Table 1. PPSC with different Petri Net types

Author	PN type	Properties	Case Study	Discrete Event Modelling	Operational Efficiency	Metrics (tokens)
Yan et al., 2018	Petri Net	Dynamic Transparency Reachability/Coverability Concurrency	Supply chain of sheep meat	Traceability	Information Flow Performance Evaluation	Quality information
Liu et al., 2018	Colored PN	Dynamic Concurrency Hierarchy	Cold chain of aquatic products	Quality Assessment Traceability Shelf-life prediction	Risk Management	Time Environment Information
Liu et al., 2018	Colored PN	Dynamic Concurrency Modularity	Supply chain of aquatic products	Decision-making Shelf-life estimation	Risk Management	Environment information Quality information
Chen et al., 2015	Colored PN	Dynamic Concurrency Context-aware agent based application	Agricultural SC	Replenishment Disruptions	Maximize System Performance Increase Robustness	Delivery Time Quantity
Van der Vorst et al., 2000	Timed Colored PN	Dynamic Parallelism Synchronisation Transparency	Supply Chain of Chilled Food Products	Discrete event simulation for decision making	Logistic chain performance	Delivery time Quality Quantity Information Flow

1.2 Extension of Petri Net Model in Perishable Product Supply Chain

There are certain petri net extensions that have being applied on supply chain and each petri net type has unique properties, fig. 4. Colored Petri Net model is used to model discrete – event which combines Petri Net and standard modelling language. CPN were useful for identifying dynamic, concurrency, context-aware agent properties of the system and analyse the uncertain phenomena of the system. With introduction of time concept in CPN, represents time as an element to execute events in the modelled system, formed Colored Time Petri Net (CTPN). CTPN addressed the time factor in the workflow and check deadlock in the system modelled. Batch Deterministic and Stochastic Petri Net model introduced batch features (discrete quantities), inhibitor arcs and specific policies such as inventory rationing policy with time concept. Table 1, discuss Perishable Product Supply Chain with application of Petri Net. Petri Net captures the dynamic nature of supply chain. It discuss the transparent and concurrent nature of supply chain.

3. Operational Efficiency of Perishable Product Supply Chain Using Petri Net

This section discuss the operation efficiency of PPSC with application of different Petri Net modelling technique. Operational efficiency has been classified into inventory management, distribution and logistics, information sharing and supply chain risk.

1.1 Inventory Management

Inventory management modelling is a difficult task in PPSC due to uncertain nature of products, short life-cycle, stochastic demand and periodic ordering. The major disadvantage for such modelling is that numerous are to be satisfies before reaching to the results. Success of supply chain depends on inventory control policies, Raghavan & Roy, 2005. So, the authors developed the model for inventory rationing policy using Generalized Stochastic PN. The model developed resulted to be a robust model and captured the dynamic involved in stock rationing. Van der Vorst et al., 2000, modelled multi-echelon food supply chain using timed colored petri net. Chen et al., 2005, developed a model for inventory systems in supply chain when inventory replenishment and distributions are made in batch way using Batch Deterministic and Stochastic Petri Net. Thus, this model enhance the performance evaluation of supply chain.

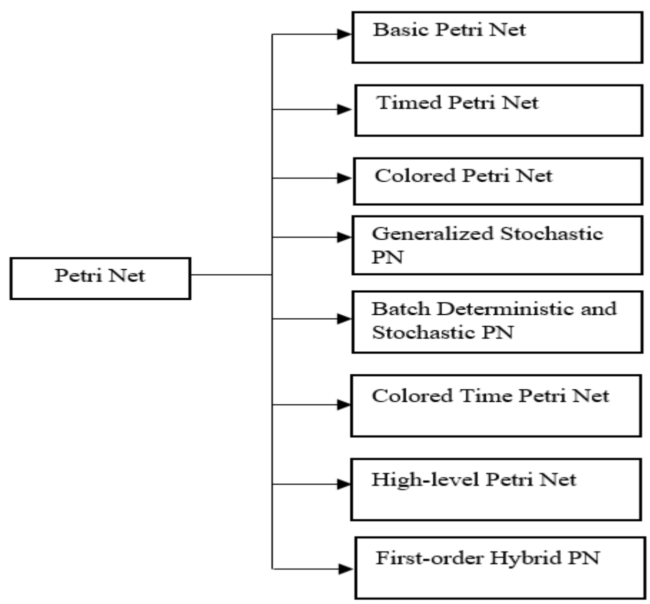


Fig. 4. Types of Petri Net Model

1.2 Logistics Management

Logistics management in PPSC process the plan for delivering of products. Perishable Products have short life cycle so implementation, control and coordination for efficient flow of products is necessary. As part of logistics management, cold chain management is crucial. Information flow and product quality from point of origin to consumption point to meet customers' requirement is function of logistics management. Van der Vorst et al., 2000, developed timed coloured Petri Net model for redesigning of PPSC in terms of logistical performance. It models the dynamic behaviour of supply chain. This model resulted in improved supply chain logistical performance. Tynjälä & Eloranta, 2007, Developed Petri Net modelling on logistics and demand supply network. The author analysed demand supply network under variants uncertainties.

1.3 Information Sharing

Information sharing among different stages of supply chain can improve the efficiency and performance evaluation. There can be reduction of bullwhip effect in supply chain through information sharing among different agents. Petri Net model developed can represent the dynamic behaviour of each agent in supply chain. Yan et al., 2018, proposed Petri Net and UML modelling for identification of traceability information and process. Traceability information flow in sheep meat supply chain captures the product quality, process and transformation information through state-transition function among different stakeholders in supply chain. The information sharing leads to effective decision-making for product quality and safety control. PPSC are complex, uncertain and dynamic in nature. To study this type of supply chain an incremental approach is required to study discrete event systems at structural level. Information sharing among each nodes at each level leads to less complexity, determine the uncertainties and captures the dynamic nature of supply chain. Liu et al., 2018, developed PN model for aquatic products which include hierarchical network modelling with multidimensional information sharing among different hierarchies of supply chain.

1.4 Supply Chain Risk

There are existing studies on supply chain risk management with single disruptive event. Colored PN model analysed different supply chain risk and built a robust optimal model for agricultural supply chain, Chen et al., 2015. Fragmented location is supply chain faces supply chain disruptions more frequently during uncertain conditions. These disruptions lead to deterioration of quality of products, delay, disrupt information flows and increased costs, Chen et al., 2015. Robust supply chain reduces cost, improve customer service and increase efficiency under uncertain condition.

Table 2. Research direction on application of PN on PPSC

Focus Area	**Research Directions**
Inventory Management	Optimization of inventory control policies Inventory Scheduling Problem Model development and performance evaluation of inventory systems Dynamic Management of storage systems Modelling inventory management with stochastic and batch demand
Logistics Management	Cold Chain Logistics model development for PPSC Development of alternative design of PPSC model for increase logistical performance
Information Sharing	Traceability information modelling for PPSC Communication and coordination approach among different agents in supply chain Modelling and analysis of uncertain environment of PPSC
Supply Chain Risk	Analysis and model development of disruption in PPSC Develop robust optimal model for PPSC Analyse different disruptions at every stage of PPSC

4. Future Direction

1.1 Modelling PPSC with uncertainty

Modelling Perishable Product Supply Chain focus on working with the uncertainty occurrence. With increasing competitive environment, different uncertainties are identified in PPSC such as demand variations, lead times, late deliveries, market change, production fluctuation and decay in product quality. These uncertainties results in inefficient supply chain system. In the beginning, most researches focused on deterministic nature of supply chain.

Because of random phenomena or stochastic nature of PPSC, there is need for modelling Petri Net is an appropriate tool to handle such random phenomena and support model development with inclusion of dynamic nature which supports the uncertainty. Petri Net model captures and represent graphically ad and analytically the dynamic nature of supply chain Such model development lead to effective decision making which leads to efficient supply chain Uncertainty quantification in supply chain operation using Petri Net modelling technique will be important in future.

1.2 Reducing Complexity in PPSC

Perishable Product supply chain is complex in nature due to its short life cycle. So, these supply chain has to behave in a responsive manner. Since, modelling of supply chain includes large number of variables, thus increasing the complexity of the problem. Petri Net can model the supply chain in modular and hierarchical manner. Petri Net can model a large supply chain into component level, interface level and system level. This type of modelling leads to less complexity and better understanding of supply chain.

1.3 Integration of PN with emerging technology

With emergence new technology such as Internet of Things (IoT), Radio Frequency Identification (RFID) tags and Wireless Sensor Networks (WSN) Data collected from IoT comes from different sources and data collected can be discrete or continuous. Since, PPSC are discrete event dynamic systems. Data collected from these emerging technology can improve the decision making and efficiency of supply chain. The modularization and semantic integration of these emerging technologies are in high demand. There is need to develop a unified and comprehensive modelling for these technologies. Petri Net modelling technique has been considered as an excellent tool for discrete event dynamic system. Petri Net incorporate both at system level and item level. Petri Net modelling technique enables us to systematically capture and categorize the data collected from these technologies and analyse accordingly.

1.4 PN involvement in Information Flow and Traceability

PPSC has uncertain nature and events occurrence are asynchronous in nature. Petri Net have the capability to coordinate these asynchronous events in supply chain at different stages and model negotiation process. . Supply chain model consists of three types of flow: material, fund and information flow. Dynamic behaviour of demand, inventory, cost, quality and delivery at different stages of supply chain can be analysed. Information flow and traceability at different stages of supply chain are coordinating actions of units. Petri Net models the traceability issue in supply chain which captures the quality of product, process and transformation information through state transition function and provide effective decision making.

1.5 Application of Petri Net in Decision-Making

Petri Net modelling technique focused on operational characteristics of PPSC, such as state transitions of process, product quality, transportation, traceability, information flow, supply chain risk management, inventory and production and planning and provides effective decision making. For the future research direction, shall explore PN variants for modelling and analysing for effective decision-making.

5. Conclusion

This paper had focused on operational efficiency of Perishable Product Supply Chain. It initially discussed the concept of PPSC with Petri Net modelling technique and adopted a reference model for the explanation of Petri Net modelling in PPSC. It also provided an overview of different PN model types in PPSC. It has been viewed that Colored PN model has been maximum used in supply chain. Next step discuss the operational efficiency of PPSC. It has been categorized into inventory management, distribution and logistics, information sharing and supply chain risk management. It intends to provide the research direction of applying Petri Net modelling technique on PPSC (operational efficiency).

Based on the classification of operational efficiency in PPSC, future directions has been discussed and are as follows: 1) modelling PPSC with uncertainty, 2) reducing complexity in PPSC, 3) integration of PN modelling with emerging technology, 4) PN involvement in information flow and traceability and 5) application of PN modelling in decision making.

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