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OPTIMAL ESTABLISHMENT OF PROCESSING UNIT AND PARTNER SELECTION PROBLEM OF PERISHABLE PRODUCT SUPPLY CHAIN: APPLE CASE STUDY OF INDIA

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Abstract. Decentralized supply chain operation in India adds to inefficiency in management and control difficulties for perishable product supply chain (PPSC). One of the important categories of factors that underly the problem in supply chain is the establishment of processing units that results in end – product distribution. This paper presents an optimal establishment of processing unit around production area for apple supply chain as a case study of India. This study proposed amalgamation of mixed integer linear programming (MILP) and colored petri nets (CPN) to model the PPSC. The mathematical model was set up in regard with capacity of processing unit and transportation cost with continuation in partner selection using MILP approach. The simulation model directs the maximization of system performance by running in CPN environment. The values of the results are subjected to transportation cost and production area with estimate of 25% loss during post harvesting such as transportation and environmental variation. The results corresponding to the case study provided an optimal establishment of processing units. Further, the specific partner associated with the facility and transportation cost. Decision-makers can identify the set of partners from the set of facilities dependent upon the transportation cost for further supply of product using a threshold values. Thereby, the model can be used as a decision-making system for processing companies to result in efficient PPSC management. The developed model was tested and validated on case study to demonstrate our approach's applicability.

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1. Introduction

The world population is expected to exceed 9 billion by 2050. The question arises of quality, accessibility, and affordability of fresh produce for the consumers around the globe. The United Nations (2009) estimated the demand of food product to be double by 2050 with growth in developing countries. Increase in population around globe, transformation of growth in developing countries offer for more demand and better-quality product across all type of products including perishable products. In last decade, there are drastic changes in perishable product supply chain of fresh produce [50]. Fresh produce demand, production patterns will adjust according to climate

Keywords. Perishable product, supply chain, fresh produce, colored petri nets, mixed integer linear programming.

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variability and technological innovations. Both demand and supply have uncertain behavior. At inventory stage approximately 12% of fruits and vegetables are damaged in disposable packaging.

Perishable product sector emerged to be an important segment of the Indian economy in terms of GDP, employment, and investment [35]. However, wastage in fresh produce items such as fruits and vegetables from harvesting, processing, transportation to distribution is a great concern in developing markets [21, 46]. The principal component in fresh produce PPSC are partner, customers, logistics, processing units, distribution networks, focal companies and retailing centers [28]. There is lack of understanding in improving the operational issues of PPSC from upstream to the wholesaler. The significant operational issues that need to address are lack of processing units, inefficient warehouse location, logistics issues, and inappropriate network design [12, 25, 34, 38, 53].

Perishable product supply chain (PPSC) is a system which involves movement of perishable items such as fruits, vegetables from the supplier (farmer) to end-consumer (customer). There are different stages in PPSC such as farmer, supplier, middleman, processing unit, distributor, retailer, and end-consumer ([1, 7]). With complex and dynamic feature of PPSC, uncertainties such as natural hazards, demand uncertainty, or quality problems have always been topic of concern [4, 48, 54]. Establishment of regional or localized processing unit is a long-term project as part of strategic decision making in supply chain. Optimal location of processing unit is of great importance where high quantities of agricultural production is spread over fragmented farm size with large number of farmers [39]. The traditional practice of small farm holdings and production of crop have resulted in diversified involvement of partners and dispersive management of fresh-produce products. With fragmented location of processing units, PPSC faces disruptions more frequently with uncertainty occurrence. These disruptions can delay fresh produce items, increase cost, adversely effect on the sales, and deteriorate the quality of product. Another problem with decision makers arises is with selection of partners under different uncertainty occurrence in order to quantify the product quality and sales. The decision makers must be able to analyze the occurrence of uncertainty and their effects [9]. There is dearth of literature on PPSC disruption and their effects and further less exploration on optimal part of operational issues of fresh produce supply chain. Existing studies discussed management of PPSC based on single disruptive events. Optimization of PPSC under multiple disruptive events are still in dearth.

Thereby, this paper focus on optimal establishment of processing unit around production area and partner selection under uncertain environment. The author proposed two techniques: mixed integer linear programming (MILP) and colored petri nets (CPN) to model the PPSC under uncertainty to reduce cost and enhance efficiency under uncertain circumstances. The mathematical model was set up in regard with capacity of processing unit, transportation cost, and partner selection using MILP approach. The simulation model directs the maximization of system performance by running in CPN environment. Thereby, the model can be used as a decision-making system for processing companies to result in efficient PPSC management. The developed model was tested and validated on case study to demonstrate our approach's applicability.

1.1. Novelty and contribution

The major contribution of this study presents optimization of planning and control of perishable product supply chain members and activity from producers to customers to achieve robustness in decision making dependent upon optimal establishment of processing unit around production area and partner selection under uncertain environment. This undertakes two techniques: mixed integer linear programming (MILP) and colored petri nets (CPN) to model the PPSC under uncertainty to reduce cost and enhance efficiency under uncertain circumstances.

The mathematical model build is in regard with capacity of processing unit, transportation cost, and partner selection using MILP approach. The simulation model directs the maximization of system performance by running in CPN environment. Thereby, the model can be used as a decision-making system for processing companies to result in efficient PPSC management. The developed model was tested and validated on case study to demonstrate our approach's applicability.

The development of CPN model provides a general case solution considering existing planning and decision variables. The parameters precisely transportation cost and demand for apple product are then varied and performance of system is quantified as the model follows the same production area with capacity constraint as constant. Uncertainty occurrence threshold value $\varphi_{\rm s}$ is proposed alternatively for partner selection, primarily to understand the distribution of product so that proper strategy can be implemented. It will help the decision makers to reduce cost burden and minimize the wastage during any disruption.

1.2. Organization of the paper

The organization of this paper is as follows: Section 2 represents literature review on operational issues of PPSC and Section 2.1 discusses literature on the research methodology. Section 3 discuss the optimization model categorized into Section 3.1 as problem formulation, and Section 3.2 as model formulation. Section 4 discuss the evaluation and simulation of model using colored petri net. And finally, the conclusion and future work is discussed in Section 5.

2. Literature review

Perishable product supply chain for fresh produce items have always seek attention for research. PPSC are perturbed with occurrence of unexpected disruption with supply and demand uncertainty [20]. Supply chain for perishable items is complex due to short life cycle of product, safety requirements and concern for resilient supply chain [2, 13, 20]. Ahumada and Villalobos [2] proposed modelling approach for efficient planning of production and distribution of fresh agricultural supply chain. Behzadi *et al.* [6] discussed uncertainty in PPSC attributed to long supply lead-times, seasonality, perishability, and yield disruptions. Rana *et al.* [46] determine warehouse dispatching policy for perishable items incorporating perishability rate and freshness keeping effort. Raut and Gardas [47] identified barriers during transportation for perishable items as lack of refrigerated vehicles and overloading on the vehicles as the highest driving power for sustainable transportation and post-harvesting loss.

To manage complex and dynamic environment of PPSC, it is necessary to work upon the operational issues for cost reduction and efficient management on performance of supply chain. Etemadnia *et al.* [15] established optimal wholesale facilities (hub) locations for food supply chain system. The problem was formulated using mixed integer linear programming approach with the objective of minimizing transportation cost as a case study made on U.S. fruit and vegetable industry. Orjuela-Castro *et al.* [39] established facility location model using MILP approach for localized collection centre and processing units in mountainous regions. The model application was evaluated on fresh produce in of Columbia based on multi-product and multi-echelon transport system. Soto-Silva *et al.* [51] represents optimization model for purchasing, transportation, and storage of fresh produce. The proposed model applied as individual or in integration form for decision making on storage, transport, and purchase of fresh produce. Ge *et al.* [19] identifies optimal location for regional fresh produce facilities across U.S. The problem was formulated using mixed integer linear programming with the objective of minimizing cost associated with fresh produce distribution facility operation. Li *et al.* [31] investigated a generalized production routing problem formulated into mixed integer linear programming. The problem provided a good near optimal solution calculated within computation time. Gómez-Lagos *et al.* [22] represented optimization model for tactical decision making for harvest planning and resource utilization of multiple orchards or farms. Hashemi-Amiri *et al.* [24] discussed an integrated approach for supplier selection of perishable product supply chain. The authors proposed a bi-objective optimization model for three-echelon supply chain to formulate integrated supplier selection with production scheduling and vehicle routing problem. The study limits using large number of constraints and to achieve a good quality optimal for a solution for a reasonable amount of time. Mateo-Forns [33] proposed a two-stage stochastic programming for selection of producers and cold storage contracts to mitigate and maintenance of quality of fresh harvested product. A research direction discussed by the authors is a risk-aversion decision model with the objective function of value-at-risk approach. Table 1, present the literature on PPSC comprising of mathematical modelling and simulation-based modelling.

TABLE 1. Literature on perishable product supply chain issues.

PPSC issues	Methodology	Objective function	Limitation/Research directions	Reference
	Literature on perishable product supply chain issues	Optimal solution in reasonable time	Model developed are highly constrained	Hiassat *et al.* [25]
Location inventory-routing	Mixed Integer Programming + Meta heuristics	Minimize network cost	Model developed are highly constrained	Biuki *et al.* [8]
	Dynamic + Stochastic Programming	Minimize cost + minimize risk measure	Inclusion of number of vehicles	Violi *et al.* [56]
	Mixed Integer Linear	Transportation cost + perishability + CO2 emission	Parameters are deterministic + high complexity + high computation time	Musavi and Bozorgi-Amiri [37]
Facility location-allocation	Programming + Meta heuristics			
	Mixed Integer Linear Programming + Meta Heuristics	Minimize total cost +Transportation cost + product wastage cost	Multiple products having different spoilage + high complexity	Fahmy *et al.* [16]
Vehicle routing-cross docking	Mixed Integer Linear Programming	Cost objective + freshness	Post distribution condition and split delivery + large computation time	Rahbari *et al.* [45]
Vehicle routing scheduling	Petri net with random invalidity approach	Optimal delivery time	Can work on more complex system	Chen *et al.* [10]
Production Routing	Stochastic programming	To obtain optimal total cost	Model developed are highly constrained	Mousavi *et al.* [36]
Inventory management	Simulation optimization approach	Minimizing inventory cost	Tracking demand and align with production system + Simulating resources with replenishment mechanism	Qasem *et al.* [43]
Cold chain management	Mixed Integer Linear Programming	Sustainability performance	Storage of perishable items with cold chain warehouses	Gallo *et al.* [18]
Location-cold chain	Virtual machines by integrated RFID-WSN	System optimization	Cost analysis of implementation of system	Mejjaouli and Babiceanu [34]
Cold chain	Colored Petri network		Quality assessment + risk control	Liu *et al.* [32]
Partner selection	Colored Petri net +stochastic values	Delivery time + delivery quantity	Interrelationship between disruptions not considered	Chen *et al.* [9]
Supplier selection, production scheduling, vehicle routing	Bi-objective optimization model + weighted goal programming	Minimize cost + maximize reliability of suppliers	Model developed are highly constrained	Hashemi-Amiri *et al.* [24]

Viswanadham and Raghavan [57] proposed generalized stochastic petri net modelling for make-to-stock and assemble-to-order polices with locating decoupling point in supply chain for cost minimization objective. van der Vorst *et al.* [55] established simulation model based on timed colored petri nets for redesigning supply chain for chilled food products. Simulation considers multi-product with periodic ordering under implementation of real-time inventory system. Raghavan and Roy [44] proposed generalized stochastic petri net model for inventory rationing problem of multi-echelon make-to-stock distribution chain. Inventory rationing problem is important when there is shortage of inventory at distribution point or retail outlets.

The model developed is robust and captures the dynamic involved in stock rationing. Labadi *et al.* [30] presents batch deterministic and stochastic petri net model for performance evaluation of inventory systems where products are purchased in batches of different sizes or in finite discrete quantities. The model describes synchronization of discrete batch processes. Piera *et al.* [41] colored petri net model together with heuristic approach formalized pallet loading problem. Zhang *et al.* [61] developed CPN model for logistics design decision making on overall supply chain performance. Aized and Srai [3] developed Petri net hierarchical model for last mile distribution system for efficient and economic final delivery of products to customer. The model is appropriate for routing and congestion planning for delivery of products in defined geographical location. Chen *et al.* [9] developed robust CPN model in regard with delivery time and quantity of the supply chain. They introduced facility agricultural enterprises with understanding of different risk level need different quantities of partner. Hubert *et al.* [26] focused on stochastic Petri net modelling and simulation of cooling systems in small and medium sized breweries. Liu *et al.* [32] developed a novel structured CPN modelling to describe cold chain for aquatic products based on network hierarchy framework. Cross-layer information structure is built to record information transmission at every hierarchy in view of cold chain management. Yan *et al.* [60] proposed a Petri Net model sheep meat supply chain. State-transition diagram for supply chain and traceability information for quality of the product was presented. The model developed, standardize the meat product flow, decision-making for control of quality through traceability management in meat industry. Balamurugan *et al.* [5] developed enhanced Petri net model for food traceability with objective of minimization of cost, automation, and reduce system complexity. Kang *et al.* [29] integrated Petri net with mixed integer linear programming as a new approach for sustainable healthcare system. This method enabled sustainable operation utilization for long-term competitive advantage.

As depicted upon the modelling approach, size and complexity of these models incorporates large number of number of variables and constraints which is difficult to maintain and simulate, thereby increases complexity of the supply chain. This paper uses Petri net model tool with MILP for modelling of PPSC. Petri net models are based on mathematical formalism which explains the dynamic behaviour of the system [40,55,59]. The graphical feature makes it a powerful tool for visual communication for individuals involved in the design process. PN tool is widely studied and applied to discrete event dynamic systems which has attracted many academicians, researchers, and practitioners.

3. Optimization model

3.1. Problem description

From literature it is identified there is lack of processing unit for perishable products in developing countries. This research proposed optimization model for processing units for perishable products based on transportation cost, capacity constraint and partner selection system. As the transportation through different partner in PPSC and processing facilities influence the maintenance of quality of product and overall supply chain cost.

After identification of critical events (Bhardwaj and Agrawal 2022), we move to next objective for optimization of planning and control of perishable product supply chain members and activity from producers to customers to achieve robustness in decision making. Figure 1 represents the schematic diagram of PPSC which includes primary activity and actors involved in PPSC. It is noticeable that involvement of commission agent/traders resulted in dearth of revenue for farmers, unavailability of packaging units to nearby processing plants, and lack of cold chain management facilities are most critical events for cost and value degradation of product.

Inefficient management of activities and actors involved which result in cost and value degradation of overall supply chain. To optimize the supply chain design, quantitative analysis of multi-echelon perishable product supply chain is assumed. The current model works on multi-echelon, perishable product item, with periodic ordering to evaluate supply chain design in consideration with total chain cost and service elements. We consider two-echelon supply chain network where retailer procures the product from partners (one or more) and sell them to end-consumers. The involvement of partners often works by the difference in the price setting by partner and wholesale market price. During this period, lack of facility location problem, the farmer must sell the produce through involvement of multiple partners in the supply chain network.

The purpose of this paper is to combine mixed integer linear programming (MILP) for optimization and colored petri nets (CPN) to evaluate PPSC performance. Petri net is opted because it represents the problem with modelling concepts in real time scenario and allow the system to be modelled in hierarchical network of processes [55]. Petri net handles the parallelism and synchronization that explains the transparency of the system modelled as represented in van der Vorst *et al.* [55] simulated supply chain as logistically transparent. Guan *et al.* [23] developed hybrid Petri net model for workflow management for geographically dispersed farms.

This modelling approach is acquired from where PPSC members are modelled through reasoning layer and communication layer. Further PPSC operations are modelled using rule-based specification thus running sim-

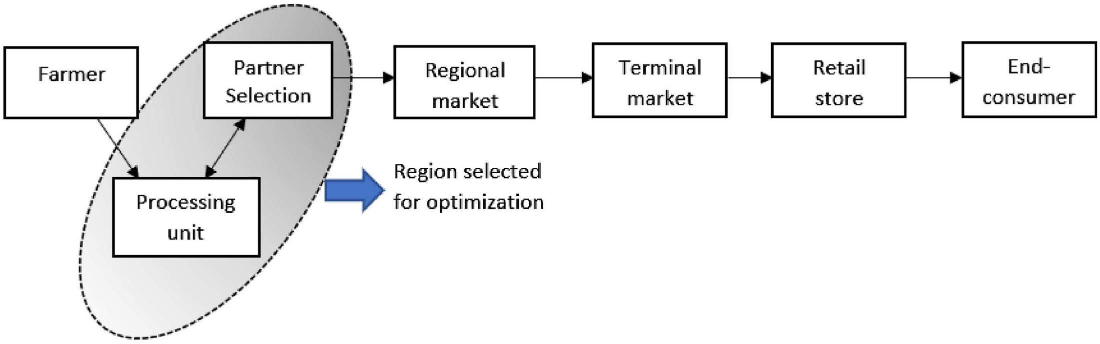


Figure 1. Schematic Diagram of PPSC.

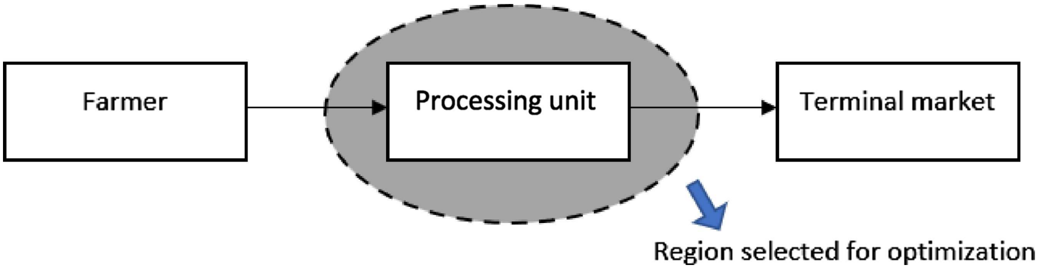


Figure 2. PPSC with processing unit as region for optimization.

ulation of supply chain operations. The logic-based approach explains the automated generation of simulated behaviours. Knowledge based technique has been incorporated to analyse the complex and dynamic system of PPSC. Thus, provides transparent and reasoning mechanism that captures the complex behaviour of the system and support the valuable explanation of different scenario.

3.2. Model formulation

3.2.1. Facility location model

The PPSC provides agri-products with high quality and high value. They deal with perishable goods with shorter lead time and adequate supply are needed with timeliness and diversity. The factors considered for optimizing of the PPSC in this article for facility location:

1. Capacity
2. Transportation cost

The construction of PPSC is shown in Figure 2. In this supply chain, PU is the processing unit where the farmers deliver the produce to the optimal facility for further processing and quality evaluation. This processing unit will act liaison between the farmer and terminal market coping up with the uncertainty factor of middleman.

For optimal PPSC, a mixed integer linear programming was employed. In the algorithm capacity and transportation cost were treated as parameters for optimal facility location. The notations that were used are summarized in the Table 2 given below

Table 2. Parameter description for facility location model.

Symbol	Description
I	Production zone in PPSC $i = 1, 2, 3, ..11 i > 0$
J	Processing unit in PPSC $j = 1, 2, 11 j > 0$
K	Terminal market in PPSC $k = 1, 2, 3, 4 k > 0$
N_j	Number of partners in PPSC
Q_{ij}	Quantity of product supplied from production zone i to processing unit j
S_{jk}	Quantity of product supplied from processing unit j to market k
D_{ij}	Estimated distance from production zone i to processing unit j
T_{ij}	Transportation cost per unit production zone i to processing unit j
T_{jk}	Transportation cost per unit processing unit j to market zone k
D_k	Demand at the terminal market k
M_j	Quantity handled at the facility j

Capacity of processing unit was calculated as

$$\begin{aligned} &\mathrm{CP} = \sum_{j=1} \sum_{i=1}^{11} X_j * Q_{ij} \\ &X_j = \left\{ \begin{matrix} 1, & \text{if processing unit located by production zone } i \\ 0 & \text{otherwise} \end{matrix} \right\}. \end{aligned} \tag{1}$$

Assumption 1. Assuming that every processing centre is located at the production zone
Q_{ij} = Quantity of product supplied from production zone i to processing unit j.

Assumption 2. Assuming from the expert knowledge that 25% of the perishable item is wasted due to climate variability, quality degradation by animals, accidents and natural disaster.

Transportation cost from production zone to processing unit

$$\mathrm{CTP} = \sum_{i=1}^{11} \sum_{j=1}^{11} D_{ij} * T_{ij} * Q_{ij}. \tag{2}$$

Assumption 3. We are considering the distance from production zone to processing unit as 1 (refer Assumption 1).

Transportation cost from processing unit to market zone

$$\mathrm{CTM} = \sum_{j=1}^{11} \sum_{k=1}^{4} T_{jk} * S_{jk}. \tag{3}$$

Assumption 4. We are considering the development of optimal facility near the production area, so thereby in our research we are neglecting the distance between processing unit

$$\mathrm{Min\ Z} = \mathrm{CP} + \mathrm{CTP} + \mathrm{CTM} = \sum_{j=1} \sum_{i=1}^{11} X_j * Q_{ij} + \sum_{i=1}^{11} \sum_{j=1}^{11} D_{ij} * T_{ij} * Q_{ij} + \sum_{j=1}^{11} \sum_{k=1}^{4} T_{jk}. \tag{4}$$

Subject to Constraints:

Quantity ($\mathrm{S_{jk}}$) we are shipping should meet the demand ($\mathrm{D_k}$) of the market k:

$$\sum_{j=1}^{11} S_{\mathrm{jk}} = D_{\mathrm{k}} \quad \mathrm{k} = 1, 2, 3, 4. \tag{5}$$

TABLE 3. Parameter description for partner selection model.

Symbol	Description
$\mathrm{N_s}$	Number of partners in PPSC $\mathrm{s} = 1, 2, 3, 4\,\mathrm{s} > 0$
$\mathrm{U_j}$	Uncertain demand of product from processing unit j
$\mathrm{V_{sj}}$	minimum quantity of product from processing unit j allocated to partner j
$\mathrm{Q_{ij}}$	Quantity of product supplied from production zone i to processing unit j
$\mathrm{S_{jk}}$	Quantity of product supplied from processing unit j to market k
$\mathrm{O_{sj}}$	Quantity of product from processing unit j to partner s
	Upper bound allocation of product depending upon the uncertain event occurrence for partner s is 50%
$\mathrm{D_{ij}}$	Estimated distance from production zone i to processing unit j
$\mathrm{T_{ij}}$	Transportation cost per unit production zone i to processing unit j
$\mathrm{T_{jk}}$	Transportation cost per unit processing unit j to market zone k
$\mathrm{P_{sj}}$	Price quoted by each partner s to produce per unit of product from processing unit j
$\mathrm{D_k}$	Demand at the terminal market k
$\mathrm{M_j}$	Quantity handled at the facility j
$\mathrm{X_j}$	A binary variable equal to 1 if processing unit located by production zone i and 0 otherwise
$\mathrm{Y_{sj}}$	A binary variable equal to 1 if partner s is selected to produce from processing unit j and 0 otherwise
φ_s	Uncertain occurrence threshold value as 0.40, 0.25, 0.20, 0.15

To fulfil the demand of the market by the facility

$$\sum_{\mathrm{k}=1}^{4} \mathrm{S_{jk}} \leq \mathrm{M_j X_j} \quad \mathrm{j} = 1, 2, 3 \dots 11 \tag{6}$$

If the jth facility is used than quantity that we are sending from facility j then $(\mathrm{S_{jk}})$ demand of the market should be less than or equal to demand

$$3\mathrm{S_{jk}} \leq \mathrm{D_k X_j} \qquad \mathrm{k} = 1, 2, 3, 4; \mathrm{j} = 1, 2 \dots 11 \tag{7}$$

$$\mathrm{S_{jk}} \geq 0 \qquad \mathrm{j} = 1, 2, \dots, 11; \mathrm{k} = 1, 2, 3, 4 \tag{8}$$

$$\mathrm{X_j} \in \{0, 1\} \qquad \mathrm{j} = 1, 2, \dots 11.$$

3.2.2. Partner selection model

We formulate the partner selection and facility location problem for outsourcing product under uncertain environment as an integration of mixed integer linear programming problem and evaluating through Colored Petri Net modelling tool. As for facility location, capacity and transportation cost are parameters considered for objective function (Sect. 3.2.1). And for partner selection problem, number of partners, amount of product supplied, and cost are considered as parameters for objective function during uncertainty occurrence.

Moving on to partner selection problem, with occurrence of uncertainty event, outsourcing of product is assigned to partners. Once the product is out of production site, the next job involves appropriate selection of partners. The partners in our case of problem set considered during uncertainty occurrence.

For purpose of uncertain occurrence of event and to assure the outcome tasks are under control, minimum number of partners N_s to be selected and capacity of each partner s from processing unit j is V_{sj}. We consider J processing sites to outsource the product to K terminal markets. During uncertain event occurrence, the demand of product from processing site j to market k is given by U_j. The price quoted by each partner s to produce per unit of product from processing unit j is P_{sj}. The threshold values taken are dependent upon the economic conditions and associated probabilities are 0.40, 0.25, 0.20 and 0.15 [14,17], refer to Table 3.

$$\text{Min} \sum_{s=1}^{s} \sum_{j=1}^{j} \varphi_s P_{sj} O_{sj}. \tag{9}$$

s.t.

Constraint (1), Service level of selected partner is well Committed

$$V_{sj} Y_{sj} \leq O_{sj} \qquad \forall s, j. \tag{10}$$

Constraint (2). Quantity of product allocated based on the threshold value

$$O_{sj} \leq U_j Y_{sj} \qquad \forall s, j. \tag{11}$$

Constraint (3). Number of selected partners should be equal or more than number of specified partners

$$\sum_{j=1}^{J} Y_{sj} \geq N_s \qquad \forall s$$

$$Y_{sj} \in \{0, 1\}$$

$$O_{sj} \geq 0$$

$$\text{For all } \; \mathrm{j} = 1, 2, \ldots \mathrm{J} \qquad \mathrm{s} = 1, 2, \ldots \mathrm{s}.$$

Now, we investigate the partner selection problem during uncertain event occurrence.Disruptions associated with supply chain are dependent upon economic conditions. These conditions are associated with probabilities which are identified to be threshold value for our model development as Φ_s which are 0.40, 0.25, 0.20 and 0.15 [14,17]. Meanwhile the upper bound for allocation of product to partners are $\mathrm{O_{sj}} = 50\%$ of product quantity to partner [17].

3.3. CPN model formulation

Colored Petri net is an extension of basic Petri net (PN). It adds another aspect of abstractness and token definition compared with basic petri net. Tokens have color associated to them and can represent different functions. Different tokens available at place determines which transition of multiple available transitions to operate. CPN models evaluates concurrency, synchronization, resource sharing, and modularity of systems [9, 11,27,58]. A CPN is a bipartite, directed, and multiway graph consisting of three structural components as places, transition nodes and arc [62]. It uses ellipses to represent nodes and rectangles to represent transitions. Directed arcs transmits information from places to transitions and vice-versa representing input-output relationship. Over time, token vary at each places along with the directed arcs. Tokens in CPN have both value and time stamp, which describe characteristics of PPSC.

In this section, we discuss the evaluation of the model developed in Section 3 to be simulated in CPN tools. The objective of this case study is to evaluate the responsiveness of PPSC in regard with optimal processing unit location and secondly, partner selection with occurrence of uncertainty. The threshold value of uncertainty factor in referred from Fu *et al.* [17] and Dupačová *et al.* [14] categorized into values as follows: 0.40, 0.25, 0.20 and 0.15. Figures 3 and 4 presents model development in CPN tools and Tables 4 and 5 represent the description of CPN models respectively. Figure 5. Flowchart representing the underlined problem identification, quantification, and analysis of case example.

The optimized network consists of places and transitions. The CPN model for facility location consists of five places and four transitions. The flow of token starts from places EFL which consists of variables facility (f), market (m), production (p), demand (d), and transportation cost (c).

Table 4. Description of places and transitions for CPN model for facility location.

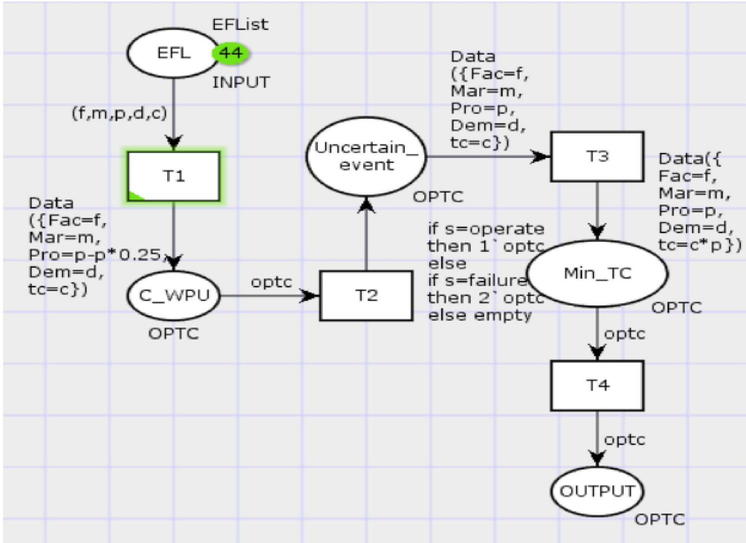
Places	Description	Transitions	Description
EFL	Estimated facility location data	T1	Flow of data from place EFL to C_EFL describing 25% of wastage of product after harvesting
C_EFL	Capacity of estimated facility location	T2	Flow of product during uncertain event
UE	Occurrence of uncertain event	T3	Flow of information with minimum transportation cost
Min_TC	Minimum transportation cost	T4	Represents the output of the information
OUTPUT	Represents the output of the model		

Table 5. Description of places and transitions for CPN model for partner selection.

Places	Description	Transitions	Description
IList	Input data values	T1	Flow of data from place EFL to C_EFL describing 25% of wastage of product after harvesting
P1, P2, P3, P4	Represent the supplier1, supplier2, supplier3, supplier4 data respectively	T2, T3, T4, T5	Determine the condition based on threshold value as 0.40, 0.25, 0.20, 0.15
P5, P6, P7, P8	data value of suppliers under uncertain occurrence	T6, T7, T8, T9	Flow of information of suppliers based on previous condition as per transition T2, T3, T4 and T5 respectively
P9, P10, P11, P12	Data value of transportation cost as per uncertainty occurrence of the suppliers respectively	T10, T11, T12, T13	Flow of information of with minimum transportation cost
P13,P14, P15, P16	Represents the output of the model		

4. Results and discussions

In this section we discuss the CPN model effectiveness considering case study approach. Section 4.1 presents the optimal establishment of processing unit problem and further, partner selection problem during uncertain condition is illustrated in Section 4.2. The developed CPN model provides a general case solution considering existing planning and decision variables. The parameters precisely transportation cost and demand for apple product are then varied and performance of system is quantified as the model follows the same production area with capacity constraint as constant. Uncertainty occurrence threshold value φ_s is proposed alternatively for partner selection, primarily to understand the distribution of product so that proper strategy can be implemented. It will help the decision makers to reduce cost burden and minimize the wastage during any disruption. The input data for the case study is as follows.



(a)

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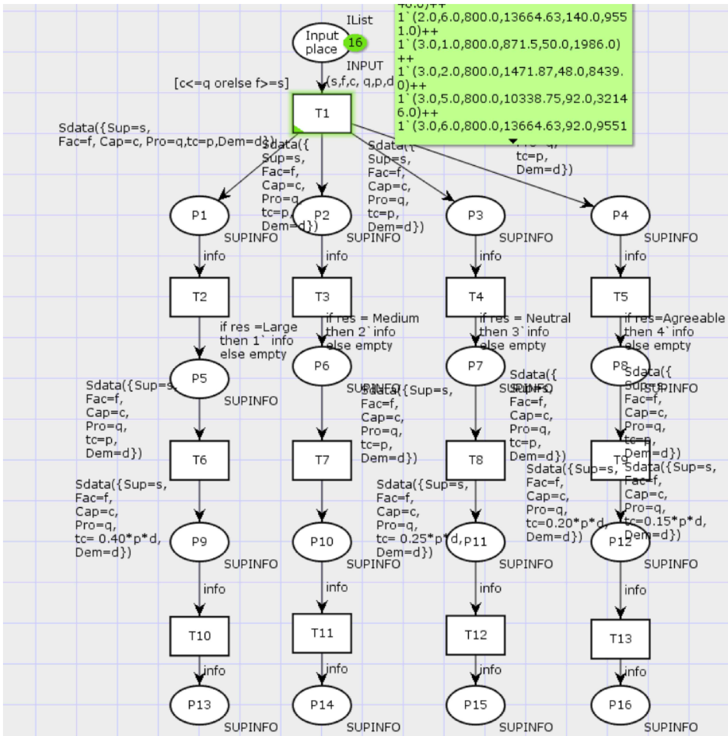
colset REAL = real;
colset STRING = string;
colset FACILITY = real;
colset MARKET = real;
colset PRODUCTION = real;
colset DEMAND = real;
colset TC = real;
colset INPUT= product FACILITY * MARKET*PRODUCTION*DEMAND*TC;
colset DATAPACK = record Fac:FACILITY * Mar:MARKET * Pro:PRODUCTION * Dem:DEMAND * tc:TC;
val EFList = 1`(1.0, 1.0, 581.0,1986.0,93.05)++1`(1.0,2.0,581.0,8439.0,338.77)++1`(1.0,3.0,581.0
  ++1`(2.0,1.0,981.0,1986.0,113.06)++1`(2.0,2.0,981.0,8439.0,406.81)++1`(2.0,3.0,981.0,32146.0
  1`(3.0,1.0,10260.0,1986.0,577.03)++1`(3.0,2.0,10260.75,8439.0,1984.32)++1`(3.0,3.0,10260.75,
  ++1`(4.0,1.0,12021.0, 1986.0,665.07)++1`(4.0,2.0,12021.0,8439.0,2283.65)++1`(4.0,3.0,12021.0
  ++1`(5.0,1.0,6892.0,1986.0,408.62)++1`(5.0,2.0,6892.0,8439.0,1411.72)++1`(5.0,3.0,6892.0,321
  ++1`(6.0,1.0,9109.0, 1986.0,519.48)++1`(6.0,2.0,9109.0,8439.0,1788.65)++1`(6.0,3.0,9109.0,32
  ++1`(7.0,1.0,16734.0,1986.0,900.73)++1`(7.0,2.0,16734.0,8439.0,3084.90)++1`(7.0,3.0,16734.0
  ++1`(8.0,1.0,16734.0,1986.0,900.73)++1`(8.0,2.0,16734.0,8439.0,3084.90)++1`(8.0,3.0,16734.0
  ++1`(9.0,1.0,20221.0,1986.0,1075.05)++1`(9.0,2.0,20221.0,8439.0,3677.57)++1`(9.0,3.0,20221.
  ++1`(10.0,1.0,11389.0,1986.0,633.45)++1`(10.0,2.0,11389.0,8439.0,2176.13)++1`(10.0,3.0,1138
  ++1`(11.0,1.0,10870.0,1986.0,607.51)++1`(11.0,2.0,10870.0,8439.0,2087.94)++1`(11.0,3.0,1087
colset TCOST = record Pro:PRODUCTION * tc:TC;
colset OPTC = union Data:DATAPACK + Cos:TCOST;
colset STATE = with operate | failure;
var f, Fac : FACILITY;
var m, Mar : MARKET;
var d, Dem: DEMAND;
var c, tc : TC;
var p, Pro: PRODUCTION;
var optc : OPTC;
var s : STATE;
```

(b)

FIGURE 3. (a) CPN model of facility location; (b) standard modelling language for CPN model.

The data input into the model is dependent on the case study approach. We explained the model using case example of apple supply chain of Shimla region of India. Apple constitutes of 49% of total fruit production in Himachal Pradesh in India with economy worth nearly Rs 40 billion with around 1.5 lakh families associated with it. The major concern areas for apple growers are production, storage, partner selection and marketing. Any discrepancy will adversely affect the farmers income [49]. The demographic detail of the region is shown



(a)

```
▶colset INTINF
▶colset TIME
▼colset REAL = real;
▼colset STRING = string;
▼colset UValue=real;
▼colset QUANTITY = real;
▼colset CAPACITY = real;
▼colset PRICE= real;
▼colset DEMAND = real;
▼colset THRESHOLD = real;
▼colset SUPPLIER = real;
▼colset FACILITY = real;
▼colset INPUT= product SUPPLIER * FACILITY * CAPACITY * QUANTITY * PRICE * DEMAND;
▼val IList = 1`(1.0, 1.0, 800.0, 871.5,130.0,1986.0)++1`(1.0,2.0, 800.0, 1471.87, 130.0,8439.0)
  ++1`(1.0,5.0, 800.0, 10338.75,125.0,32146.0)++1`(1.0,6.0,800.0, 13664.63,125.0,9551.0)
  ++1`(2.0,1.0,800.0, 871.5,100.0,1986.0)++1`(2.0,2.0, 800.0, 1471.875, 110.0,8439.0)
  ++1`(2.0,5.0, 800.0, 10338.75,130.0,32146.0)++1`(2.0,6.0,800.0, 13664.63, 140.0,9551.0)
  ++1`(3.0, 1.0,800.0, 871.5,50.0,1986.0)++1`(3.0,2.0,800.0, 1471.87,48.0,8439.0)
  ++1`(3.0,5.0, 800.0, 10338.75, 92.0,32146.0)++1`(3.0,6.0, 800.0,13664.63,92.0,9551.0)
  ++1`(4.0,1.0,800.0, 871.5,90.0, 1986.0)++1`(4.0,2.0,800.0, 1471.87,90.0,8439.0)
  ++1`(4.0,5.0,800.0,10338.75, 110.0,32146.0)++1`(4.0,6.0,800.0, 13664.63,110.0,9551.0);
▼colset SUPDATA = record Sup:SUPPLIER * Fac:FACILITY *
  Cap:CAPACITY * Pro:QUANTITY * tc:PRICE* Dem:DEMAND;
▼colset SUPINFO = union Sdata:SUPDATA;
▼colset STATE = with Large|Medium|Neutral|Agreeable;
▼var f, Fac : FACILITY;
▼var Dem, d: DEMAND;
▼var p, tc : PRICE;
▼var q, Pro: QUANTITY;
▼var c, Cap :CAPACITY;
▼var info : SUPINFO;
▼var s,Sup : SUPPLIER;
▼var u, Unc: THRESHOLD;
▼var res:STATE;
```

(b)

FIGURE 4. (a) CPN model for partner selection Figure 3; (b) standard modelling language for CPN model.

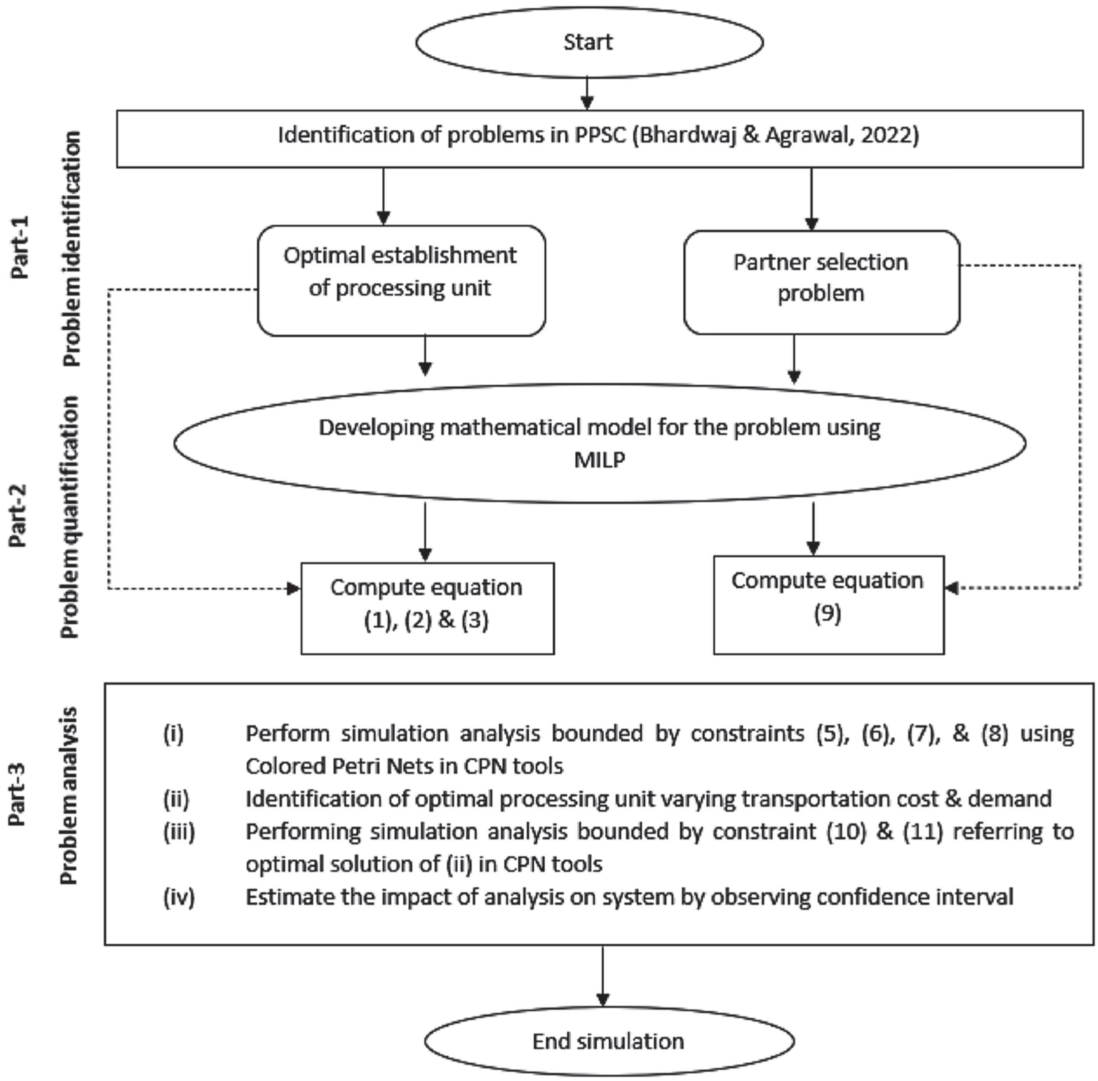


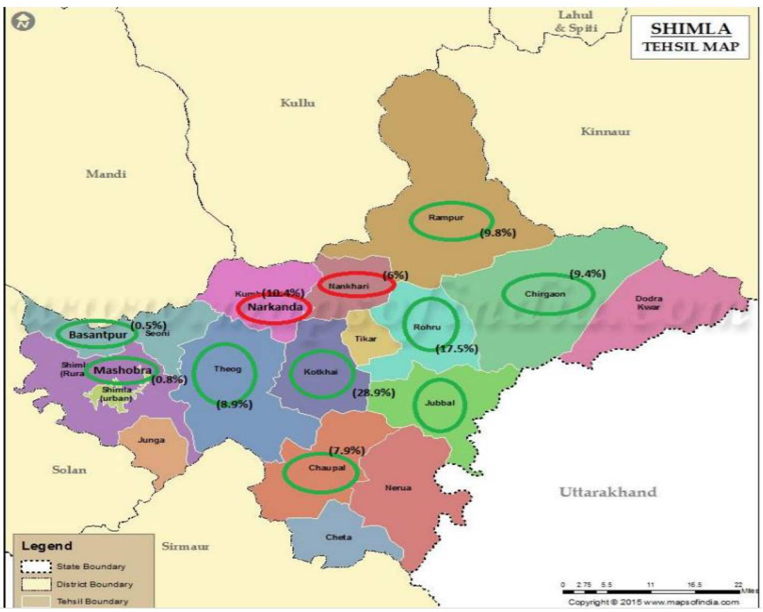
FIGURE 5. Flowchart representing the underlined problem identification, quantification, and analysis of case example.

in Figure 6. The secondary data is collected from Economic survey of Himachal Pradesh, and monthly price-arrival bulletin from National Horticulture Board, India. The transportation cost data as per parameter of arrival quantity (MT.) of the apples purchased at distribution center is specified in Table 3.

4.1. Evaluation of CPN model for optimal processing unit location

The model captures the establishment of optimal processing unit location dependent upon the production area and transportation cost. To carter the problem, we developed an MILP formulation. It is approximated to used linearization technique. Finally, the MILP formulation is solved using Colored Petri Nets simulation software. The decision variables and constraints as represented in CPN tools provides more efficient result with set of input parameters represented in Table 6.

(a)



(b)

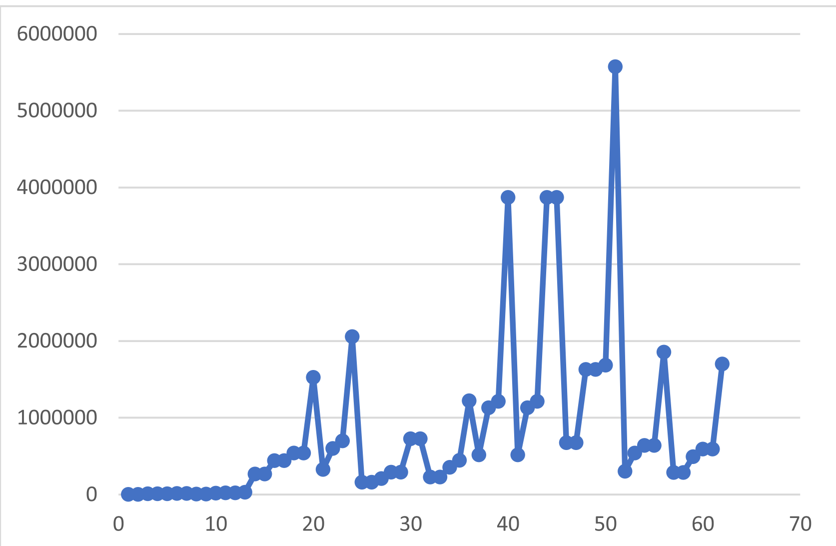
Figure 6. (a) Demographic detail of Shimla. (b) Percentage share of apple production in different blocks of Shimla.

Table 6. Input data for facility location CPN model.

Market	1.0	2.0	3.0	4.0	
Demand (MT)	1986	8439	32146	9551	
Facility		Transportation cost			Production area (MT)
Seoni (1.0)	93.05	338.77	303.93	250.53	581
Shimla (2.0)	113.06	406.81	320.42	254.53	981.25
Theog (3.0)	577.03	1984.32	702.74	347.32	10260.75
Kumarsain (4.0)	665.07	2283.65	775.28	364.93	12021.5
Nankhari (5.0)	408.62	1411.72	563.97	313.64	6892.5
Chaupal (6.0)	519.48	1788.65	655.32	335.81	9109.75
Jubbal (7.0)	900.73	3084.90	969.47	412.06	16734.75
Kothkai (8.0)	900.73	3084.90	969.47	412.06	16734.75
Rohru (9.0)	1075.05	3677.57	1113.10	446.93	20221.0
Rampur (10.0)	633.45	2176.13	749.22	358.61	11389.0
Chiragaon (11.0)	607.51	2087.94	727.85	353.42	10870.25

Table 7. Optimal transportation cost with respect to facilities.

Facility	Total cost (unit)
1 (Seoni)	429771.51
2 (Shimla)	805513.81
5 (Nankhari)	13945703.55
6 (Chaupal)	22539719.51
3 (Theog)	27791506.79
11 (Chiragaon)	30789709.8
10(Rampur)	33461536.87
4 (Kumarsain)	36864770.65
7 (Jubbal)	67360541.58
8 (Kothkai)	67360541.58
9 (Rohru)	95736071.74



Maximum	55,77,310.723
Minimum	4,05,465.375
Mean	50,62,31.49
Std Dev	10,80,781.03
95% Confidence interval	

Figure 7. Optimal establishment of processing unit cost (in Millions).

TABLE 8. Input data for partner selection CPN model.

φ_s	0.4	0.25	0.20	0.15		
Market (i)	A	B	C	D		
Demand (d)	1986	8439	32146	9551		
N_s	1	2	3	4	5	
Facility			Price			Quantity
1	130	100	50	90	100	871.5
2	130	110	48	90	100	1471.87
5	125	130	63	92	110	10338.75
6	125	140	120	92	110	13664.63

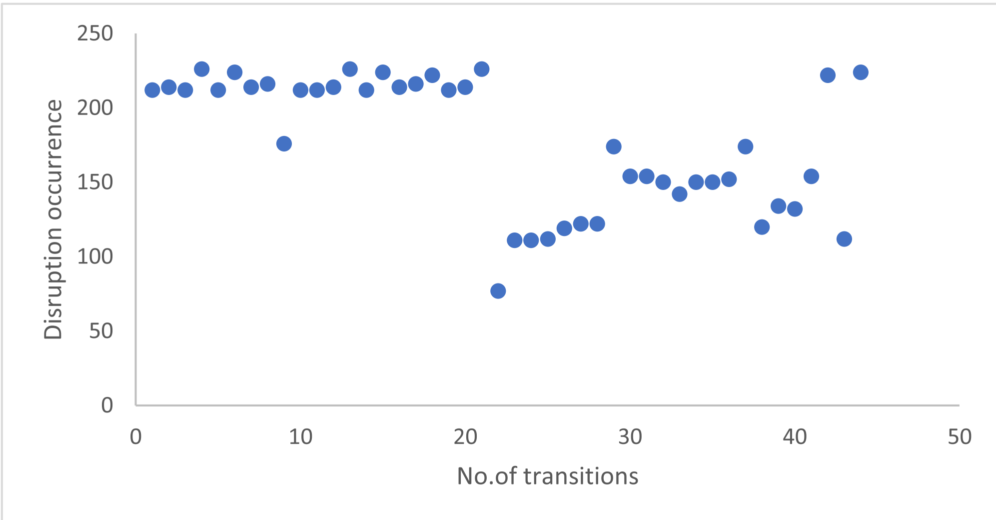


FIGURE 8. Depiction of disruption in PPSC.

The first objective is to study the efficiency of PPSC by identifying establishment of processing units around the production areas and further discuss the responsiveness of supply chain by identifying the partners in regard to uncertain conditions. The results as shown in Table 7 of data processing collected from Data Collection Log files from CPN model based on optimization as per Section 4 is displayed in Table 5.

The values for the above results are subjected to transportation cost and production area with estimate of 25% loss during post harvesting such as transportation and environmental variation (Bhardwaj and Agrawal 2022). The results corresponding to the case study with optimal establishment of processing units are Seoni, Shimla, Nankhari, Chaupal and Theog, refer to Table 4. These results were obtained using flow of token in the CPN model using calculation of decision variables and solving problem of deterministic equivalent. It is the monetary value that bisects for optimal establishment of processing unit location for partners to work upon the transportation of product to end consumer during occurrence of disruption. It was observed that the cost for establishment of processing unit increases as per the area of production. Since, the establishment of processing unit are considered for a state region, cost tradeoff is priority and inter-region transportation is as compared small distances. Also, at 95% confidence interval, the expected establishment cost will lie between 12,23,579.43 and 5,56,39,964.99. Figure 7 realized various cost incurred considering values of transportation cost, production area and stochastic demand of single product.

TABLE 9. Output data for partner selection CPN model.

Partner	Facility	Cost	Partner	Facility	Cost
1	1	645450	3	1	24825
	2	438828		2	81014.4
	5	803650		5	1182973
	6	238775		6	175738.4
2	1	297900	4	1	371316
	2	232072.5		2	189877.5
	5	1671592		5	707212
	6	334285		6	157591.5

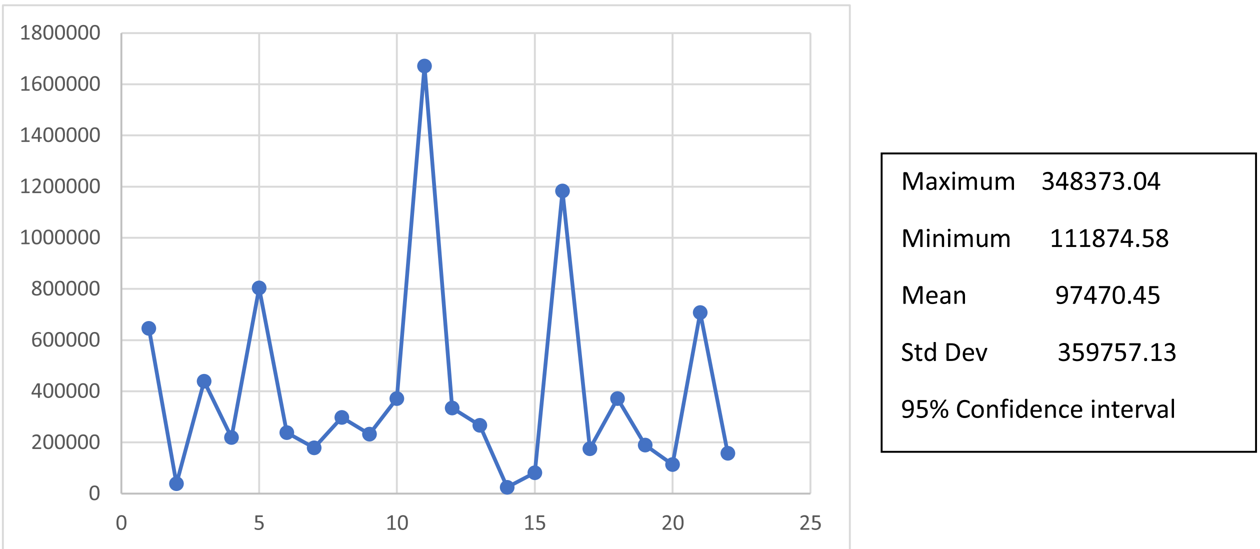


FIGURE 9. Optimal partner selection cost.

Figure 3 transition T2 and place Uncertain_event represents any occurrence of disruption during post harvesting. The primary focus of this area is to capture the rate of disruption through simulations. It was observed that the random occurrence of disruptive event is counted in drop of transitions as shown in Figure 8.

4.2. Evaluation of CPN model for partner selection

This section demonstrated the selection of partner from the optimal established processing unit as per Section 4.1. The decision variables and constraints as represented in CPN tools provides more efficient result with set of input parameters represented in Table 8. Place Uncertain_event represents disruption during post-harvesting. The values φ_s are the threshold values as captured in terms of economic conditions [17]. The values captured from the data log files of CPN model is presented in Table 9. This table describes the specific partner associated with the facility and transportation cost. Decision-makers thereby can identify the set of partners from the set of facilities dependent upon the transportation cost for further supply of product. Such as partner 1 with lowest cost of 238775 from facility 6 to partner 1 with maximum cost of 803650 from facility 5. Also, at 95% confidence level the expected transportation cost lies between 219414 and 1182972.8, Figure 9.

5. Discussion

The optimization model is motivated from decision maker challenges involved in perishable product processing and transportation. One of the many inefficiencies in PPSC that was examined was establishment of processing unit and partner selection during disruption. The novelty of the work can be stated with help of case study approach and disruption scenario to mathematical modelling and simulation. To the best of our knowledge, there is dearth of studies considering optimal establishment of processing unit with concurrent selection of partners under disruption problem of PPSC. Furthermore, optimization for identification of processing units depends upon the minimum transportation cost and production area with the help of mixed integer linear programming simulated through CPN tools. Further dependent upon the identified optimal processing units, identification of partner selection during disruption is again simulated through CPN tools.

Some of the significant inferences relevant to the optimal model for theory and practical application of the study are as follows.

(1) The literature presented in this study is amalgamation of mixed integer linear programming and Colored petri nets based on technical aspect. The grouping of both techniques reduces the time of computation and constraints applied on the variables. Variables are explained in terms of tokens whereas the constraints are taken up as decision making elements in the transition.
(2) Majorly, the model focus on single item production problem in optimal establishment of processing unit context further with partner selection under disruption. OR technique such as MILP are considered with simulation performed in CPN tools. The CPN tools software has primarily helped with the simulations and analysing the conditions scenario for the case study.
(3) Although the optimized model is motivated in perspective of decision maker and business implementation, it theoretically connects real-world problems to conceptual parameters, cost functions and decision variables.
(4) The model discusses production-planning including strategic and operational decisions under disrupted environment. The model simulated in concurrent effects of disruption categorized in terms of probability associated with economic terms.
(5) The MILP model formulation to Colored petri nets transformation effectively managed the random variables in terms of events and transitions nature. The model transformation particularly reduced computational efforts and solution complexity.
(6) The model development for partner selection is profitable. With occurrence of uncertainty adversely affects the product such as transportation delay, degradation of perishable item as well as have decreases the economic terms. Such losses should be of prime consideration for the decision makers. Possible solution explored in the paper by keeping in consideration partner selection operational issue during uncertainty with minimization of cost.

6. Conclusion and future work

Solving operational issues under uncertain business environments is a difficult task. Nevertheless, the study develops amalgamation of mixed integer linear programming model and Colored petri nets to make operational decisions for PPSC under such conditions. The decision variables in our model include operational level transportation cost and production area updates related to partner selection. To facilitate the planning process, the study uses the case-study approach for decision-making process. The simulation captures the optimal region for establishment of processing units. Such a model is widely applied using MILP approach in literature but hardly identified with use of CPN tools in PPSC design context.

In this paper, we examined through case study approach using single type of product, that is, apple. Production and planning network with different product categories of perishable product can be suitable for extension. However, different criteria and variables among product categories must be considered. The study is suitable of decision making for future events such as partner selection during uncertain scenario. The mathematical model developed using MILP and simulation in CPN tools for concurrency and efficiency of the model. Thereby, the model can be used as a decision-making system for processing companies to result in efficient PPSC management. The developed model was tested and validated on case study to demonstrate our approach's applicability.

The study conducted has opened promising vistas for future research. Moreover, a similar study can be carried out dependent upon different geographical regions or compared with supply chain of other countries. The further studies could incorporate Petri Net into existing supply chain production system using advanced technologies as IoT, RFID, WSN and smart systems. The studies could work upon data using meta heuristics techniques. More advanced optimization methods such as swarm optimization and ant colony optimization would algo discuss a more efficient and large data set of results. Research directions towards information sharing leads to traceability information model development for PPSC, communication and coordination approach among different agents in supply chain. A similar empirical study might be carried out for supply chain of related sector as food processing unit, beverages industry, cold chain and other fresh produce such as mango, litchi, and onions. Finally, an attempt can also be made to develop a similar model for the organization/industry for the AI advanced supply chain.

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