SYSTEM DYNAMICS APPROACH FOR MANAGEMENT OF PERISHABLE FRESH PRODUCE SUPPLY CHAIN

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Abstract: Growing interest in the food security and food quality has highlighted the need for efficient management of food supply chains. The fruits & vegetables supply chain is so dynamic in behavior because of perishability and limited shelf life, and there is a very limited supply chain modeling attempts on perishable food items in the literature. This paper proposes a modeling framework using system dynamics (SD) approach to simulate the operations of fruits and vegetables supply chain. In a developing country like India where cold storage facilities & logistics infrastructure is still developing, there is a need for alternative ways to capture the dynamics of fruit & vegetable supply chain efficiency. The ability to give a holistic perspective and the capability of dynamic modeling through feedback loops make SD an ideal approach to analyse and comprehend fruits & vegetables supply chain. The developed model is useful in understanding the issues affecting food quality and food waste in the fruits & vegetables supply chain and the behavior of the system under various real-life operational scenarios can be analysed.

Keywords: Food Wastage, Fruits & Vegetables Supply Chain, India, System Dynamics.

Introduction: A supply chain is defined as a network of organisations that are involved in processing a business function such as manufacturing, distribution, supplying, subcontracting and so on, at any stage of the value chain. In a supply chain, there are three types of flow, that of materials, information and finance. Supply chain management (SCM) is expected to improve the overall performance of the network by coordinated activities and efficient control and management of the three flows taking place across the supply chain network. Supply chain management describes the discipline of optimising the delivery of goods, services and related information from supplier to customer. It is concerned with the effectiveness of dealing with final customer's demand by the parties engaged in the provision of the product as a whole. A supply chain consists of different levels, namely supplier, manufacturer, distributor, and consumer, and it is a network of organisations that influence each other and affect one another's performance. (Beamon, 1998)

The supply chain of agri-foods, as any other supply chain, is a network of organizations working together to bring agri-products to the market, with the purpose of meeting customers' demand. 'Shelf life' is a most commonly used terminology in perishable items. It refers to the time in number of days or hours that a food product has 'acceptable quality' and is safe to consume. The shelf life depends on the storage temperature and transportation conditions of the perishable agri-fresh produce. The limited shelf lives of food products, requirements with regard to temperature and humidity, possible interaction effects between products, time windows for delivering the products, high customer expectations, and low profit margins make food distribution management a challenging area that has only recently began to receive more attention. (Akkerman et al., 2010). Measuring the performance of agri-food supply chains is rather difficult because they have many characteristics that set them apart from other types of supply chains. (Aramyan et al., 2007).

The following factors differentiate food supply chain with that of manufacturing supply chain:

- shelf life constraints for raw materials and perishability of products;
- long production throughput time;
- seasonality in production;
- physical product features like sensory properties such as taste, odor, appearance, color, size and image;
- requires conditioned transportation and storage;
- product safety issues; and
- natural conditions affect the quantity and the quality of farm products.

According to National Horticulture Database 2014, India is the second largest producer of fruits and vegetables next to China. India produced 88.97 million metric tonnes of fruits and 162.98 million metric tonnes of vegetables during 2014 which constitutes around 12.6% and 14% of the total world production. In spite of this huge volume production, the exports in F&V are very miniscule in the order of 1-2%. Around 25-40% of the fruits and vegetables are wasted from the post-harvest stage till it reaches consumer. This can be attributed to the lack of integrated approach and poor supply chain management. This is a humungous loss of more than Rs. 44,000 crores per year due to poor supply chains. An efficient supply chain is required to minimize the food loss. (Shukla & Jharkharia, 2013).

There is an ample scope to study the supply chain efficiency in fruits and vegetables chain particularly in Indian context. Food waste in the Fruits & vegetable supply chain is due to the processing waste, lack of cold-storage facilities, higher delivery lead time among the actors, process contamination, Inappropriate packaging, transportation losses, higher inventory due to poor forecasts (E. Papargyropoulou et al., 2014). The purpose of this paper is to model the food quality and food wastage and simulate the operations of fruits & vegetables supply chain using system dynamics approach. System dynamics approach is identified as the suitable simulation technique in modeling highly dynamic supply chains such as fruits & vegetables.

Literature Review: The literature review of fruits & vegetable supply chain is discussed in this section.

Food Supply Chain Design & Management: Beamon (1998) argued that the design of the supply chain impacts costs, flexibility and customer service level. Van der vorst et al. (2000) proposed a method for modeling the dynamic behaviour of food supply chains and evaluated alternative designs of the supply chain infrastructure and operational management and control by applying discrete-event simulation for chilled salads. The following principles for food supply chain redesign are putforth:

- diminish time windows for business processes (waiting times, processing times);
- synchronise, eliminate or reallocate business processes;
- shorten cycle times and increase the execution frequency of business processes;
- co-ordinate decision policies;
- implement real-time information systems;
- standardise and implement definitions of supply chain metrics;
- create information transparency

Dynamics of Fruits & Vegetables Supply Chain: Fruits & vegetables have very limited shelf life and are the most perishable agricultural produce. Managing fruits and vegetables supply chains is highly complicated due to the product specific characteristics. One of the critical parameters of fresh produce F&V supply chain is food quality which degrades over the period of time depending upon the environmental conditions of storage and transportation facilities. This quality degradation makes the food items perishable in a span of time which results in the loss of the value of the food items. Van der Vorst (2007) proposed the quality controlled logistics which integrates the quality dimensions with the logistics operations. This dynamic nature makes the F&V supply chain very challenging for its integrated management approach. Rong et al. (2011) proposed a mixed integer linear programming model for the planning of food production and distribution with the focus on food quality. This model analysed the interactions between shelf life, temperature, relative transportation costs and quality degradation which could facilitate the decision maker to analyse the optimal scenario. But this optimization model is quite large for a simple application. An efficient fruit & vegetable supply chain would effectively manage the dynamic interrelationships between shelf life, food quality, food wastage and would result in increased profitability.

Fruits & Vegetables Supply Chain in Indian Context: Post harvest losses of fruits & vegetables constitute around 25-40% of total production for different produces. Joshi et al. (2009) identified and inter-related the inhibitors that significantly influence the efficiency of a cold chain. Two sectors, Milk and Milk Products (MMP) and Fruits and Vegetables (F&V) were selected for this study because the MMP and F&V temperature range (- 18^{o}C to +10^{o}C) covers most types of perishable items. The 13 inhibitors are as follows; Lack of awareness about the use of IT, Improper collaboration planning, Incompetent professional skills, High cost for installation and operation, Lack of quality and safety measures, Inadequate education of growers/Farmers, Too many intermediaries, Lack of standardization, Government regulation, Improper tracing, Poor infrastructure, Lack of top level commitment and Customer ignorance towards quality.

Anika Trebbin (2014) argued that very little research work has been done on Indian agri-food supply chains when compared to other developing countries and analysed the impact of modern retail in redesigning the food supply chains. The author discussed the role of farmer producer organizations (FPO) in the Indian retail transformation resulting in redesigned supply chains.

Modeling the Fruit & Vegetable Supply Chain: Supply chain modeling is an important activity that allows firms to understand its current performance and to evaluate the likely performance of its alternatives. Basically, there are three approaches found in the literature for supply chain modeling: Optimisation, Heuristics and Simulation. Optimisation techniques are most widely used in supply chain modeling but have its own limitations with respect to handling the forecast error and inaccuracy. Also, when the business goals are changed over time and some problems are too complex to model with the optimization techniques. Heuristics are limited in its applications and its solution has unknown quality. Simulation techniques have strengths in dealing with uncertainty, impact of variation, forecast error, supplier reliability and quality variance. It is useful in modeling highly dynamic systems. Three approaches of dynamic simulation are System Dynamics (SD), Discrete Event Simulation (DES) and Agent Based Modeling (ABM).

The most fundamental difference between SD & DES is the treatment of time, which is continuous in SD and discrete in DES. Though both SD & DES are useful in studying the dynamic response of the systems at the aggregate level, DES is more suitable for analyzing the delays. DES is best suited when the system structure at the aggregate level is not known and the behavior of the system emerges as the result of interactions between agents. Figure-1 shows the various approaches for supply chain modeling. System Dynamics models are useful to understand and anticipate changes over time in highly complex systems. It is also useful for modeling the problems with scarce data but the system structure is adequately known. SD would provide thought provoking insights in understanding messy situations by sketching increasingly sophisticated causal loop diagrams.

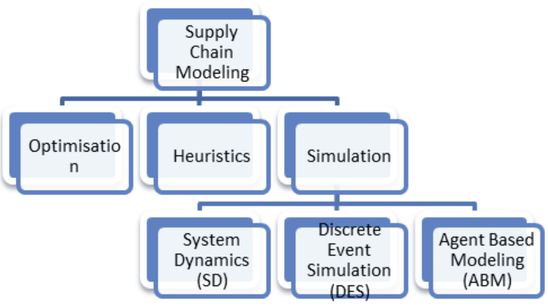

Figure 1: Various Approaches for Supply Chain Modeling

Systems Dynamic Approach: System Dynamics (SD) is the holistic approach to model the real world supply chains and to achieve significant performance. According to Forrester who developed SD approach, System Dynamics is defined as "the study of information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy." (Sterman, 2000)

In SD the real-world processes are represented in terms of stocks (e.g. of material, knowledge, people, money), flows between these stocks, and information that determines the values of the flows. SD abstracts from single events and entities and takes an aggregate view concentrating on policies. To approach the problem in SD approach, the system behavior as a number of interacting feedback loops, balancing or reinforcing should be described. It deals with 'feedback' mechanisms and is built on 'cause and effect' relations among the factors influencing the system under investigation. System Dynamics approach is used to simulate the complex environment and it is an indispensable tool to foster creativity, maximize productivity, enhance performance, promote innovation and increase customer satisfaction.

System dynamics (SD) is a methodology that is capable of studying and modeling complex systems as it is the case for food supply chain networks. The operations performed within a supply chain are a function of a number of key variables which often seem to have a strong interrelationship. Systems dynamics aims to provide a holistic view of the system and to identify how these interrelationships affect the system as a whole. The ability of understanding the whole system as well as analyzing the interactions between various components of the integrated system and eventually supplying feedback without breaking it into its components make SD an ideal methodology for modeling supply chain networks of fruits and vegetables.

Characteristics of System Dynamics Approach

- SD is modeled in Aggregate Level and is homogenous
- High level of abstraction, useful for strategic decision making
- Modeled using stock & flow diagrams, feedback loops.
- Structure of the system is known, and the aim of SD is to analyse the dynamic response of the system.

System dynamics is a powerful method to gain useful insight into situations of dynamic complexity. It is increasingly used to design more successful policies in companies and public policy settings. The field of system dynamics is itself dynamic. Recent advances in interactive modeling, tools for representation of feedback structure, and simulation software make it possible for several decision makers to engage in the modeling process. There are many software tools which are available for modeling and simulation using system dynamics approach like Powersim, Vensim, Stella etc.

Minegishi et al. (2000) applied system dynamics approach to poultry production and processing and analysed the consequences of the dioxin infection to the supply chain of the chicken industry. Georgiadis et al. (2005) applied system dynamics methodology as a modeling and analysis tool to tackle strategic issues for multi-echelon food supply chains. The holistic model can be used to identify effective policies and optimal parameters for various strategic decision-making problems. The methodology has been implemented for the transportation capacity

planning process of a major Greek fast-food restaurant supply chain.
Sachan et al. (2005) used the system dynamics approach to model the total supply chain cost of the Indian grain supply chain. They analysed different models (cooperative model, contract farming model and collaborative model) to minimise the total supply chain cost (TSCC) under different scenarios – optimistic, most likely and pessimistic – to devise policies accordingly. They argued to reduce the number of intermediaries in the three suggested models of grain supply chain. The proposed system dynamic cost model will help the members in the supply chain to understand the system behavior with respect to various cost elements under different market scenarios. Sameer kumar et al. (2010) used system dynamics approach to study the behavior and relationships within a supply chain for a non-perishable product, and to determine the impact of demand variability and lead-time on supply chain performance. They analysed the model under 13 scenarios by changing the daily customer demand and lead time and studied the several performance metrics. Their model can be used as a high-level tool to analyze the design of the supply chain network and also it serves as a template to illustrate concepts and the potential of the system dynamics approach in designing and studying supply chains. From the literature it is found that system dynamics approach has not been applied to analyse the perishable fresh produce supply chain though it is found that this is the suitable method in modeling & simulation of the fruits & vegetables supply chain.

Illustration of the Application of SD approach in a Fruits & Vegetables Supply Chain: John D Sterman proposed the stages of the system dynamic modeling as problem articulation, mapping of systems, formulation of simulation model, testing and evaluation. Problem articulation with defined boundaries is the first step in system dynamics modeling. The identified problem is that of analyzing food waste in fruits & vegetables supply chain. The key variables are food quality, degradation rate, inventory level, food wastage. The system under study is from the aggregator to retailer which is shown in Figure 2.

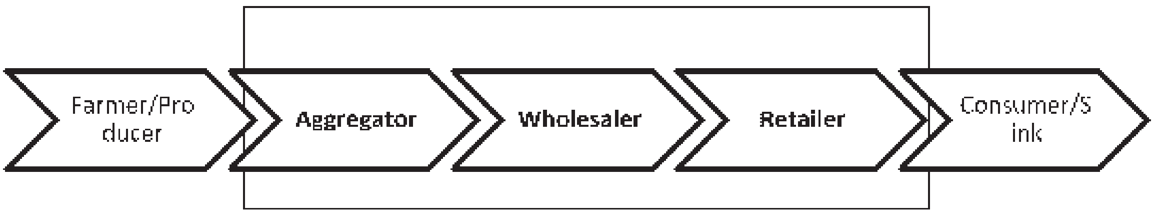

Figure 2: System Boundaries of the Fruit & Vegetable Supply Chain Under Study

Food quality and Food waste is identified as the key variables which impact the Fruits & Vegetables supply chain particularly in Indian context. This paper attempts to model these variables and analyse the system behavior under different scenarios.

Simulation Model: Quality degradation of food products depends on storage time t, storage temperature T, and other constants depending on the storage conditions (e.g., activation energy, gas constant). Quality degradation can be described by the following equation:

$$\frac{dq}{dt} = kq^n \quad (1)$$

where q is the quality of a product, k the rate of degradation depending on environmental conditions like temperature, and n is the power factor which is called the order of the reaction, determining whether the reaction rate is dependent on the amount of quality q left. (Labuza, 1982) Usually, power factor n will have a value of either 0 or 1 (zero-order and first-order reactions), leading to linear or exponential quality decay. From the literature it is understood that items like fresh meat and fish where quality degradation depends on microbial growth, it follows the first-order reactions. Fresh fruits and vegetables follow the zero-order reactions. (Rong et al., 2011)
The relation between quality degradation k and temperature T is expressed by the following Arrhenius equation (Zanoni et al., 2011)

$$k = k_o e^{-(E_a/RT)} \quad (2)$$

where k_o is a constant, E_a the activation energy [J/kg] (an empirical parameter characterizing the exponential temperature dependence), R the gas constant [J/kg^{o}K], and T the absolute temperature [^{o}K].

Causal Relations in Fruits & Vegetables Supply Chain: In system Dynamics approach, establishing the causal relations between the variables of study is the starting stage of model development. The list of variables under study and all associated variables are related causally. The variable may have positive or negative impact on each other.
Table-1 lists the causal loop variables. Figure-3 shows the causal loop diagram.

Loop Number	Causal loop variables	Positive/Negative
Causal loop # 1	Storage temperature, relative humidity, degradation rate and shelf life	Positive
Causal loop # 2	Food availability, supply, inventory, shelf life, obsolescence loss and food wastage	Positive

Table 1: Feedback loops

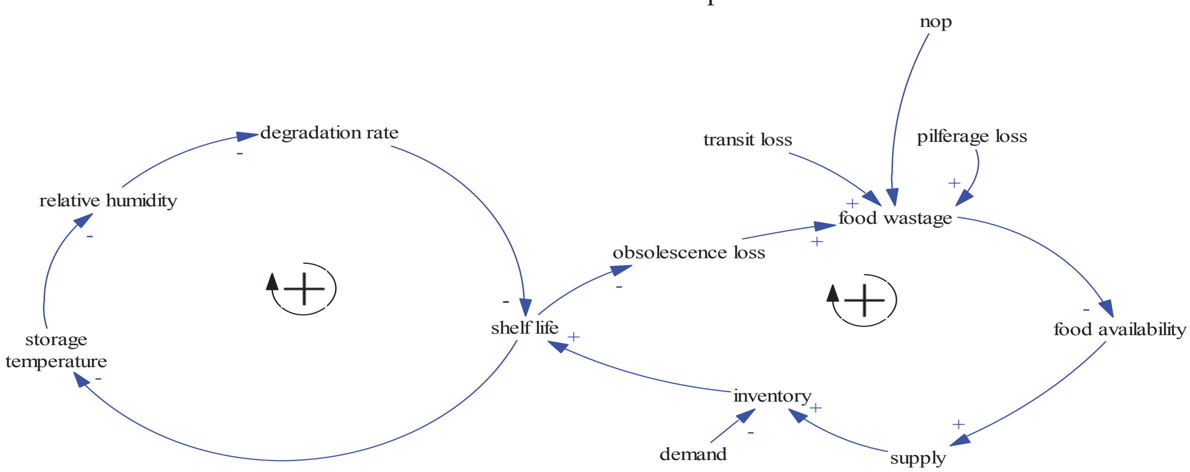

Figure 3: Causal loop diagram

The stock-flow diagram is modeled using Stella and is illustrated in Figure 4. The time step is chosen to be 1 day.

Variables notation are as follows:

T- Temperature

RH-Relative humidity

SL-Shelf life

OL-Obsolescence loss

TL – Transit loss

PL-Pilferage loss

NOP-Number of players

FW- Food wastage

FA- Food availability

SR-Supply rate

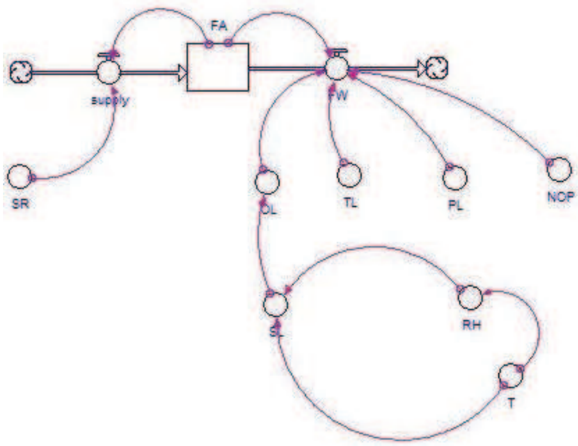

Figure 4: Stock-Flow diagram

Model Validation: Model validation is very important step in system dynamics study. It gives the confidence about the model and its accuracy can be validated. The first step is to test the validity of the structure and then test the model behavior under several testing conditions (Senge, 1980). The structure validity test is done by assessing the model with the real system through the interaction with the experts in the food industry. Structure verification may include the review of the model assumptions.

Extreme condition tests involve the model testing under extreme conditions of the inputs and the behavior is validated. The model equations are likely to give the results that would be the same in the real life scenario.

Initial model equations are given below:

Food Availability (FA) is represented as stock variable and is represented as the function of supply and food wastage. Initial value of food availability is set to 100 units.

FA(t) = FA(t - dt) + (supply - FW) * dt (3)

INIT FA = 100 (4)

Inflows: Supply is a flow variable and depends on supply rate.

supply = FA*SR (5)

Outflows: Food wastage represents the outflow variable and is a function of obsolescence loss, pilferage loss, transit loss and number of players. Higher the shelf life, lesser is the obsolescence loss. Shelf life is a function of relative humidity and storage temperature and is represented by the equation 10. Supply rate (SR) and Transit losses (TL) are set at 0.5 & 0.1 respectively.

FW = FA*OL*PL*TL*NOP (6)

NOP = 4 (7)

OL = 1/SL (8)

PL = 0.05 (9)

SL = ((-0.045*RH)+4.669)/exp(((-10022/T)+32.74)) (10)

SR = 0.5 (11)

TL = 0.1 (12)

Dynamic Analysis: Table 2 lists the input and output variables. Change in the shelf life per unit change in the temperature increases up to a point then it starts decreasing. Food wastage is increasing considerably when more is the number of players.

Temperature (degree centigrade)	Expected RH %	Shelf Life in Days	Change in the shelf life in hours by reducing 1 degree
2	86	32.44	19.45
3	84	31.62	25.85
4	82	30.55	30.29
5	80	29.29	33.19
6	78	27.90	34.89
7	76	26.45	35.65
8	74	24.96	35.69
9	72	23.48	35.19
10	70	22.01	34.30
11	68	20.58	33.11
12	66	19.20	31.73
13	64	17.88	30.21
14	62	16.62	28.62
15	60	15.43	27.00
16	58	14.30	25.37
17	56	13.25	23.77
18	54	12.25	22.21
19	52	11.33	20.71
20	50	10.47	19.27
21	48	9.66	17.90
22	46	8.92	16.60
23	44	8.23	15.37
24	42	7.59	14.23
25	40	6.99	13.15

Table 2: Shelf life calculations for various levels of storage temperature

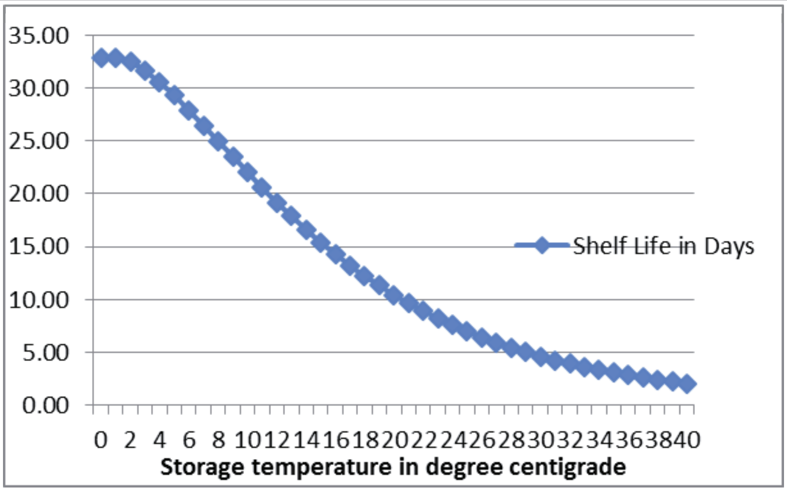

Figure 5: Shelf life and storage temperature graph

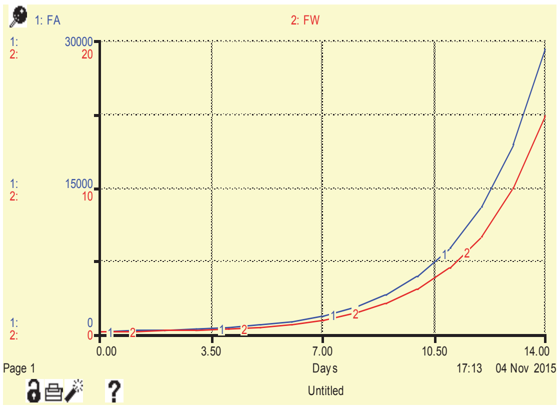

Figure 6: Food availability and food wastage curves

The interactions among the shelf life, storage temperature, food availability and food wastage can be analysed in the above simulation model. The change in shelf life (ΔSL) achieved by reducing one unit of temperature is increasing up to a point and then starts decreasing (Figure 5). Food wastage is directly related to the number of players in the chain which means more is the number of intermediaries more is the food wastage which is likely to happen. The decision maker can choose optimum storage temperature and corresponding shelf life based on the lead time availability. Figure 6 shows the food availability and corresponding food wastage of the given input of the variables. A "what-if decision making tool" is available to decision makers to analyse the transit loss & pilferage losses and assess the total food availability & food wastage at the end of a particular simulation period. Transit losses & pilferage losses can be reduced by modern packing & stacking methods, usage of appropriate material handling equipments and good logistics infrastructure.

Conclusion: The causes for inefficient fruits & vegetables supply chain are studied. Food quality & food wastage are identified as the key variables in F&V supply chain and modeled using system dynamics approach. The proposed model could be served as an illustration for the application of system dynamics approach in managing fruits and vegetables supply chain. It can also be used as a high level tool in taking strategic decisions with respect to food logistics. The model is useful in analyzing the interactions among several variables like storage temperature, shelf life, food quality and food wastage levels. In order to limit the scope of the study, this model doesn't take in to account the costs associated with inventory, transportation and food wastage. The developed model is also useful for sensitivity analysis or what-if analysis for several scenarios of operational conditions. The model can be enhanced by analyzing the several types of emerging supply chains like contract farming, collaborative farming etc. This model could be a good starting point for strategic decision makers, regulators involved in the fruits & vegetables supply chain.

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