CHAPTER 2

LITERATURE REVIEW

This chapter deals with the literature review related to uncertainty, selection of post harvest technology, optimal route of supply chain and risk management problems in agro-industry and non- agro-industry.

2.1 CLASSIFICATION OF LITERATURE

In the last few decades, several Systems Engineering tools and techniques have been applied in various problems deals with uncertainty. The literature review carried out is classified into two major categories, Decision making problems in agro-industry and in non-agro-industry. Overview of classification of literature review is shown in Figure 2.1.

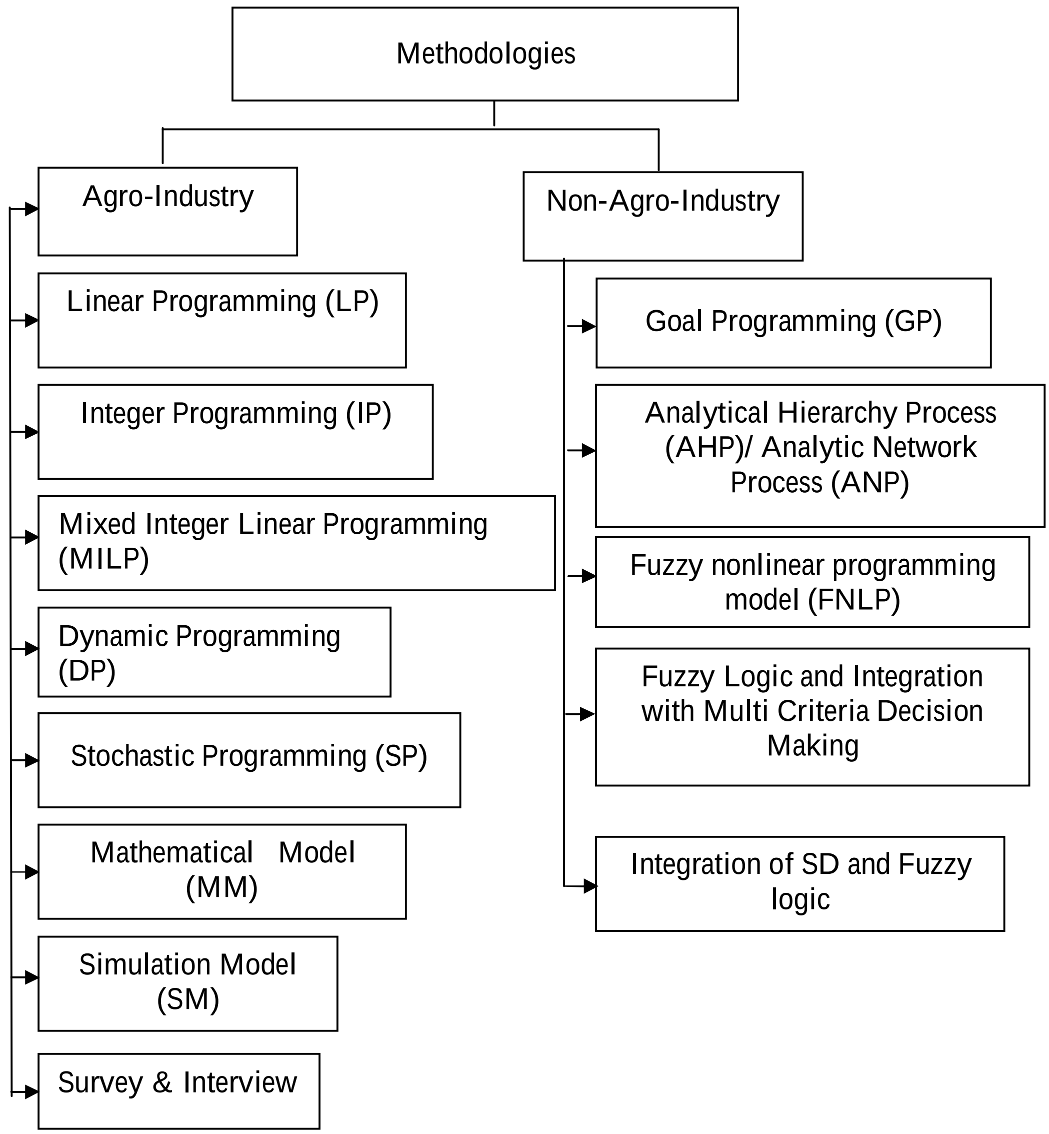

Figure 2.1 Classifications of Literature Review

2.2 APPLICATION OF APPROACHES IN AGRO-INDUSTRY PROBLEMS

This section deals with the deterministic, probabilistic heuristic approaches applied for decision making problems in agro-industry. The details are shown in Table 2.1.

Table 2.1 Systems engineering approaches for analysis in agro-industry problems

Methods	Author(s)	Detail (s)
Integer Linear Programming (IP)	Foulds and Wilson (2005)	Scheduling of harvesting product of renewable resources
Mixed Integer Linear Program (MILP)	Maia et al (1997)	Selection of post harvest technology
	Depuy et al (2002)	Traceability analysis and batch dispersion optimization in production planning
	Etrup et al (2005)	Shelf-life-integrated planning and scheduling in fresh food
	Rong et al (2011)	Planning with controlling the product quality throughout the food supply chain
Dynamic Programming (DP)	Gigler et al (2002)	Optimization of agro-food chain with desired quality level at the final stage
Mathematical Model (MM) (Technology basis)	Buck et al (1999)	Determination of differences in production risks between conventional and sustainable farming systems
	Bogataj et al (2005)	An appropriate control which keeps the product on the required level of quality and quantity at the final delivery
	East et al (2009)	Quantitative risk assessment of temperature control during transport
Mathematical Model (MM)	Xu et al (2002)	Improving Quality of stored Potatoes

Table 2.1 (Continued)

Methods	Author(s)	Objective (s)
	Aranda-Sanchez et al (2009)	classification of Fruit ripening
	Allaisa and Létang (2009)	Study on the impact of mist-chilling on high-grade strawberry postharvest quality
Stochastic Programming (SP)	Arnold and Minner (2011)	Financial and operational instruments for commodity procurement
Goal Programming (GP)	Leung and Ng (2007)	Production planning of perishable products with postponement
Analytic Hierarchy Process (AHP) and GP	Guo and He (1999)	Resources allocation under quantitative and qualitative decision criteria
Genetic Algorithm (GA)	Makino (2001)	Selection of packaging conditions for shredded cabbage
	Yao and Huang (2005)	Solving the economic lot scheduling problem with deteriorating items
Fuzzy Logic (FL)	Davidson et al (2006)	Fuzzy risk assessment tool for early stage risk assessment in food systems
FL and Artifical Nueral Network (ANN)	Kupongsak and Tan (2006)	Determination of food process and control set points for producing products of certain desirable sensory quality
Simulation Model (SM)	Van der Vorst et al (2009)	Integration of logistics, sustainability and food quality for redesigning food chain optimization

Table 2.1 (Continued)

Methods	Author(s)	Objective (s)
	Rosario et al (2009)	Performance improvement under the context of lack of information on postharvest packinghouse
SM and MM	Wang et al (2009)	Optimization of traceability and operations planning for perishable food production.
System Dynamics (SD)	Minegishi and Thiel (2000)	Knowledge improvement of the complex logistic behaviour of an integrated food industry
	Georgiadis et al (2005)	The strategic capacity modelling of single and multi-echelon food supply chains
	Ashayeri and Lemmes (2005)	Demand planning of economic value added supply chain
	Villegas and Smith (2006)	Inducing variation under safety stock in production and distribution order quantities
	Vo and Thiel (2007)	Capacity planning for the shortages in upstream and downstream unpredictable consumer behavior
SD and AHP	Rabelo et al (2007)	Decision making with experiences, preferences and qualitative assessments
Interview and Survey	Ljungberg (2007)	Operations planning and route optimization in meat logistics chain

Table 2.1 (Continued)

Methods	Author(s)	Objective (s)
	Olarinde et al (2007)	Assessment of the profitability status of farmers' post harvest actions, the risks and uncertainties attached to these actions.
	Von der Vost and Beulens (2002)	Identification of source of uncertainty to generate supply chain redesign strategies of fresh food products.

The literature review for uncertainty problems related to agro-industries given in Table 2.1 are classified based on the problem and the methodology used for analysis and it is observed that mathematical models are the most used methods shows that advanced mathematics model technology in this field, followed by the system dynamics approach.

2.2.1 Methods for Selection of Post Harvest Technology and Process Control

Maia et al (1997) studied and compared capital investment of post harvest technology with capacity by using Mixed Integer Linear Programming (MILP). The model was proposed for selection of technology route for fruit and vegetable crops between harvesting and marketing stage and to optimize capital investment in food preservation facilities under uncertainties. This study was based on alternative routes and a set of crop and market scenarios.

Rosario et al (2009) developed a discrete event simulation model to evaluate the sizing and inspection performance of 3 onion packinghouses and to demonstrate the impact of improving these performance variable on potential sales revenue generation.

Kupongsak and Tan (2006) studied the application of Fuzzy set and neural network techniques to determine food process control set points for producing products of certain desirable sensory quality. Fuzzy sets were employed to interpret sensory responses while neural networks were applied to model the relationships between process and sensory variables. Rice cake production was used as a model process. Product sensory attributes were evaluated by a trained panel. Multi-judge responses were formulated as fuzzy membership vectors, which in turn were formed into fuzzy membership matrices of multiple sensory attributes. Neural networks were used to determine the sensory attribute controllability and the process control set points for achieving a given target of sensory quality.

Makino (2001) studied about the selection of packaging conditions for shredded cabbage by genetic algorithms. This work was to find an elective procedure to select packaging conditions for storage of horticultural commodities. Mass of commodities in a package and thickness of packaging film as packaging conditions were generated at random was progressively optimized by the evolutionary process found in the biological world. Shredded cabbage was enclosed in a package of a polymeric film according to the optimized packaging conditions. Oxygen and carbon dioxide concentrations in the package were controlled at effective levels for the storage of shredded cabbage.

Davidson et al (2006) developed a fuzzy risk assessment tool (FRAT) for early stage risk assessment of microbial hazard in food systems that use fuzzy value for system parameters and interval arithmetic to characterize hazards and to compute it. The user defines the parameters to describe initial hazard level, potential change during processing and consumer preparation as well as factors related to consumption and health impact. These parameters are defined in linguistic terms or semi-quantitative levels which are then converted to fuzzy values. This tool was used for early stage microbial risk assessment in food systems, in particular, for ranking risk based on total illness and severity of illness. This work is useful in the practice of quality risk assessment based on the HACCP system.

2.2.2 Methods for Production Planning and Scheduling

Dupuy et al (2005) studied traceability analysis and optimization methods in production planning of sewage industry. The author proposed a MILP model to minimize the sum of tracking and tracing dispersions of all the raw material batches. This proposed model helps in minimizing cost of recalls in terms of product quality and media impact. The authors also introduced new measures (downward dispersion, upward dispersion) to evaluate the accuracy of tractability in production process.

Etrup et al (2005) proposed the Mixed-Integer Linear Programming approach to study integrated shelf life issues into production planning and scheduling of fresh food. This research was based on an industrial case study of yoghurt production. Numerical experiments showed that near-optimal solutions can be obtained within reasonable computational time. For planning and scheduling problems for the case industry considered.

Leung and Ng (2007) applied a goal programming model for production planning of perishable products with postponement. One of the important characteristics of perishable products is that a decision-maker has to take into account significant price drop after a day or season. Hence, over-production and storage of such products is not recommended. The production process for perishable products proposed has divided into two phases by applying the concept of postponement. Consequently, three production activities – direct production, master production and final assembly were considered. A preemptive goal programming model to solve aggregate production planning for perishable products was developed. Results demonstrated that the decision-makers can find the flexibility and robustness of the proposed model by adjusting the goal priorities with respect to the importance of each objective and the aspiration level with respect to desired target values.

Wang et al (2008) proposed an optimization model that integrates traceability initiatives with operation factors to achieve desired product quality and minimum impact of product recall in an economic manner. An integrated model was presented for simultaneously optimizing the production batch size and batch dispersion policy in a food manufacturing context. This model incorporates operational costs (production setup cost, inventory holding cost, raw material cost and product perish cost) with the cost related to safety and quality assurance (recall cost). Simulation experiments were conducted to numerically analyze the model performance. The results showed that the performance of the proposed approach with different options of operational parameters. This research demonstrates the benefits from seamless integration of operational planning with strategic considerations in food quality and safety issues.

Rong et al (2011) proposed a methodology integrated with MILP to model food quality degradation. The mixed-integer linear programming model is used for production and distribution planning in order to achieve controlled product quality throughout the food supply chain. The model developed was applied in to illustrative case study, and this can be used to design and operate food distribution systems using both food quality and cost criteria.

2.2.3 Methods for Agro-Industrial Chain Optimization

Gigler et al (2002) proposed dynamic programming for optimization of agro-food chain. The model explicitly deals with the appearance and quality of products. This model developed helps in the construction of optimal routes with minimal integral cost by defining the role of each enabler in the chain and action to be carried out at appropriate process condition. The developed model helps in describing the quality change of a product as function of the process conditions, which can be included into the DP approach.

Bogataj et al (2005) extended the appo lication of the Laplace transform to certain economic problems introduced by Grubbstrom (1967) to the logistic chain, on the stability of perishable goods, this work tried to find the appropriate control necessary to keep the product on the required level of quality and quantity at the final delivery. This work is especially important to assure the stability of cold chains in the cold chains management (CCM).

Foulds and Wilson (2005) developed ILP Integer Linear Programming model for scheduling operations of renewable resources. The ILP model was applied for two practical harvesting case agricultural involving minimum and maximum time lags and resource constrains.

System dynamics methodology is widely applied in modeling and analyzing supply chain behavior in uncertain environment. There are some applications in agro-industrial supply chain. Villegas and Smith (2006) used SD approach to demonstrate the impact of inclusion of safety stock policies in causing induced variation in production and distribution of order quantities along the supply chain. The developed SD model is applied for Mexican branch of a multinational food and beverage company. Based on simulation results using SD production order distortions and modification to the operating policies were suggested to the case organization.

Georgiadis et al (2005) adopted the system dynamics methodology as a modelling and analysis tool to tackle strategic issues for the strategic modelling of single and multi-echelon food supply chains. Through this tool the author analysed and examined in depth about the long term capacity planning which is a key issue of strategic supply chain management.

Vo and Thiel (2007) developed system dynamics model for chicken meat supply chain faced by considering Bird Flu. They studied the behavior of the entire chicken meat supply chain coping with sanitary crises effects. The proposed model was used to study the supply chain behavior dealing with the shortages in upstream supply capacity and downstream unpredictable consumer behavior affected by the crisis as well.

Ashayeri and Lemmes (2005) studied about the economic value addition of supply chain demand planning. They proposed a system dynamics simulation modelling framework that allows different managers to examine how improvements in their demand reliability will impact the overall corporate bottom-line. With this model Supply chain managers could investigate the changes in the supply chain demand forecasting structure, suppliers, and logistics routes for overall profitability.

Minegishi and Thiel (2000) proposed a system dynamics model to understand and explain the complex behaviour of poultry industry. The model enabled improved knowledge of the complex logistic behaviour of an integrated food industry.

Rabelo et al (2007) proposed the integrated model comprising of Analytic Hierarchy Process (AHP) and system dynamics simulation and approached for service and manufacturing activities of the global supply chain. The model helped the managers to utilize their own experiences, preferences and qualitative assessments which increase the level of their confidence in the decisions.

Arnold and Minner (2011) studied financial and operational instruments for commodity procurement in quantity competition. The authors analyzed a commodity procurement problem under uncertain future procurement prices and product demands. A stochastic optimization model was presented to find the best mix of advance procurement, spot market procurement and financial options to satisfy demand in an asymmetric and duopolistic sales market.

Van der Vorst et al (2008) proposed a new integrated approach towards logistics, sustainability and food quality analysis. They introduced a new simulation environment, ALADINTM which it embedded food quality change models and sustainability indicators in discrete event simulation models.

Ljungberg (2007) studies were based on interviews, field measurements, and observations of activities during animal transport and slaughter operations. The objective of this work was to describe the logistics chain of animal transport and abattoir operations in order to demonstrate potential effects of operations planning and route optimization considering animal welfare, meat quality and the environment. Queues, before delivery and vehicle washing, created problems as reported by the drivers. Time and distance of transport could be reduced through route optimization. The analysis of collection routes indicated potential for savings of more than 20% in time, for individual routes.

2.2.4 Methods for Supply Chain Risk Management

Buck et al (1999) proposed a mathematical model that determine the differences in production risks. Conventional and sustainable farming systems (CAFS and IAFS). To assess risks caused by weather conditions, the major aspects of crop husbandry in various crops have been modeled. Using tactics in crop husbandry (decision rules) and weather uncertainty as input, the developed crop husbandry models (HMs) helps in calculating management tracks that require resources.

Von der Vost and Beulens (2002) studied risk in the fresh food supply chain. Questionnaire and discussion were applied for identifying sources of uncertainty to generate supply chain redesign strategies for fresh food products.

East et al (2009) proposed a mathematical model for quantitative risk assessment of temperature control in insulated boxes that uses historic climatic data to estimate temperature of the environment during transport and subsequently provides a quantitative estimate of the likelihood of package temperature control failure. The temperature of the product during transport was governed by the temperature of the environment and the protection provided by the box's insulation and accompanying coolant (e.g. ice). This work demonstrated the combination of weather prediction software and mathematical modelling of heat transfer to quantify the performance of insulated boxes exposed to real world conditions.

Aranda-Sanchez et al (2009) employed a Bayesian classifier using repeated measurements for discrimination of tomato fruit ripening stages. Quality control of postharvest fruits was moving towards substituting traditional sensory testing methods by more reliable quantitative methods. Ripening in fruits, such as tomatoes, is a complex phenomenon affected by chemical and physiological properties as a function of time. This work attempted to solve the problem of ripening classification with a focus mostly on single sensors.

Xu et al (2002) proposed a simple mathematical model that can be used quickly and cost-effectively to improve the quality of stored potatoes. Uniformity of air flow is a key factor affecting the quality of potatoes during storage. Storage stores with non-uniform air flow often suffer from condensation resulting in consequent rotting and poor quality of the potatoes. A model based on computational fluid dynamics software (CFDS-CFX4) was developed to identify modifications to air distribution systems that would improve the uniformity of the air flow. This model treats the potatoes as a porous resistance around the ducts and predict the flow inside the air supply ducts.

Allaisa and Létang (2009) studied the influence of mist-chilling on postharvest quality of fresh strawberries to assess the impact of mist-chilling on high-grade strawberry postharvest quality.

Guo and He (1999) applied multi-criteria decision making model for allocation of facilities. This they have done for case study in Chinese agriculture. The developed model considers the multiple conflicting goals with inconsistent units requiring prioritization.

Olarinde et al (2007) studied quantitative assessment of the profitability status of farmers' post harvest actions, the risks and uncertainties attached to these actions and determination of the most optimal economically viable and sustainable actions. 300 smallholder farmers from 100 farming communities scattered over 20 local government areas from the 4 agricultural development project zones. The data collected include (1) primary: types of food crops grown, outputs and sales, information on socioeconomic and demographic characteristics of the farm holidays; (2) secondary data: time-series information on monthly and periodic market and farm gate prices of food crops in the state. Data sets were analyzed by using descriptive statistics such as percentages, means and frequencies and the Bayesian (risk) decision theory. The Bayesian theory was used to determine farmers' optimum farming strategies prior to market predictions and to know when markets are "normal" in "short supply.

Yao and Huang (2005) developed a genetic algorithm for solving the Economic Lot Scheduling Problem (ELSP) with deteriorating using the extended basic period approach under Power-of-Two (PoT) policy. The ELSP is concerned with the lot sizing and scheduling decision of n items and PoT policy requires the replenishment frequency of each item to be a PoT integer. Since the conventional ELSP was shown as an NP-hard problem, a hybrid genetic algorithm (HGA) was proposed which was equipped with a feasibility testing procedure, namely Proc FT, and a binary search heuristic to efficiently solve the ELSP with deteriorating items. Proc FT was used to test the feasibility of the local optimum for the set of replenishment frequencies obtained by the evolutionary process of the genetic algorithm.

2.3 APPLICATION OF APPROACHES WITH UNCERTAINTY ISSUES IN NON-AGRO-INDUSTRY PROBLEMS

Deterministic, probabilistic, and heuristic approaches were employed for decision making models with uncertainty issues in the non-agro-industry. Moreover, incorporation of more than one approach was broadly employed for decision making problems under uncertainty. The details are given in Table 2.2.

Table 2.2 Systems Engineering Approaches for analysis under uncertainty in non- agro-industries

Methods	Author(s)	Objective (s)
MILP	Galasso et al (2009)	Supply chain planning under uncertain demand
MM	Bachlaus et al (2004)	Analysis of complexity and inherent uncertainty in the supply chain operation
	Blackhurst and O'Grady (2007)	Analysis of supply chain disruption
	Huang (2007)	Risk management in supply chains with high levels of uncertainty in product demand, and manufacturing process
	Bachlaus et al (2008)	Assignment of multi-objective resource problems in a product-driven supply chain
AHP and ANP	Ming-Lang et al (2009)	Approach for selection of optimal supplier in supply chain management
Regression Analysis (RA)	Hsu et al (2009)	Proposition of supply chain management practices and the relationship between operations capability and firm performance
SP	Bachlaus et al (2004)	Network-based approach to model uncertainty in a supply chain
GP	Leng and Chan (2008)	Aggregate production planning with resource utilization constraint
FL	Carrera and Mayorga (2008)	Application of a modular fuzzy inference system approach in supplier selection for new product development

Table 2.2 (Continued)

Methods	Author(s)	Objective (s)
Fuzzy Nonlinear Programming Model (FNLP)	Chen and Ko (2009)	New product design using Quality Function Deployment
Fuzzy Goal Programming (FGP)	Lee and Wen (1997)	Solving multi-objective Water quality management optimization problems involving vague and imprecise information
	Pal and Moitra (2003)	Solving a class of FP problems with the characteristics of DP with preemptive priority
Fuzzy Goal Programming (FGP)	Hu et al (2007)	Multi-objective optimization problem with priorities
	Tsai and Hung (2009)	Green supply chain (GSC) optimization
FL and group decision making	Wang and Lin (2003)	Selection of items configuration for software development
	Chuu (2009)	Selection of advanced manufacturing technology for improving manufacturing system competitiveness
SD and FL	Change et el (2006)	Solving information problem regarding the system's behavior uncertainties.
	Nasizadeh et al (2008)	Modelling of risk management issues in construction

From Table 2.2, it is understood that many researchers attempted integration of fuzzy logic with many MCDM tools like Goal Programming (GP) and Analytic Hierarchy Process (AHP) for addressing uncertainty issues in non-agro industry problems. Moreover, there are some wonderful research work which deals with uncertainty and risk management issues in non-agro industrial problems by using integrated system dynamics and fuzzy logic approaches.

The literature review as shown in Table 2.2 considered only uncertainty and risk management issues. Issues in non-agro industrial engineering sectors, similar kind of problems can be found in various industries including agro industry. Hence an attempt is made in this research to explore the application in agro-industry.

2.3.1 Application of Linear Programming and Mathematical Models

Huang (2007) proposed a risk management approach by applying a dynamic system model for proactive control of dynamic events in full-load states of manufacturing chains. The dynamic events in full-load states are a major concern in supply chains that have high levels of uncertainty in product demand, manufacturing process or part supply. The uncertainties frequently manifest as dynamic events that pose a threat to interrupting supply chain operation. Depending on the nature and severity of uncertainty, the impact of dynamic events can be distinguished into three categories: deviation, disruption, and disaster. A dynamic system model of supply chains was described which can be applied to managing disruptive events in full-load states of manufacturing chains. An example of disruptive events was given which arises from demand shocks in distribution channel. The procedure to construct full-load production functions of complex manufacturing nodes with internal queuing delay is described. Analytic optimal solution was derived for the dynamic model. Given an unordinary event of demand shock, this model can be used to determine if demand shock can be absorbed by a manufacturing chain and the level of contingent resources that must be synchronously activated in multiple nodes of the chain.

Galasso et al (2009) proposed decision support framework for supply chain planning with flexible demand to manage networked organizations under an uncertain demand so as to provide a good service to the customer at low cost. A mixed integer linear planning model embedded in a framework simulating a rolling horizon planning process was described on the basis of this analysis. The model takes into account the capabilities of reaction of the planned system and of its environment (suppliers, sub-contractors and customers), as well as the corresponding costs. The suggested simulation framework may assist the decision maker for coping with an uncertain or flexible demand, using various planning strategies. Some possible applications of this simulation framework were given in order to illustrate how it can help to solve various types of practical planning problems.

Blackhurst and O'Grady (2007) proposed the methodology for supply chain disruption analysis. Given the size, complexity and dynamic nature of many supply chains, there was a need to understand the impact of disruptions on the operation of the system. This work presents a network-based modelling methodology to determine how changes or disruptions propagate in supply chains and how those changes or disruptions affect the supply chain system. The contribution of the network-based disruption model methodology offers a better understanding of how perturbations or disturbances can affect a supply chain, what can be done to better understand how far disruptions propagate through a supply chain system and how these disruptions affect system performance. This modelling approach provides insight into managing supply chain systems that face disruptions and can allow a company to offer: quicker response times to the customer, lower costs, higher levels of flexibility and agility, lower inventories, lower levels of obsolescence and reduced demand amplification throughout the chain.

Ming-Lang and Lan (2009) proposed a selection approach for optimal suppliers in the supply chain management strategy with an Analytic Network Process and choquet integral. This work proposed a novel hierarchical evaluation framework to assist the expert group to select the optimal supplier in SCMS. The rationales for the evaluation framework are based upon (i) multi-criteria decision making (MCDM) analysis that can select the most appropriate alternative from a finite set of alternatives with reference to multiple conflicting criteria, (ii) Analytic Network Process (ANP) technique that can simultaneously take into account the relationships of feedback and dependence of criteria, and (iii) choquet integral—a non-additive fuzzy integral that can eliminate the interactivity of expert subjective judgment problems. A case of PCB manufacturing firm was studied and the results indicated that the proposed evaluation framework was simple and reasonable for identifying the primary criteria influencing the SCMS, and it was effective to determine the optimal supplier even with the interactive and interdependent criteria/attributes.

Hsu et al (2009) studied the supply chain management practices as a mediator of the relationship between operations capability and firm performance. This work employed mediated regression analysis and structural equation modelling to test the proposition that supply chain management practices mediate the relationship between operations capability and firm performance. Operations capability was defined in terms of a firm's new product design and development, total quality management and just-in-time capabilities. Results support the research model and also suggest the existence of a direct relationship between operations capability and performance.

2.3.2 Application of Stochastic Programming

Bachlaus et al (2004) employed a network-based approach to modelling uncertainty in a supply chain. Modelling such supply chains is a difficult and challenging research task, particularly given the need to model the stochastic operations of typical supply chains. Giving added urgency to the need to address this issue are the recent developments in communications. The developments are primarily based on internet technologies that offer the promise of connecting suppliers, assemblers and customers in a seamless network of information. Scholars offered the promise of substantially improved decision-making and a consequent considerable improvement in operations. However, fulfillment of this promise is dependent on the development of a suitable modeling methodology for supply chains.

2.3.3 Application of Goal Programming

Leng and Chan (2008) proposed a goal programming model for aggregate production planning with resource utilization constraint. This work addressed the aggregate production planning problem with different operational constraints, including production capacity, workforce level, factory locations, machine utilization, storage space and other resource limitations. Three production plants in North America and one in China were considered simultaneously. A pre-emptive goal programming model was developed to maximize profit, minimize repairing cost and maximize machine utilization of the Chinese production plant hierarchically. A set of data from a surface and materials science company was used to test the effectiveness and the efficiency of the proposed model. Results illustrate the flexibility and the robustness of the proposed model by adjusting goal priorities with respect to importance of each objective and the aspiration level with respect to desired target values.

Carrera and Mayorga (2008) studied the supply chain management and applied a modular fuzzy inference system approach in supplier selection for new product development. A fuzzy Inference system was proposed as an alternative approach to handle effectively the impreciseness and uncertainty that are normally found in supplier selection processes.

2.3.4 Application of Fuzzy Non-Linear Programming

Chen and Ko (2009) studied fuzzy approaches to quality function deployment for new product design. This work determines the fulfillment levels of design requirements (DRs) and parts characteristics (PCs). Fuzzy nonlinear programming models were developed based on Kano's concept to determine the fulfillment levels of PCs with the aim of achieving the determined contribution levels of DRs for customer satisfaction. In order to deal with the design risk, this study incorporates failure modes and effects analysis (FMEA) into QFD processes, and treats it as the constraint factor in the models. To cope with the vague nature of product development processes, fuzzy approaches are used for both FMEA and QFD.

2.3.5 Application of Fuzzy Logic and Multi-Criteria Decision Making

Lee and Wen (1997) proposed fuzzy goal programming approaches for water quality management in a river basin. Two fuzzy goal programming (FGP) approaches were applied to water quality management in a river basin for solving multi-objective optimization problems involving vague and imprecise information. Several FGP models, including equal weight and unequal weight, non-preemptive priority and preemptive priority, were proposed to assist water quality management involving multiple conflicting goals. Optimal water quality management involves obtaining optimal analysis of assimilative capacity and treatment cost of wastewater based on models and standards of water quality, as well as an equitable removal of wastewater in a river basin. Two FGP schemes that are capable of maximizing achieved membership function and minimizing the deviation from a set of preferred target assimilative capacity and treatment cost are considered.

Tsai and Hung (2008) applied fuzzy goal programming for green supply chain (GSC) optimization. The authors proposed a fuzzy goal programming (FGP) approach that integrates activity-based costing (ABC) and performance evaluation in a value-chain structure for optimal GSC supplier selection and flow allocation. The FGP approach was particularly suitable for such a decision model which includes flexible goals, financial and non-financial measures, quantitative and qualitative methods, multi-layer structure, multiple criteria, multiple objectives, and multiple strategies. An activity-based example of structural GSC with relevant costs and performances was presented for computing the composite performance indices of the GSC suppliers. A green supply chain of a mobile phone is used as an illustrative case. Several objective structures and their results were compared. The sensitivity analysis showed that pure maximization of financial profit can achieve the highest profit level, which also has the largest Euclidean distance to the multiple aspiration goals. In order to determine the final objective structure, an analytic hierarchy process (AHP) was used. This paper provided a new approach to assess and control a complex GSC based on value-chain activities, and obtain a more precise solution.

Pal and Moitra (2003) proposed a goal programming procedure for solving problems with multiple fuzzy goals using dynamic programming. In this paper, the preemptive priority based goal programming (GP) is used to solve a class of fuzzy programming (FP) problems with the characteristics of dynamic programming (DP). The membership functions of the objective goals of a problem with fuzzy aspiration levels were defined first. Then, under the framework of preemptive priority based GP a multi-stage DP model of the problem for achievement of the highest degree (unity) of each of the membership functions was developed. The goal satisfying philosophy of GP was used recursively to arrive at the most satisfactory solution.

Hu et al (2007) applied fuzzy goal programming approach to multi-objective optimization problem with priorities. The general equilibrium and optimization are often two conflicting factors. The authors proposed a generalized varying-domain optimization method for fuzzy goal programming (FGP) incorporating multiple priorities. According to the three possible styles of the objective function, the varying-domain optimization method and its generalization were proposed. The method can generate results consistent with the decision-maker (DM)'s expectation that the goal with higher priority may have a higher level of satisfaction.

2.3.6 Application of Fuzzy Logic and Group Decision Making

Wang and Lin (2003) proposed a fuzzy multi-criteria group decision making model to select configuration items for software development. Selection of configuration items in software configuration management is important to determine the software quality and reduce development time and cost. The objective of this research was to develop a multi-criteria group decision making model based on fuzzy set theory to improve the configuration items selection process. Since most information available in this stage was not numerical, fuzzy set theory was used to represent the evaluation ratings of candidate items. The developed model ranks candidate items into partial or complete orders that can assist decision makers in selecting a more proper set of configuration items. The consensus measures are also developed to determine the group acceptability of the obtained ranking orders. In addition, sensitivity analysis can be performed to examine the solution robustness. An example of a flight simulator development project was used to illustrate this concept.

Chuu (2009) proposed an approach for a selection of advanced manufacturing technology for improving manufacturing system competitiveness. This study built a group decision-making model using fuzzy multiple attributes analysis to evaluate the suitability of manufacturing technology. Since numerous attributes have been considered in evaluating manufacturing technology suitability, most information available in this stage is subjective and imprecise, and fuzzy sets theory provides a mathematical framework for modeling imprecision and vagueness. The proposed approach involved developing a fusion method of fuzzy information, which was assessed using both linguistic and numerical scales. In addition, an interactive decision analysis was developed to make a consistent decision. When evaluating the suitability of manufacturing technology, it may be necessary to improve upon the technology, and naturally advanced manufacturing technology was seen as the best direction for improvement. The flexible manufacturing system adopted in the Taiwanese bicycle industry was used in this study to illustrate the computational process of the proposed method.

2.3.7 Application of Fuzzy Logic and System Dynamics

Change et al (2006) presented a system dynamics analysis based on the application of fuzzy arithmetic. Traditional crisp system dynamics observe that some variables/parameters may belong to the uncertain factors. It was necessary to extend the system dynamics to treat the vague variables/parameters. The evaluation of fuzzy system dynamics may provide the decision maker information regarding the system's behavioral uncertainties. The customer–producer–employment model was examined with the fuzzy system dynamics in two types of fuzzy arithmetic, α-cut fuzzy arithmetic and T_ω weakest t-norm operator. Symmetrical and nonsymmetrical triangular fuzzy number (TFN), varied amount of fuzzy inputs' fuzziness, and length of the system time delay were examined with useful results.

Nasizadeh et al (2008) employed the integration of system dynamics and fuzzy logic modelling for construction risk management. This wonderful approach take into account all relevant factors arising from dynamic internal and external interactions throughout the life cycle of the project. This approach was presented in a risk analysis and response process. Starting from the imprecise and uncertain nature of risks, fuzzy logic was integrated into system dynamics modelling structure. Risk magnitudes are defined by a fuzzy logic based risk magnitude prediction system. Zadeh's extension principle and interval arithmetic was employed in the System Dynamic simulation model to present the system outcomes considering uncertainties in the magnitude of risks resulting from the risk magnitude prediction system.

2.4 IMPORTANCE OF POST HAVREST TECHNOLOGIES IN THE SUPPLY CHAIN

In agro-industrial supply chains, fresh fruits and vegetables play a vital role in human nutrition. They especially serve as sources of vitamins, minerals, dietary fiber, and antioxidants. Increased consumption of a variety of fruits and vegetables on a daily basis is highly recommended because of associated health benefits, which include reduced risk of some forms of cancer, heart disease, stroke, and other chronic diseases. Both quantitative and qualitative losses occur in horticultural commodities between harvest and consumption. Qualitative losses, such as loss in edibility, nutritional quality, caloric value and consumer acceptability of fresh produce, are much more difficult to assess than are quantitative losses. Post-harvest losses vary greatly across commodity types, with production areas and the season of production. The relative importance given to a specific quality attribute varies in accordance with the commodity concerned and with the individual (producer, consumer, and handler) or market concerned with quality assessment. To producers, high yields, good appearance, ease of harvest and the ability to withstand long-distance shipping to markets are important quality attributes. Appearance, firmness, and shelf-life are important from the point of view of wholesale and retail marketers. Consumers, on the other hand, judge the quality of fresh fruits, ornamentals, and vegetables on the basis of appearance (including 'freshness') at the time of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of flavor (eating) quality of the edible part of produce.

2.4.1 Quality Attributes of Fresh Produce

The major factors that contribute to the various quality attributes of fresh produces are: appearance, texture, flavor, nutrition, and safety.

2.4.1.1 Appearance

These may include size, shape, colour, gloss, and freedom from defects and decay. This category of attribute can be seen, and checked. Defect can originate before harvest as a result of: damage by insects, diseases, birds, hail, chemical injuries and various blemishes. Post-harvest defects may be morphological, physical, physiological, or pathological.

2.4.1.2 Texture

These include firmness, crispness, juiciness, mealiness, and toughness, depending on the commodity. Textural quality of horticultural crops is not only important for eating and cooking quality but also for shipping ability. Soft fruits cannot be shipped over long distances without substantial losses due to physical injuries. In many cases, the shipment of soft fruits necessitates that they be harvested at less than ideal maturity, from the flavor quality standpoint.

2.4.1.3 Flavor

Flavor includes sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Flavor quality involves perception of the tastes and aromas of many compounds. An objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about the flavor quality of fresh fruits and vegetables. This approach can be used to define a minimum level of acceptability. In order to assess consumer preference for the flavor of a given commodity, large-scale testing by a representative sample of consumers is required.

2.4.1.5 Nutrition

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (Vitamin C, Vitamin A, Vitamin B, thiamine, niacin), minerals, and dietary fiber. Other constituents of fresh fruits and vegetables that may lower the risk of cancer and other diseases include carotenoids, flavonoids, isoflavones, phytosterols, and other phytochemicals (phytonutrients). Grade standards identify quality attributes in a commodity that are the basis of its use and value. Such standards, if enforced properly, are essential tools of quality assurance during marketing and provide a common language for trade among growers, handlers, processors, and receivers at terminal markets.

2.4.1.6 Food safety

A number of factors threaten the safety of fruits and vegetables. These include naturally occurring toxicants, such as glycol alkaloids in potatoes; natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins, and heavy metals (cadmium, lead, mercury); environmental pollutants; pesticide residues; and microbial contamination. While health authorities and scientists regard microbial contamination as the number one safety concern, many consumers rank pesticide residues as their most important safety concern. Unless fertilized with animal and/or human waste or irrigated with water containing such waste, raw fruits and vegetables should normally be free of most human and animal enteric pathogens. Organic fertilizers, such as chicken manure, should be sterilized prior to their application in fruit and vegetable production, so as to avoid the risk of contaminating fresh produce with Salmonella, Listeria, and other pathogens. Commodities that touch the soil are more likely to be contaminated than those that do not come in contact with the soil. The best approach to achieving and maintaining the safety of fresh fruits and vegetables is to focus on limiting potential contamination during their growth, harvesting, handling, treatment, packaging and storage. Strict adherence to Good Agricultural Practices, i.e. basic food safety principles associated with minimizing biological, chemical and physical hazards from the field throughout the distribution chain of fresh fruits and vegetables; Good Hygienic Practices, i.e. conformance to sanitation and hygienic practices to the extent necessary to protect against contamination of food from direct or indirect sources, is strongly recommended to minimize microbial contamination. Careful handling and washing of all produce to be consumed raw and the strict observance of proper sanitary measures are strongly recommended to reduce microbial contamination at the food-service, retail, and consumer levels.

2.4.2 Application of Post-Harvest Technology

Post-harvest management procedures are critical to maintaining the quality and safety of horticultural crops. There are some methods that can maintain quality attribute as showing below.

2.4.2.1 Packing and packaging of fruit and vegetables

Preparation of produce for market may be done either in the field or at the packing house. This involves cleaning, sanitizing, and sorting according to quality and size, waxing and, where appropriate, treatment with an approved fungicide prior to packing into shipping containers. Packaging protects the produce from mechanical injury, and contamination during marketing. Corrugated fiberboard containers are commonly used for the packaging of produce, although reusable plastic containers can be used for that purpose. Packaging accessories such as trays, cups, wraps, liners, and pads may be used to help immobilize the produce within the packaging container while serving the purpose of facilitating moisture retention, chemical treatment and ethylene absorption.

Either hand-packing or mechanical packing systems may be used. Packing and packaging methods can greatly influence air flow rates around the commodity, thereby affecting temperature and relative humidity management of produce while in storage or in transit.

2.4.3 Temperature and Relative Humidity Management

Temperature is the most important environmental factor that influences the deterioration of harvested commodities. Most perishable horticultural commodities have an optimal shelf-life at temperatures of approximately 0°C. The rate of deterioration of perishables however increases two to three-fold with every 10°C increase in temperature.

Temperature has a significant effect on how other internal and external factors influence the commodity, and dramatically affects spore germination and the growth of pathogens.

2.4.4 Cooling Method

Temperature management is the most effective tool for extending the shelf life of fresh horticultural commodities. Packing fresh produce with crushed or flaked ice provides rapid cooling, and can provide a source of cooling and high RH during subsequent handling. The use of crushed ice is, however, limited to produce that is tolerant to direct contact with ice and packaged in moisture-resistant containers. Clean, sanitized water is used as the cooling medium for the hydrocooling (shower or immersion systems) of commodities that tolerate water contact and are packaged in moisture-resistant containers. Vacuum cooling is generally applied to leafy vegetables that release water vapor quickly, thereby allowing them to be rapidly cooled. During forced-air cooling on the other hand, refrigerated air is forced through produce packed in boxes or pallet bins. Forced-air cooling is applicable to most horticultural perishables. Precise temperature and RH management are required to provide the optimum environment for fresh fruits and vegetables during cooling and storage. Precision temperature management (PTM) tools, including time-temperature monitors, are increasingly being employed in cooling and storage facilities.

2.4.5 Refrigerated Transportation and Storage

Cold storage facilities should be appropriately designed with good construction adequate equipment. Their insulation should include: a complete vapor barrier on the warm side of the insulation, sturdy floors, adequate and well-positioned doors for loading and unloading, effective distribution of refrigerated air, sensitive and properly located controls, refrigerated coil surfaces designed to adequately minimize differences between the coil and air temperatures and adequate capacity for expected needs. Commodities should be stacked in the cold room or the refrigerated vehicle with air spaces between pallets and room walls so as to ensure proper air circulation. Storage rooms should not be loaded beyond their capacity limit if proper cooling is to be achieved. Commodity temperature rather than air temperature should be measured in these facilities. Temperature management during transportation of fresh fruits and vegetables over long distances is critical. Loads must be stacked so as to enable proper air circulation, in order to facilitate removal of heat from the produce as well as to dissipate incoming heat from the atmosphere and off the road. Stacking of loads must also incorporate consideration for minimizing mechanical damage. Transit vehicles must be cooled prior to loading the fresh produce. Delays between cooling after harvest and loading into transit vehicles should also be avoided. Proper temperature maintenance should be ensured throughout the handling system. As far as possible, environmental conditions (temperature; relative humidity; concentrations of oxygen, carbon dioxide, and ethylene) should be optimized in transport vehicles. Treatment with ethylene to initiate ripening during transportation is feasible, and is commercially used to a limited extent on mature green bananas and tomatoes. Produce should be cooled prior to loading and should be loaded with an air space between the palletized product and the walls of the transport vehicles in order to facilitate temperature control. Vibration during transportation should be minimized, so as to avoid damage due to bruising. Controlled-atmosphere and precision temperature management should, where possible, be observed so as to allow non-chemical insect control for markets which possess quarantine restrictions against pests endemic to exporting countries and for markets that do not want their produce exposed to chemical fumigants. Mixing several produce items in one load is common and often compromises have to be made in selecting an optimal temperature and atmospheric composition when transporting chilling-sensitive with non-chilling sensitive commodities or ethylene-producing with ethylene-sensitive commodities. In the latter case, ethylene scrubbers can be used to remove ethylene from the circulating air within the vehicle. Several types of insulating pallet covers are available for protecting chilling-sensitive commodities when transported with non-chilling-sensitive commodities at temperatures below their threshold chilling temperatures.

2.4.6 The Cold Chain and its Importance

The cold chain encompasses all the critical steps and processes that foods and other perishable products must undergo in order to maintain their quality. Like any chain, the cold chain is only as strong as its weakest link. Major limitations experienced by the cold-chain include poor temperature management due to either the lack of, or limitations in: refrigeration, handling, storage, and humidity control. Investment in cold chain infrastructure ultimately leads to a reduction in the level of losses and quality degradation in fresh produce, with overall net positive economic returns. Deficiencies in cold chain management whether due to limitations in refrigeration, improper handling and storage, or inadequate humidity control, can lead to profit loss. Overcoming such deficiencies necessitates improvements in methodologies, operations and handling along the chain. Often the level of investment required in overcoming such deficiencies is minimal in comparison to the level of losses sustained over time.

2.4.7 Modified Atmosphere Storage

When used as supplements to keeping fresh horticultural perishables within their optimum ranges of temperature and relative humidity, controlled atmospheres (CA) or Modified atmospheres (MA) can serve to extend their post-harvest-life. Optimum oxygen and carbon dioxide concentrations lower respiration and ethylene production rates, reduce ethylene action, delay ripening and senescence, retard the growth of decay-causing pathogens, and control insects. CA conditions which are not suited to a given commodity can, however, induce physiological disorders and enhance susceptibility to decay. Several refinements in CA storage technology have been made in recent years. These include: the creation of nitrogen-on-demand by separation of nitrogen from compressed air through the use of either molecular sieve beds or membrane systems, use of low (0.7 to 1.5 percent) oxygen concentrations that can be accurately monitored and controlled, rapid establishment of CA, ethylene-free CA, programmed (or sequential) CA (such as storage in 1 percent O_2 for 2 to 6 weeks followed by storage in 2-3 percent O_2 for remainder of the storage period), and dynamic CA where levels of O_2 and CO_2 are modified as needed based on monitoring specific attributes of produce quality, such as ethanol concentration and chlorophyll fluorescence.

The use of CA in refrigerated marine containers continues to benefit from technological and scientific developments. CA transport is used to continue the CA chain for commodities (such as apples, pears, and kiwifruits) that had been stored in CA immediately after harvest. CA transport of bananas permits their harvest at a more advanced stage of maturity, resulting in the attainment of higher yields at the field level. In the case of avocados, CA transport facilitates use of a lower shipping temperature (5°C) than if shipped in air, since CA ameliorates chilling injury symptoms. CA in combination with precision temperature management allows insect control without the use of chemicals in commodities destined for markets that have restrictions against pest endemic to exporting countries and for markets with a preference for organic produce. The use of polymeric films for packaging produce and their application in modified atmosphere packaging (MAP) systems at the pallet, shipping container (plastic liner), and consumer package levels continues to increase. MAP (usually designed to maintain 2 to 5 percent O_2 levels and 8 to 12 percent CO_2 levels) is widely applied in extending the shelf-life of fresh-cut fruits and vegetables. Use of absorbers of ethylene, carbon dioxide, oxygen, and/or water vapor as part of MAP is increasing. Although much research has been done on the use of surface coatings to modify the internal atmosphere within the commodity, commercial applications are still very limited due to inherent biological variability of commodities. At the commercial level, CA is most widely applied during the storage and transport of apples and pears. It is also applied to a lesser extent on kiwifruits, avocados, persimmons, pomegranates, nuts and dried fruits. Atmospheric modification during long-distance transport is used for apples, avocados, bananas, blueberries, cherries, figs, kiwifruits, mangoes, nectarines, peaches, pears, plums, raspberries and strawberries. Technological developments geared toward providing CA during transport and storage at reasonable cost (positive benefit/cost ratio) are essential if the application of this technology to fresh fruits and vegetables is to be expanded Although MA and CA have both been shown to be effective in extending the post-harvest life of many commodities, their commercial application has been limited by the relatively high cost of these technologies.

2.4.8 Ethylene Treatment

Many green vegetables and most horticultural produce are quite sensitive to ethylene damage. Their exposure to ethylene must therefore be minimized. Ethylene contamination in ripening rooms can be minimized by 1) using ethylene levels of 100 ppm instead of the higher levels often used in commercial ripening operations, 2) venting ripening rooms to the outside on completion of exposure to ethylene, 3) at least once per day ventilating the area around the ripening rooms or installing an ethylene scrubber, 4) use of battery-powered forklifts instead of engine-driven units in ripening areas. Ethylene-producing commodities should not be mixed with ethylene-sensitive commodities during storage and transport. Potassium permanganate, an effective oxidizer of ethylene, is commercially used as an ethylene scrubber. Scrubbing units based on the catalytic oxidation of ethylene are used to a limited extent in some commercial storage facilities.

Ethylene treatment is commercially used to enhance the rate and uniformity of ripening of fruits such as Bananas, Avocados, Mangoes, Tomatoes, and Kiwifruits. Optimum ripening conditions are shown in Table 2.3.

Table 2.3 Optimum ripening conditions

Parameters	Level Control
Temperature	18 °C to 25 °C (65 °C to 77 °F)
Relative humidity	90 to 95 percent
Ethylene concentration	10 to 100 part per million(ppm)
Duration of treatment	24 to 74 hours depending on fruit type and stage of maturity
Air circulation	Sufficient to ensure distribution of ethylene within the ripening room
Ventilation	Require adequate air exchange in order to prevent accumulation of O_2 which reduces the effectiveness of C_2H_4.

2.5 CRITERIA FOR THE SELECTION OF APPROPRIATE POST-HARVEST TECHNOLOGIES

The basic recommendations for maintaining post-harvest quality and safety of produce are the same regardless of the distribution system (direct marketing, local marketing, export marketing). However, the level of technology needed to provide the recommended conditions varies in accordance with the distance and time between production and consumption sites, the intended use of the produce (fresh vs. processing) and the target market. In situations where the point of sale is only a matter of hours away from the site of harvest, careful harvesting and handling and the observance of proper sanitation practices are adequate measures for assuring the quality and safety of fruits and vegetables targeted for the fresh market. Pre-cooling, refrigeration and packaging however become essential when fresh produce must be moved over long distances. The following should be considered when selecting appropriate post-harvest technologies.

2.5.1 Economy of Use

The technology used elsewhere is not necessarily the best for use under conditions of a given developing country. Many of the recent developments in post-harvest technology in developed countries have come in response to the need to economize on labor, materials, and energy use, and to protect the environment. Currently used practices in other countries should be studied, but only those which are appropriate for local conditions should be adopted and used.

2.5.2 Education and Management

Expensive equipment and facilities are useless without proper management. Furthermore, over-investment in handling facilities can result in economic losses if consumers in the target market are unable to absorb these added costs. Proper education of all stakeholders along the post-harvest chain (growers, harvesters, handlers and those involved in marketing) is more critical than the level of sophistication of the equipment used in post-harvest handling. Effective training and supervision of personnel must, therefore, be an integral part of quality and safety-assurance programs.

2.5.3 Needs of Commodities

Commodity requirements can be met through the use of simple and inexpensive methods in many cases. Proper temperature management procedures, for example, include: (1) Protection from exposure to the sun; (2) Harvesting during cooler periods of the day or even at night; (3) Adequate ventilation in containers and non-refrigerated transport vehicles; (4) Use of simple and inexpensive cooling procedures, such as evaporative cooling or night ambient air; and (5) Expedited handling of fresh produce.

2.5.4 Procedures of Handling

Mechanical injuries are major causes of losses in the quality and quantity of fresh horticultural commodities in all handling systems. The incidence and severity of mechanical injury can be greatly minimized by reducing the number of steps involved in harvesting and handling, and by educating all personnel involved about the need for careful handling.

2.5.5 Food Safety

Assuring food safety throughout the post-harvest handling system is very critical and should be made the highest priority by a manager. This includes: traceability with minimization of batch dispersion, reduction of biological hazard, chemical hazard, physical hazard risk, prevention of cross contamination, etc.

2.5.6 Facility Coordination in the Supply Chain

Solving the post-harvest technology problems in a given country necessitates cooperation and effective communication among research and extension personnel. Post-harvest horticulturists therefore need to coordinate their efforts and to cooperate with production horticulturists, agricultural marketing economists, engineers, food technologists, microbiologists, and others who may be involved in various aspects of the marketing systems.

2.6 NEED OF POST-HARVEST TECHNOLOGY MANAGEMENT

In most cases, solutions to existing problems in the post-harvest handling system require the use of existing information rather than new technology research.

Researcher should study of source of uncertainty, causes of quality losses, and causes of quantity loss. Questionnaires and group discussion can be used to quantify the magnitude of loss and obtain necessary information from field works. Post-harvest technology that has been implemented successfully in one region cannot guarantee success in the other. Partners who are willing to implement technology must do survey for knowing available tools and facilities for harvesting, packing and packaging, transport, storage, and marketing of each commodity in the environment. Evaluation of post-harvest technology implementation is required. Practitioners must evaluate the impact of simple modifications in the handling system (such as stage of harvesting, method of harvest, type of container, and quality sorting) on quality and safety maintenance. They must extend information on recommended harvesting and handling procedures to all those who can use it. All appropriate extension methods for the intended audiences should be used.

2.7 SUPPLY CHAIN RISK ASSESMENT

There is no agro-industrial supply chain risk assessment guideline is available at present but rapid agricultural supply chain risk assessment developed by the Agricultural Risk Management Team of the World Bank can be used.

2.7.1 Identification of Major Risks

This session explains based on major risks from rapid agricultural supply chain risk assessment reported by World Bank (Jaffee et al 2010). An agricultural supply chain may be subjected to or experience multiple risks, with farmers and firms facing risks from different sources. Table 2.4 portrays different types of risk that may be encountered. As the following discussion indicates, such risks can impact the reliability, costs, and efficiency of production, processing, and marketing activities. Particular risks are generally idiosyncratic or covariate for the supply chain.

Table 2.4 Categories of Major Risks in Agricultural Supply Chains

Type of Risk	Examples
Weather-related risks	Periodic deficit and /or excess rainfall or temperature, hailstorms, strong winds
Natural disasters (including extreme weather events)	Major floods and droughts, hurricanes, cyclones, typhoons, earthquakes, volcanic activity
Biological and environmental risks	Crop and livestock pests and diseases; contamination related to poor sanitation, human contamination and illnesses; contamination affecting food safety; contamination and degradation of natural resources and environment; contamination and degradation of production and processing processes
Market-related risks	Changes in supply and/or demand that impact domestic and/or international prices of inputs and/or outputs, changes in market demands for quantity and/or quality attributes, changes in food safety requirements, changes in market demands for timing of product delivery, changes in enterprise/ supply chain reputation and dependability
Logistical and infrastructural risks	Changes in transport, communication, energy costs, degraded and/or undependable transport, communication, energy infrastructure, physical destruction, conflicts, labor disputes affecting transport, communications, energy infrastructure and services

Table 2.4 (Continued)

Type of Risk	Examples
Management and operational risks	Poor management decisions in asset allocation and livelihood/enterprise selection; poor decision making in use of inputs; poor quality control; forecast and planning errors; breakdowns in farm or firm equipment; use of outdated seeds; lack of preparation to change product, process, markets; inability to adapt to changes in cash and labor flows
Public policy and institutional risks	Changing and/or uncertain monetary, fiscal and tax policies; changing and/or uncertain financial (credit, savings, insurance) policies; changing and/or uncertain regulatory and legal policies and enforcement; changing and/or uncertain trade and market policies; changing and/or uncertain land policies and tenure system; governance-related uncertainty (e.g., corruption); weak institutional capacity to implement regulatory mandates
Political risks	Security-related risks and uncertainty (e.g., threats to property and/or life) associated with politico-social instability within a country or in neighboring countries, interruption of trade due to disputes with other countries, nationalization/confiscation of assets, especially for foreign investors

Source: Jaffee et al (2010)

2.7.2 Transmission of Risk

It is important to examine how risks and risk response are transmitted throughout the agri-food supply chain. Some adverse events (i.e., idiosyncratic supply chain risks) are experienced only locally by particular supply chain participants. Other participants may be unaffected, or they may be beneficiaries (due to lower prices for their own inputs or higher demand for their services). Other risks (i.e., covariate supply chain risks) have snowball effects, impacting prevailing conditions of factor and product market demand and supply for other parties. How the supply chain participants go about in managing the risks that they face can help or hinder the risk management efforts of other participants. Thus risks and risk management in a supply chain are linked, requires a systems approach that consider the distribution and transmission of risk. Supply chain risk assessment focuses on the distribution of risks among individual participants and their transmission between participants. Table 2.5 provides details about how the different risks, experienced by primary agricultural producers, can transmit themselves to the operations of input suppliers and entities involved in the collection, processing, trading, and final distribution of food and agricultural commodities (Jaffee et al 2010).

2.7.3 Risk Analysis

There is a need for a systematic assessment highlighting patterns of risk exposure and the associated expected losses from various risky events for different supply chain participants. The team of risk assessment should map out different patterns of risk transmission throughout the supply chain. With particular regard to the risk analysis and risk management dimensions, the sequence of analytical and consultative steps involves:

(1) Characterizing and charting key players in the supply chain and identifying critical flows and transactions of product, information, finance, and logistics,

(2) Identifying and characterizing the range of risks faced by players along the supply chain, with a focus on critical flows and transactions,

(3) Ranking risks in terms of probability and potential severity—identifying the key risks and their expected losses,

(4) Identifying the existing ex-ante and ex-post risk management strategies taken by players in the supply chain and/or external parties,

(5) Assessing the apparent effectiveness, costs, and benefits of the risk management strategies taken by players, as well as options to improve risk management effectiveness.

Table 2.5 Risks that Impact the Farmers and the Transmission of Impacts to Agro-enterprises

Risk	Input Suppliers	Farmers	Buyers	Processors	Traders	Distributors
Weather-related risks	Demand for inputs Repayment for inputs on credit	Planting decisions Yield and quality Income decline	Availability, price, quality of products Logistic costs	Availability, price, quality of products Logistic costs	Availability, price, quality of products Logistic costs	Availability, price, quality of products Logistic costs
Natural disasters	Demand for inputs in current and subsequent year Repayment for inputs on credit	Yield and quality Farm asset loss Longer-term output and income decline	Availability, price, quality of products Logistic costs	Availability, price, quality of products Logistic costs Costs to develop alternative supply sources	Availability, price, quality of products Logistic costs Loss of market contracts	Availability, price, quality of products Logistic costs Costs to develop new supply sources
Biological and Environmental risks	Demand for inputs Repayment for inputs on credit	Input use Yield and quality Production costs Income decline	Availability, price, quality of products Need to screen or test supplies	Availability, price, quality and safety of products Brand reputation Market access	Availability, price, quality of products Brand reputation Market access	Availability, price, quality of products; Brand reputation; Product liability Need to procure from alternative sources

Table 2.5 (Continued)

Risk	Input Suppliers	Farmers	Buyers	Processors	Traders	Distributors
Market-related risks	Demand for inputs Repayment for inputs on credit	Planting decisions Input use Yield and quality Income decline	Availability, price, quality of products	Availability, price, quality of products	Availability, price, quality of products	Availability, price, quality of products
Policy and institutional risks	Demand for inputs Repayment for inputs on credit	Planting decisions Input use Yield and quality Ability to sell	Availability, price, quality of products Operating costs Ability to intermediate	Availability, price, quality of products Availability, price other products Need to procure from alternative sources Operating costs	Availability, price, quality of products Need to procure from alternative sources Operating costs Ability to sell	Availability, price, quality of products Need to procure from alternative sources Operating costs
Logistics-related risks	Demand for inputs in current and subsequent year (or season)	Input access and use Yield and quality Postharvest losses Income decline	Availability, price, quality of products Availability and price of other products Operating costs	Availability, price, quality of products Availability and price of other products Operating costs	Availability, price, quality of products Availability and price of other products Operating costs	Availability, price, quality of products Availability and price of other products Operating costs

Table 2.5 (Continued)

Risk	Input Suppliers	Farmers	Buyers	Processors	Traders	Distributors
Management and operational risks	Demand for inputs in current and future years	Inappropriate planting decisions and input use Reduced yield and quality	Availability, price, quality of products Operating costs	Availability, price, quality, and safety of products Product liability Operating costs	Availability, price, quality of products Operating costs Product rejections and market access	Availability, price, quality of products Operating costs Loss of brand reputation; market or regulatory sanctions

This stage of the assessment results in a number of key outputs such as a presentation of the risk profile of individual supply chain entities and the supply chain, as a whole, as well as the documentation and summary of key informant interviews. This step involves interviews with representative entities throughout the supply chain (farmers, input suppliers, market intermediaries, transporters, processors, and others), as well as additional service providers (farm extension advisors, financial institution representatives, and the like). For supply chain participants, perceptions about the risks they face should be sought in relation to their sourcing of inputs (goods, services, raw materials): own production and processing of goods or services: marketing of the product (whether it is a finished or intermediary good or service).

Chain participants should provide perspectives on exposures to their relevant risks, risks of their suppliers and buyers, and risks of the overall supply chain. Survey instruments and/or stakeholder meetings should be structured to obtain both perceptions and data so that the probability and severity of different risks can be quantified and ranked with some degree of confidence. Additional information can be obtained from published price and weather data. Service providers (e.g., financial institutions, freight and transport operators, technical advisors) should be also interviewed to assess the risks that they face in their business relations with the supply chain and to gauge their perceptions about the risks borne by those chain participants.

The methodological guidelines for the analysis of key risk categories, including the definition and scope of different risks must be prepared. The methodological guidelines set out semi structured interview guidelines to assess the risk perceptions of supply chain entities and to examine how these risks and have possible negative impacts. For supply chain entities, the interviews are structured to determine their respective roles and the relative importance of their commodities to business enterprises, to prioritize risks and estimate expected losses, to overview supply chain linkages, and to elicit risk management options and capacities.

Guidelines for interviewing the supply chain service providers are designed to assess supply chain risk perceptions and spillover risk effects that the providers facing in both the public and private sectors. The risk analysis should address a number of issues, including

(1) The risk and uncertainty factors that can disrupt the supply chain (differentiating among risk-related deviations, disruptions, disasters);

(2) The extent to which risks and uncertainties are idiosyncratic (affecting individual chain participants), covariate within the chain (affecting multiple chain participants), and/or covariate outside the chain (impacting chain participants and the overall economy);

(3) Changes in costs, prices, and productivity levels that result in financial loss for supply chain participants;

(4) The transmission of risks through the supply chain—where and when risk and uncertainty unfold and they spread throughout the chain (via individual participants and among chain participants);

(5) Whether there are perceptions of equitably or inequitably shared risks in the chain;

(6) Which supply chain participants are most exposed to risk and uncertainty;

(7) What is exposed in terms of assets and/or livelihoods and enterprise strategies;

(8) How risks are manifested, how they impact enterprises (e.g., the destruction of assets and/or lowering of income and consumption);

(9) The key transaction points and types of transactions associated with risk and uncertainty;

(10) The what, who, how, where, and when of the greatest expected losses;

(11) Which losses or impacts tend to be short-term rather than long-term;

(12) How important the expected losses are internally for different participants in the chain, relative to their assets, livelihood/enterprise strategies, and performance outcomes.

Expected losses from a risky event include both tangible and intangible losses and short- and long-term losses. It is critical to consider losses in terms of how they affect short-term outcomes (e.g., a decline in producer prices after harvest) and in terms of how they affect livelihoods and outcomes in the long term (e.g., a decline in the water table that impacts planting decisions and yields in the future). Thus, in addition to examining whether risks are idiosyncratic or covariate, it is important to examine whether they impact performance flows (e.g., the movement of goods and services, incomes) and/or damage assets. For example, the nonpayment of a loan or the failure to achieve quality standards or timely delivery can result in the termination of future supply contracts, the compromise of business reputation, and the loss of access to credit and other supply services. Expected losses are a function of the probability of a risky event actually occurring and the exposure to that risky event, that is, how performance outcomes might be influenced if the risk materializes. Expected losses are another way of considering the potential severity of negative impacts from a given risk, without any (ex-ante or ex-post) risk management.

Even when only qualitative information or perceptions can be obtained, the team can make efforts to organize such feedback in a systematic way, enabling comparisons and rankings, and then prioritizing them according to expected losses. The potential severity of a risk is mapped against the probability of the event occurring. Depending on the point of intersection, a prioritization on expected losses (low, medium, high) can be determined, as outlined in Table 2.6.

Table 2.6 Ranking of expected losses: Separating the High from the Low

		Potential Severity of Impact				
		Negligible	**Moderate**	**Considerable**	**Critical**	**Catastrophic**
Probability of Event	Highly probable					Priority 1
	Probable					
	Occasional			Priority 2		
	Remote	Priority 3				
	Impossible					

Priority 1= High expected loss Priority 2= Medium expected loss

Priority 3= Low expected loss

Source: Jaffee (2010)

2.7.4 Risk and Vulnerability

Risky events can be characterized by their magnitude, scope or spread, frequency and duration, and their history, all of which affect vulnerability. Risks can be classified as

(1) Idiosyncratic risks that usually affect only individual farms or firms (e.g., plant and animal pests and diseases, illnesses of the owner or laborers);
(2) Covariate risks that affect many enterprises simultaneously (e.g., major droughts or floods, fluctuating market prices).

Risk is the possibility that an event will occur with a potentially negative impact on the achievement of a farm or firm's performance objectives and/or on the successful functioning of the overall supply chain. The exposure of farms and firms to risk depends on various factors, notably their assets and their allocation via livelihood and/or business strategies. An enterprise's assets and their allocation (crop and livestock mix, diversification of activities—farming, off-farm, and non-farm) influence exposure to risk, and these allocation decisions are in turn influenced by risks. In addition, the allocation of assets and exposure to risk determine the severity of risk-related impacts. By combining the likelihood of risk, risk exposure, and the severity of risky events, one can estimate the expected losses from a risky event for different participants in the supply chain as well as the cumulative losses throughout the chain. Indeed, researchers and practitioners examining exposure to risk have identified a set of key factors:

(1) Inherent commodity characteristics: Product perishability complicates exposure to market and logistical risks. Commodity quality may have both observable and non-

observable characteristics, with impacts on managerial and operational risks.

(2) Inherent production characteristics: Technically sophisticated production processes and greater specificity of production assets may exacerbate operational and market risks.

(3) Geography and agro-ecology: Logistically remote and/or otherwise difficult terrain increases risk exposure, as do agro-climatic conditions conducive for pests and diseases.

(4) Political boundaries: Border controls and crossing procedures add to risk exposure.

(5) Transaction points: The number of transport nodes and transaction points and the frequency of use influence risk exposure, as does the number of compliance points.

(6) Infrastructure conditions: The condition of transport, communications, energy water, and sanitation infrastructure, in addition to their availability, influences risk exposure.

The vulnerability of individual chain participants and the overall supply chain depends on the nature of the risks (correlation, frequency and timing, and severity) and on the effectiveness of the risk management instruments in use. The magnitude, timing, and history of risks and the timing and effectiveness of responses determine the outcome. For the farm or firm and for the supply chain as a whole, the outcome of the risk and response process, in terms of performance loss relative to a given benchmark, is an indicator of major interest. To make the concept of vulnerability useful, an appropriate performance benchmark is needed for each participant in the supply chain. However, risk-related performance losses for individual supply chain participants are neither necessary nor sufficient conditions for the existence of supply chain vulnerability. Supply chain vulnerability is associated only with losses that disrupt the flow of products in a manner that causes serious damage to the supply chain. To illustrate when yield declines, cost increases, and/or price declines resulting in income loss. This is sufficient to determine enterprise disruptions and supply chain vulnerability. However, sometimes the resultant income loss is so severe that forces the enterprise to below minimum performance standard, perhaps resulting in production and delivery losses that cannot be made up elsewhere in the chain. In such cases, an individual enterprise can substantially hinder the performance of the overall supply chain. The enterprise-specific performance standards (benchmark indicators) should thus be based on objectives relevant for sustainable participation in the supply chain. Resilience is the enterprise's ability to resist and to recover from the potential negative impacts of risky events—especially when assets are degraded. An overall supply chain can also have greater or lesser capacities of resilience. Given the varying portfolios of assets among and between enterprises, the same risky event can have different performance outcome effects. Similarly, enterprises with similar assets but different risk management responses might experience dissimilar outcomes. Table 2.6 illustrates a continuum of vulnerability conditions. If the capacity to manage risks is low, enterprises facing high expected losses could, in fact, be vulnerable to profound disruptions that would curtail their ability to participate effectively in the supply chain. Yet, even when exposed to the same risky event, impacts vary depending on the farm or firm (or supply chain's capacity to manage risk.

2.7.5 Alternative Instruments for Managing Supply Chain Risk

An array of approaches and instruments are available to help manage risks in an agricultural supply chain. These can be grouped into several broad categories:

(1) Technology development and adoption: Agricultural research and development of improved varieties and breeds, postharvest technology, software development, information and knowledge technology, basic and advanced applied education programs

(2) Enterprise management practices: Farm and firm diversification practices, farming systems approaches, just-in-time management, inventory control, improved forecasting capacity, food safety practices, certification of best practices, logistics planning, early warning systems, among other practices

(3) Financial instruments: Credit and savings (formal and informal), insurance (formal and informal), warehouse financing, price hedging instruments, and other vehicles

(4) Investments in infrastructure: Investments in transport and communication infrastructure (including air- and seaports), energy infrastructure, informatics and knowledge transfer infrastructure, storage and handling facilities, marketplaces, processing facilities, weather stations, and other structures

(5) Policy and public programs: Institutional arrangements, regulatory measures, government policies, property and human rights, labor laws, disaster management units, safety nets, and similar programs Private collective action: Commercial and no-commercial actions taken by farmer groups, cooperatives, industry associations, and other groups, in addition to various types of commercial contractual arrangements and partnerships.

(6) Multiple strategies are typically combined because no single approach or instrument can effectively reduce, mitigate, or transfer the broad range of risks normally encountered.

Problems in Banana supply chain in India and Bamboo shoot supply chain in Thailand are discussed in chapter 3.