8.2 Quality Issues for Agricultural Product Chains

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Abstract. *This section presents some theoretical background on supply chains and supply chain management, examines the role of emerging technologies in supply chain management, and provides some information on actions that should be taken to assure environmentally conscious supply chains in agriculture. Then, focus is given to the way supply chain management is applied in agribusiness. Finally, the latest technological advancements on traceability and tagging systems in agricultural processes are presented.*

Keywords. *Supply chain management, Agribusiness, Traceability, Tagging systems.*

8.2.1 Introduction

In the past, organizations have operated independently by taking strategic decisions within a facility, without taking into account component dependencies and interactions along the supply chain. The *supply chain* concept arose from a number of changes in the manufacturing environment such as increased manufacturing cost, shrinking resources, shortened product life cycles, and the globalization of market economies [1]. In fact, the competitive realities of the current marketplace and the impact on the contemporary operations manager are aptly summarized by Skinner [2]: "make an increasing variety of products, on shorter lead times with smaller runs, and flawless quality. Improve the ROI (return on investment) by automating and introducing new technology in processes and materials so that prices can be reduced to meet local and foreign competition. Mechanize–but keep the schedule flexible, inventories low, capital cost minimal, and the work force contented." The advent of *total quality management (TQM)* to achieve consistent and flawless quality, *flexible manufacturing systems*

(FMS) to achieve quick response and agile manufacturing at reasonable cost, and *supply chain management (SCM)* mechanisms to deliver products quickly with low inventories are regarded as responses to these new competitive pressures [3].

A supply chain, according to Stevens [4], is a system whose constituent parts include material suppliers, production facilities, distribution services, and customers, linked together via the feedforward flow of materials and the feedback flow of information (Figure 1). In other words, it is a network of multiple businesses and relationships. It can be described in terms of five interconnected business systems: (1) engineering, (2) marketing, (3) manufacturing, (4) logistics, and (5) management systems.

According to Beamon [1], the supply chain involves two basic and highly integrated processes: (1) the production planning and inventory control process and (2) the distribution and logistic process. The production planning and inventory control process encompasses the manufacturing and storage processes as well as their interfaces. Production planning describes the design and management of the entire production process while inventory control concerns the design and management of the storage policies and procedures. The distribution and logistic process determines how products are retrieved and transported from the warehouses to distribution facilities and finally to retailers. An integrated supply chain is obtained by the extensive interaction of these two processes.

With the increasing complexity of supply chains today, as global markets continue to open and more firms are becoming multinational, independently managing facilities can result in very poor overall behavior [5]. It is now clear that focusing on a single element in the supply chain cannot assure the effectiveness of the whole system. The quality of data and the high complexity of the supply chain make the overall formulation of the supply chain problem very difficult and the use of an integrated supply chain management completely necessary.

The term *supply chain management* was originally introduced by consultants in the early 1980s [6]. There are several definitions of SCM. A good number appear in [7]. According to the Global Supply Chain Forum, SCM is the integration of key business

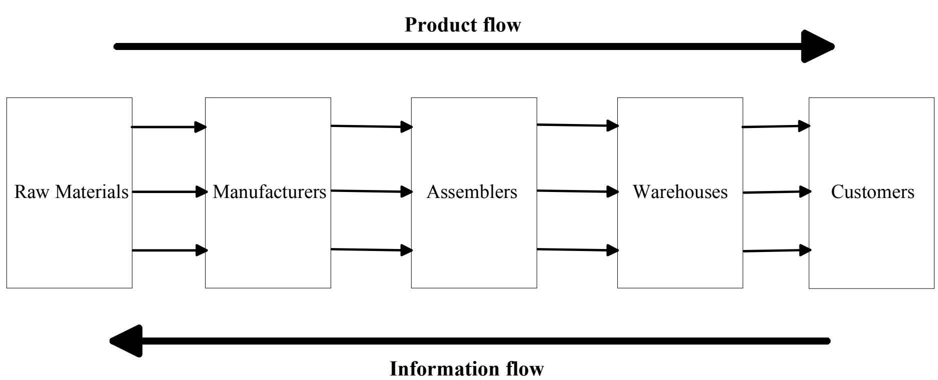

Figure 1. Schematic representation of a generic supply chain.

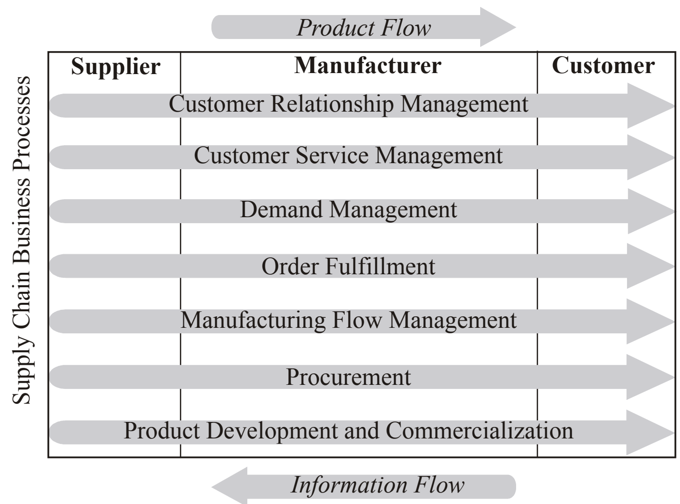

Figure 2. Integrating and managing business processes during SCM across the supply chain.

processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders. To this extent, business processes become supply chain business processes linked across intra- and inter-company boundaries [8] (Figure 2). This means that all activities are managed at the inter-organizational level as well as the departmental level. Instead of focusing on the management of interfirm inventory and transportation capacities, SCM aims to integrate the activities of an entire set of organizations from procurement of material and product components to deliver completed products to the final customer [9].

SCM has evolved in recent years to reflect the fundamental changes that have occurred in the relationship between marketing and corporate strategy. It leads to improvements in channel performance among all channel members and not solely within the focal firm. These improvements are due to the following [10]:

- avoidance of duplication effects by concentrating on core competencies;
- use of inter-organizational standards like *activity based costing (ABC)* and *electronic data interchange (EDI)*; and
- elimination of unnecessary inventory levels by postponing customization towards the end of the supply chain.

The key element of SCM is activity integration. It is a strategy that brings together the application of logistics and its focus on transactions between channel members with that of management and its focus on relationships within the channel. It seeks to achieve a relationship of mutual benefit by defining the organizational structures and contractual relationships between buyer and seller.

8.2.2 Theory and Principles of SCM

A critical literature review analysis on the SCM field [7] concluded that there is a relative lack of theoretical work in the field, compared to empirical studies. A conceptual framework of SCM tries to emphasize the interrelated nature of SCM and the need to proceed through several steps to design and successfully manage a supply chain [8]. It consists of three closely interrelated elements: the supply chain network structure, the supply chain business processes, and the supply chain management components. The network structure consists of the member firms and the links between these firms. Business processes are all the activities that produce a specific output of value to the customer. The management components are the managerial variables by which the business processes are integrated and managed across the supply chain.

In a supply chain, all firms, from the raw materials to the ultimate consumer, participate. The degree of the required management of this chain depends on several factors; the most important ones are the complexity of the product, the number of available suppliers, and the availability of raw materials. The dimensional complexity of the structure is given by the length of the supply chain and the number of suppliers and customers at each level. The closeness of the relationship at different points in the supply chain may differ. Management needs to choose the level of partnership appropriate for particular supply chain links [11]. The most appropriate relationships are the ones that best fit the specific set of circumstances [12].

The performance of a supply chain is influenced by the structure of business processes, information systems, and decision support rules, as well as the nature of collaboration between supply chain members. If the supply chain has not been structured properly, as measured by its physical attributes, little can be done to repair the resulting "damage." If the supply chain infrastructure has lengthy and variable lead times, poor understanding of customer demand patterns, poor product quality, or uncertain production capacity, then little competitive advantage can be achieved through more extensive adoption of information systems, decision support tools, or efforts to collaborate with partners. Thus, competitive advantage will exist only if several key elements exist in a supply chain. These include knowing the customer, constructing a lean supply chain organization that eliminates waste, viability and uncertainty, building tightly coupled information infrastructures and business processes, and finally constructing tightly coupled decision support systems.

8.2.3 Major Forms of SCM

Supply chain management systems in use today have evolved over time and often are based on operations research modeling paradigms. The two most popular forms of SCM are summarized below, while modeling approaches are presented in Section 8.2.4.

Efficient Consumer Response (ECR)

One of the quite recent and most important strategies of SCM is *efficient consumer response (ECR)*. It is defined as "a grocery industry strategy in which distributors, suppliers and brokers jointly commit to work closely together to bring greater value to the grocery consumer" [13]. This SCM approach aims to meet the goal of better fulfillment of consumer needs via the implementation of a four-part process: efficient

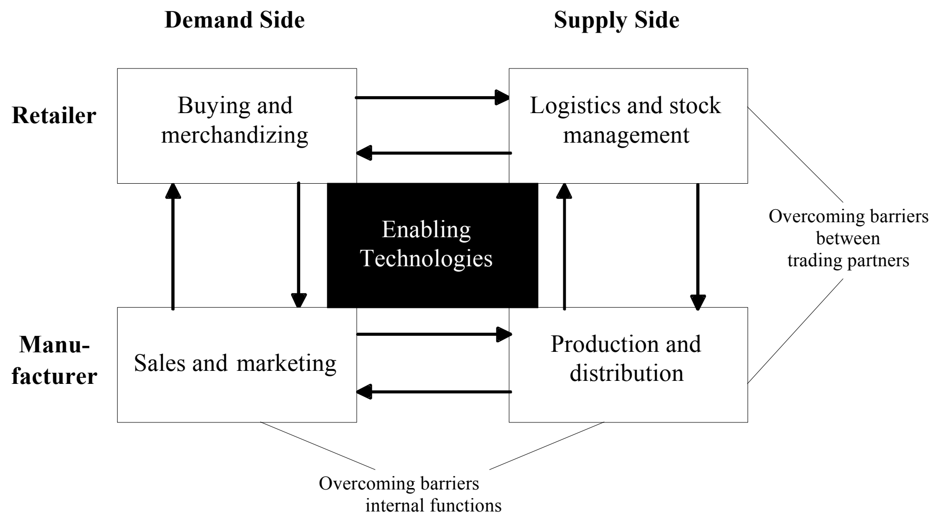

Figure 3. ECR harmonization process by focus areas [14].

replenishment, efficient promotion, efficient store assortment, and efficient product introduction [10]. The realization of ECR strategy requires the use of enabling technologies such as information systems and improved business processes [14]. As a result, harmonization among the various channel members is achieved (Figure 3). The four focus areas (sales and marketing, production and distribution, buying and merchandizing, logistics and stock management) that are shown in Figure 3 are supposed to be installed within the participating companies. They should be interpreted as interorganizational and interdepartmental working groups, thus their implementation suggests the loss of functional and organizational borders within and between firms [10]. In this way, financial and procedural waste from the channel is eliminated and team members are encouraged to work for an increase in performance of the entire channel.

ECR strategy has given positive results in general, even though in various cases more time is needed for the results to be realized. It is true that more empirical evidence is needed on the organizational level and new research should be focused on the evaluation of results from ECR and its influence on the overall performance of the firm.

Just In Time (JIT)

Just in time (JIT) is a management philosophy of continuous improvement that aims to bring certainty and smoothness to the flow of materials through the supply chain by identifying and eliminating wasteful practices and activities, such as holding safety stocks. Businesses hold stocks because of uncertainty, either about the future level of demand or about the lead time to manufacture or replenish stocks. What the JIT approach tries to develop is a network of quality-assured supply partners who can deliver the right quantity to the right place at the right time, every time. The supplies are delivered against an agreed schedule with absolute certainty on the day they are required, rendering expensive safety stocks redundant.

The American Production and Inventory Control Society (APICS) has the following definition of JIT: “A philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery and including all stages of conversion from raw material onward. The primary elements include having only the required inventory when needed; to improve quality to zero defects; to reduce lead time by reducing setup times, queue lengths and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum cost.”

The main purposes of JIT implementation are reducing the cost, improving delivery time, improving quality and performance, adding flexibility, and increasing innovativeness. Some of the prominent types of waste to be eliminated are waste of overproduction and waiting time, transportation, inventory, and processing waste, as well as waste of motion and waste from product defects. When its principles are implemented successfully, significant competitive advantages are realized. However, there are several requirements for the successful implementation of JIT. Among these requirements are:

- improvement of sales forecasts and, where appropriate, production planning so that both purchasing and suppliers can be better informed about requirements;
- set up of effective information systems so suppliers are immediately aware of any changes to programs;
- a quality assurance program under which suppliers are accepting responsibility for quality, monitoring quality during rather than after production, and working towards zero defects; and
- removing non-value-adding activities throughout the whole supply chain, i.e., looking at the total cost picture.

8.2.4 Modeling the Supply Chain

The generic supply chain shown in Figure 1 consists of five stages. Each stage can be considered as a source for the stages that follow or as a sink for the stages that precede. Each stage is characterized by its [15]:

- location,
- demands for products and raw materials,
- cost associated with each product or process within the stage,
- customer service requirements,
- technical, legal, or operational constraints,
- capacity constraints (maximum and minimum by product and location),
- maximum inventory investment constraints, and
- order handling requirements and constraints.

Multi-stage models for supply chains design and analysis can be categorized into *descriptive* models or *optimization* models [16]. Descriptive models are developed by modeling practitioners in order to improve their understanding about the functional relationships in the company and the outside world. Descriptive models include the following [16]:

- *forecasting models,* to predict demand or raw material cost based on historical data;
- *cost relationships,* which describe how costs vary as functions of cost drivers;
- *resource utilization relationships,* which describe how scarce resources are consumed; and
- *simulation models,* which help evaluate certain circumstances and conditions where real data are not available, or used as models for construction of simulated data.

Optimization models are developed by modeling practitioners in order to help managers make better decisions. Clearly, the development of optimization models requires data and models as inputs and, consequently, descriptive models are used for this task.

Min and Zhou [17] have classified supply chain models into four major categories: deterministic (non-probabilistic), stochastic (probabilistic), hybrid, and IT-driven. In deterministic models it is assumed that all parameters and data are known while in stochastic models uncertainty is involved in this information. In a recent paper Melachrinoudis and Min [18] present a representative deterministic modeling approach together with an enlightening discussion of the multifaceted nature of the supply chain systems modeling. Lee et al. [19] present a representative stochastic modeling approach by developing a dynamic programming model that aimed to minimize the expected cost of production, inventory holding, and excess demand penalty, subject to production satisfying capacity constraints. Hybrid models involve elements of both stochastic and deterministic models. A representative example is given in [20]. They use a combination of mixed-integer programming models and simulation to determine the number and location of distribution and processing centers as well as the set of market areas covered by each distribution center.

IT-driven models aim to integrate and coordinate various phases of supply chain planning on a real-time basis using application software. The aim is to enhance visibility throughout the supply chain. Models in this category include, among others, warehouse management systems (WMS), transportation management systems (TMS), distribution resource planning (DRP), and geographic information systems (GIS). A representative example is given in [21].

Supply Chain Performance Measures

Apart from the need for a model that describes the behavior of the supply chain there is also the need to evaluate its performance. Performance measures are used to determine the efficiency and the effectiveness of an existing system, and more importantly to compare competing alternative systems in order to design proposed systems by determining the values of the decision variables. The most commonly used measures of performance can be categorized in *qualitative* and *quantitative* performance measures.

Beamon [1] defines qualitative performance measures to be the measures for which there is no single direct numerical measurement. *Customer satisfaction* (the degree to which the customers are satisfied with the product) is among the most important qualitative performance measures and is comprised of three elements: pre-transaction satisfaction (prior to product purchase), transaction satisfaction (services related to the physical distribution of products), and post-transaction satisfaction (related to the use of products). Supply chain *flexibility* (degree of response to random fluctuation in the demand) and *risk management* (minimizing the effects of the risk inherent to all relationships within the supply chain) are also among the most important qualitative performance measures.

Most of the quantitative performance measures are directly related to the cost or profit of the supply chain. The minimization of cost, the minimization of inventory investment, the maximization of sales or the maximization of profit (revenues – cost) are the performance measures related directly to the cost or profit. Other quantitative measures are measures based on customer responsiveness. Maximizing the fraction of customer orders filled on time and minimizing the time between the placement of an order and the delivery of the product are among the more commonly used performance measures not directly related to cost or profit.

Design Variables in Supply Chain Modeling

The models and the performance criteria discussed above can be integrated in order to help obtain decisions related to the structure and the operation of the supply chain system. These decisions are expressed in terms of the design variables of the supply chain and are related to the activities of supply chain management that can be classified into three levels [22]: operation level, tactical level, and strategic level. The design variables can be classified as [23] design variables at configuration level or design variables at operational management and control level. Variables that belong to the configuration level are normally related to the tactical and strategic level activities and determine the configuration (topology) of the supply chain with regard to the parties involved, roles to be performed, manners of co-operation, constraints to executing roles, and the IT or physical infrastructure used. Variables that belong to the operational management and control level are normally related to the tactical and operational level activities and determine, for a given topology, the co-operation and integrated planning of operations.

The most important decision variables that are functionally related to the performance of a supply chain are related to:

- *location decisions*—the number, size and physical location of the production units, warehouses and distribution centers;
- *production decisions*—the allocation of suppliers to plants, products produced at each plant, etc.;
- *inventory decisions*—the management of the inventory levels; and
- *transportation decisions*—the type of transportation means, size of shipments, etc.

Optimization Models and Their Solution

A model can be used as a means for describing the essential features of the problem under consideration. The completeness and precision that a mathematical model offers, as well as the understanding involved in its development, make models (and modeling development) invaluable tools in improving our understanding of complex, interacting, and highly integrated systems such as the supply chain. The greatest value of supply chain models comes from the fact that a proper model can be used in order to assist in the decision-making process.

In the past, the use of optimization models was determined by the availability of large and expensive computers. As a result their use and value was limited and many users were forced to settle for heuristic or simulation approaches in order to determine the optimum values of the decision variables. Currently, computer power is available at acceptably low cost and, combined with the availability of cost-effective data processing systems, it allows the extensive use of optimization techniques for determining the optimum values of the design variables related to the structure, control, and operation of a supply chain.

The mathematical models used in the optimization of supply chains involve binary variables together with continues variables and they can be stated in the following general form:

$$\min_{\mathbf{x},\mathbf{y}} \mathrm{J}(\mathbf{x},\mathbf{y})$$

$$\text{subject to } \mathbf{f}(\mathbf{x},\mathbf{y}) = \mathbf{0} \text{ and } \mathbf{g}(\mathbf{x},\mathbf{y})$$

$$\text{and } \mathbf{g}(\mathbf{x},\mathbf{y}) \leq \mathbf{0}, l_i \leq x_i \leq u_i, \forall i, y_j \in \{0,1\}, \forall j \tag{1}$$

where $\mathbf{x}$ = the vector of continuous variables,

$\mathbf{y}$ = the vector of binary optimization variables

J = a single or multi-objective quantitative performance criterion

$\mathbf{f}$ and $\mathbf{g}$ = the vector-valued functions that describe the behavior and the constraints of the supply chain

This general form of the mathematical programming problem is known as mixed-integer, non-linear programming problem (MINLP, [24]). When the objective function and the constraints are linear then Equation 1 is simplified to:

$$\min_{\mathbf{x},\mathbf{y}} \mathbf{c}^{\mathrm{T}}\mathbf{x} + \mathbf{d}^{\mathrm{T}}\mathbf{y}$$

$$\text{subject to } \boldsymbol{Ax} + \boldsymbol{By} = 0$$

$$\text{and } \boldsymbol{Dx} + \boldsymbol{Ey} \leq 0,\ l_i \leq x_i \leq u_i, \forall i, y_j \in \{0,1\}, \forall j \tag{2}$$

This form is known as a mixed-integer, linear programming problem (MILP) and is considerably easier to solve compared to the MINLP problem. However, due to the combinatorial nature of the domain of $\mathbf{y}$ variables any attempt to enumerate completely all alternative solutions (there are 2^n alternative combinations for n binary variables) is deemed to fail. Furthermore, MILP problems belong to the class of *NP*-complete problems. Accessible sources on modeling using integer variables and the solution of MIP problems (mixed integer, linear or non-linear programming problems) are the books by Floudas [24] and Williams [25], while Wolsey [26] offers a more advanced (yet readable) presentation.

Algorithmic approaches for solving MILP problems can be classified as *branch and bound* methods, *cutting plane* methods, *decomposition* methods, *logic-based* methods, or *branch and cut,* which is a combination of the branch and bound and cutting planes methods.

A very important idea in solving MIP problems is the idea of *relaxation* [26]. A problem (*RP*) $\mathbf{z}^{RP} = \min\{\varphi(\mathbf{z}): \mathbf{z} \in \mathrm{T} \subseteq \mathrm{R}^n\}$ is a relaxation of (*IP*) $\mathbf{z}^{IP} = \min\{\theta(\mathbf{z}): z \in \mathrm{W} \subseteq \mathrm{R}^n\}$ if: $\mathrm{W} \subseteq \mathrm{T}$ and $\varphi(\mathbf{z}) \leq \theta(\mathbf{z}), \forall \mathbf{z} \in \mathrm{W}$. If *RP* is a relaxation of *IP*, then $\mathbf{z}^{RP} \leq \mathbf{z}^{IP}$. The most well-known relaxation is the relaxation of the integrality constraints (when the constraints $y_j \in \{0,1\}$ are relaxed to $y_j \in [0,1]$) denoted as linear programming relaxation. In this case the resulting problem is a linear programming problem (LP), a problem much easier to solve compared to the MILP problem. By solving the LP problem we obtain a lower bound of the solution of the initial MILP problem. An upper bound of the solution of the MILP problem can be obtained by fixing arbitrarily the binary variables (*restriction*).

The branch and bound methodology for solving MIP problems is based on the idea of performing an "intelligent" enumeration of the alternatives without examining all combinations of the **y** variables. A key element in such an enumeration is the representation of alternatives via a binary tree. At each node of this tree a linear programming relaxation is solved. Then, based on branching criteria, children nodes are generated. A node is not branched (fathomed) if the linear programming relaxation is infeasible, if the solution of the linear programming relaxation is an integer solution, or if the solution of the linear programming relaxation is worse that the current best integer solution.

Details of many of the recent mathematical programming systems as well as modeling languages are given in the web page maintained by the Institution for Operations Research and the Management Sciences (see for example www.lionhrtpub.com/orms/surveys/LP/LP-survey.html for the most recent survey). AMPL (www.ampl.com), GAMS (www.gams.com) and XPRESS-MP (www.dash .co.uk) are among the most well-known languages, while CPLEX (www.ilog.com), OSL (www.research.ibm.com/osl) and XPRESS (www.dash.co.uk) are among the most successful general MIP solvers.

8.2.5 The Role of Emerging Technologies in SCM

SCM used to be simple compared to what it is today. Manufacturers sold to wholesalers or directly to retailers. Salespeople called on their supply chain customers and wrote orders. Or, retailers called in their orders or sent them by mail. This low-tech supply chain started to die out in the 1980s and was almost extinct by the mid-1990s. Supply chains are changing dramatically as the world economy becomes networked and the Internet and other emerging technologies are playing an important role in the interactions between members of the supply chain.

Figure 4, taken from [27], shows the extended supply chain where networks/technology/and the Internet are at the nexus of the vendor/retailer/customer triangle. The traditional domain of logistics and supply chain management has been

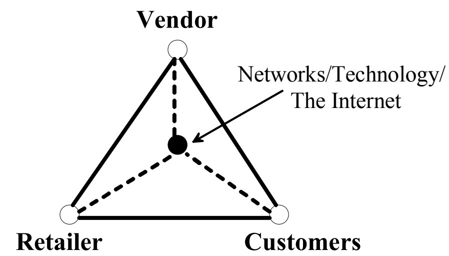

Figure 4. A networked, economy-induced supply chain [27].

the vendor-to-retailer link, which included topics like inventory control systems, category management, channel coordination, channel partnerships, and retailer networks. In the retailer-to-customer link, several new problems and research questions have arisen, which are managed with processes like data warehouses and loyalty programs, multiple selling channels, assortment planning, third party logistics intermediaries, and reverse logistics (which is the process of getting merchandise back through the channel). Finally, the growth of the Internet has expanded the research opportunities in the vendor-to-customer link and in supply chains in general, especially for cost reduction and service improvements [28]. Disintermediation, resulting from manufacturers selling directly to the ultimate consumer, has occurred with increased frequency and intensity as a result of the Internet. Also, manufacturers have an increased interest in and ability to strengthen their customer orientation [27].

8.2.6 Environmentally Conscious SCM

The supply chain contains the extraction of raw materials, manufacturing, distribution, and use of goods. Waste generated in each component on the supply chain is collected at the end of the chain. The emissions and waste of the supply chain are transported and transformed and result in water, air, and soil pollution with damaging effects to the environment. The amount of waste and emissions can be reduced with certain actions and changes within the supply chain. That is, new decisions are necessary to decrease emissions and waste flows. Legal requirements and changing consumer preferences increasingly make suppliers and manufacturers responsible for their products, even beyond their sale and delivery [29].

Figure 5 presents potential environmental actions in a supply chain. The first actions, such as waste treatment, have been effect-directed. Somewhat more integrated are waste-directed and emission-directed adaptations in technology, such as reuse of materials and packaging and recovery of products. The most integrated approach is source-directed and deals with adaptation of raw materials, product redesign, and process changes [29].

It is a fact that there is a growing attention for environmental issues in SCM during the last years, in concordance with the general shift from corrective policies towards prevention. This development has led to a close interaction between SCM and environmental management. In the majority of supply chain cases, environmental

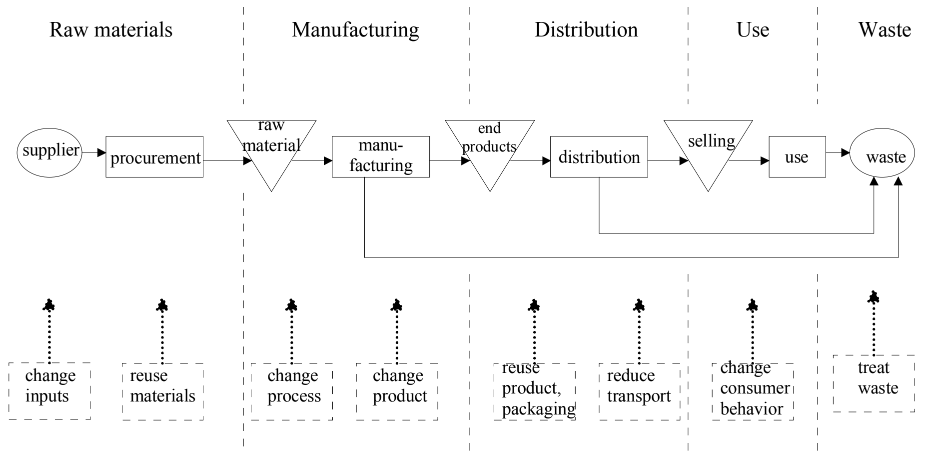

Figure 5. Environmentally conscious supply chain [29].

management is embedded into the general SCM scheme with appropriate actions that lead to environmentally conscious decisions and results. Moreover, these environmental actions are not taken at the end of the chain as correction measures, like some years before; they are now taken throughout the entire supply chain process, mostly as prevention measures.

8.2.7 SCM in Agribusiness

The first scholarly effort in the disciplines of marketing and logistics, which are parts of SCM, seems to be a report on the distribution of farm products [30] (cited in [27]). The design of supply chains of agricultural commodities like dairy products, fruits, and flowers can be complicated because in each link of the supply chain the quality of a product is influenced intentionally and unintentionally [31]. Agri-food supply chain managers must be concerned with control of food quality and safety and with the potential for weather-related supply variability. These concerns, unique to the food sector, may justify a different approach to supply chain management than the product-based approach suggested by general management theory [32]. Perishable products like food require a time-efficient supply chain, even if rapid delivery is costly.

The general members of a supply chain of a product are shown in Figure 6. Examples of members are factories, farmers, auctions, transporters, wholesalers, and retailers. In non-agri chains, the actions of each member of the chain modify the product characteristics in such a way that the product reaches the end user according to target specifications. During transportation and storage, basically nothing happens to the product states. In supply chains for agricultural products, however, a very important feature is product quality, which is continuously liable to changes. This continuous process is referred to as *quality development*, which can be slowed down or accelerated. Generally, changes are irreversible. Quality development of agricultural com-

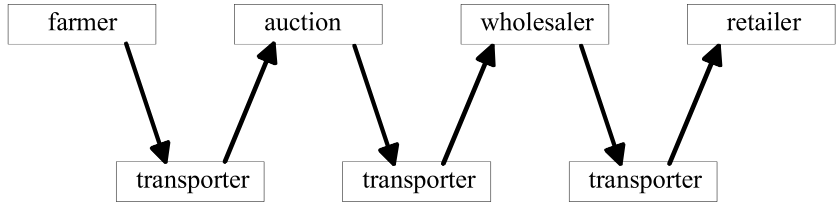

Figure 6. Example of members of an agri chain.

modities largely based on biological, physical, and chemical processes [33]. The following factors influence quality development [34]:

- *process conditions,* which are ambient conditions influencing product characteristics, such as temperature, relative humidity, light intensity, concentration of gasses and physical forces on the product;
- *throughput time* in a link during which the product is exposed to the process conditions; and
- *appearance state* of the product, such as packing and particle size.

The following three types of actions can be distinguished in agri chains [31]:

- *handling,* which are actions that intentionally alter or modify the appearance states of a product, e.g., wrapping, cutting, and labeling;
- *processing,* which are actions that intentionally alter or modify the quality states of a product, e.g., cooling and drying; and
- *transportation and storage,* which are actions that intentionally and unintentionally alter the quality states of a product.

The control of conditions during these processes can be costly. An additional difficulty is that in some cases, an action cannot be easily defined as one of the categories above. If there are models that describe the physical, chemical, and biological changes of the products due to specific process conditions and the associated costs, it is possible to optimize step-wise decision problems of agri chains, as it was done for example in [31], using dynamic programming.

In general, agribusiness research evolves along two parallel levels of analysis: the study of coordination between vertical and horizontal participants within the agri chain, known as agribusiness economics, and the study of decision-making within the alternative agri chain governance, known as agribusiness SCM [35].

As the agribusiness supply chain has become more complex, mainly by the increased liberalization of market policies and the globalization phenomena during the 1990s, its management requires advanced methodologies and strategies, even in developing countries. (For a collection of recent papers on agri-product SCM in developing countries, see [36].) If one also considers that in addition to economizing on transaction costs, other objectives like quality, screening, animal safety, traceability, and community development are emerging, then it is a consequence that new frameworks, such as networking models, system simulations, ecological footprinting, and reverse logistics, are necessary for the integrated management of agri chains.

Emerging Technologies in Agribusiness SCM

A variety of emerging technologies have transformed the way SCM operates in agribusiness. Information technology (IT) can provide information about a wide range of product attributes and is an effective and important way to coordinate activities in the supply chain [37]. Examples of IT methodologies are the electronic data interchange (EDI), such as EDI-pigs and EDI-flowers in the Netherlands, the identification and recording (I & R) systems of produce, and the quality assurance systems to assure quality of produce and, by doing so, improve competitiveness.

It has been suggested [38] that characteristics of agricultural products should be considered in decisions about IT-based coordination of the supply chain. The nature of the product being sold is the main characteristic of interest here, and more specifically, understanding whether the product is “functional” or “innovative” [32]. *Functional* products are those that have predictable demand. *Innovative* products are differentiated, have many varieties, and usually exhibit short lifecycles.

According to Fisher [38], the primary objective of SCM for a functional product should be the reduction of costs of the physical functions along the chain. Typical examples of IT for physical functions include the automation of ordering processes and payment mechanisms, scheduling of warehousing and delivery and control systems for quality assurance in production [32]. The SCM of innovative products should focus less on costs and more on delivering the attributes that consumers desire. The consumer demand is the primary factor that has to be analyzed and the choice of suppliers should be based on speed and flexibility. The problem with innovative products is that the companies that introduce them cannot know *a priori* their consumption rates, thus the ideal SCM is responsive. Major tools for this responsive operation are JIT production and systems that link orders to sales, in order to limit stockouts or overstocks, while IT systems that are usually used are scanner data collection and customer loyalty cards, which enable food retailers to understand and predict consumer desires.

Several IT systems are applied in agribusiness SCM cases in order to offer solutions in several food-specific issues. Food safety issues, for example, are very important in agri chains. Fast detection and response to food safety problems require the ability to trace back small lots, from retail to processor or even to the farm [32]. The solution is given by IT systems involving bar-coded products at all stages of processing. Another food-specific issue that can be managed by the implementation of IT systems in SCM is the supply variation due to biological cycles and weather conditions. This variation causes food input costs to vary, because raw material costs are not easily controllable and perhaps not even predictable. This supply unpredictability makes necessary for SCM to better understand commodity markets, using a variety of information sources [39]. Finally, the seasonality of agricultural production, particularly for crops, can affect SCM approaches. However, no amount of IT investment could eliminate the need for extensive storage of products [32].

E-commerce is a quite recent IT methodology in agriculture. It gained a great expansion with the development of the Internet. Common agribusiness transactions such as buying, selling, trading, delivering, and contracting seem to be natural targets for conversion to e-commerce [40]. The main theoretical benefits of e-commerce in agribusiness include promotion of information flow, market transparency and price discovery, facilitation of industry coordination, and reduction or elimination of transaction costs [41]. Internet-based e-commerce is a very recent phenomenon. Several Internet-based e-commerce business models exist: auctions, exchanges, and catalogs. Sachs [42] discussed the general barriers cited by businesses to Internet-based e-commerce adoption. Those include unclear return on investments, lack of stakeholder support, and complicated technology.

In summary, competitive advantages to the entire supply chain can be brought by the information generated by the use of appropriate IT systems in agri-food SCM, to the extent that information is shared. IT is a valuable tool for managing agribusiness supply chains that are capable of rapid response but of course it has its limits. However, the rapid development of IT and the Internet promises the minimization of those limits in the near future.

8.2.8 Traceability and Tagging Systems in Agriculture

The rapid development of agriculture during the last years, together with the dynamics of the global food system, have resulted in high demand for capturing and sharing information within the agri-food supply chain. This is achieved with the development of appropriate traceability and tagging systems. *Traceability* is the ability to track a product batch and its history through the whole production chain (or part of it) from harvest through transport, storage, processing, distribution, and sales *(chain traceability)* or internally *(internal traceability)* in one of the steps in the chain, for example the production step [43]. Traceability is a general concept and its fundamentals are independent of the type of product, production, and control system it serves [44].

Principles of Traceability Systems

Simple traceability systems existed from early times in the food industry. With the increasing implementation of Good Manufacturing Practice [45] and ISO 9000 quality management in food manufacture, traceability systems have become more advanced. They now cover more information and more steps in the production chain. The four fundamental features of traceability, according to [43], are:

1. *product,* which may relate materials, their origin, processing history and their distribution and location after delivery;
2. *data,* which relates calculations and data generated throughout the quality loop;
3. *calibration,* which relates measuring equipment to national or international standards, basic physical constants or properties, or reference materials; and
4. *IT and programming,* which relates design and implementation back to the requirements for a system.

According to [46], an integrated supply chain traceability system in agriculture and food business, must encompass the following features: product traceability, process traceability, inputs traceability, disease traceability, genetic traceability, and measurement traceability. The main concept of product traceability is the ability to identify products uniquely. This identification can be made by physical marking on the product or its package or by use of records [47]. The use of computers and IT enables a large amount of data to be handled, therefore traceability systems with very detailed information about both the product and its processing history can be developed.

Traceability can be distinguished in chain traceability and internal traceability. Chain traceability can be applied by managing information in two main different ways: (1) information can be stored locally in each of the steps in the chain sending only product identification information along with the product, and (2) information can follow the product all the way through the chain, something that is necessary if it is desired to bring information from early steps in the chain to the consumer or to advertise special features of a product. In practice, most information is stored locally and little follows the product. The advantages of chain traceability are that it [43]:

- establishes the basis for efficient recall procedures to minimize losses;
- provides information about the raw material that can be used for better quality and process control;
- avoids unnecessary repetition of measurements in two or more successive steps.
- improves incentive for maintaining inherent quality or raw materials;
- makes possible the marketing of special raw material or product features; and
- meets current and future government requirements.

On the other hand, internal traceability is performed within a step in the chain. Some advantages that can be drawn with this type of traceability are [43]:

- the possibility for improved process control;
- cause-and-effect indications when product does not conform to standards;
- the possibility of correlating product data with raw material characteristics and processing data;
- better planning to optimize the use of raw material for each product type;
- the avoidance of uneconomic mixing of high- and low-quality raw materials;
- the ease of information retrieval in quality management audits; and
- better grounds for implementing IT solutions to control and management systems, e.g., computer-based quality management systems, etc.

The establishment of internal traceability can be easy enough for pure batch processing, but it can be very difficult for continuous or semi-continuous processing.

Product Identification and Tagging Systems

Advances in geospatial science and technology [48] such as *remote sensing (RS)*, *geographic information systems (GIS)*, and *global positioning systems (GPS)*, can be used to collect site-specific data on individual animals, plants, soil properties, maturity, yield, and quality, as well as environmental and climatic data and to monitor animal movement and disease epidemiology. Grains and fresh products are generally handled in batches that may contain materials from different farms, particularly when the volume supplied by each individual farm is not sufficient to warrant a separate supply chain. Even so, it is possible to label each product or bag of grain so that it can be traced back to the origin [46].

Bar codes are the most common technologies for identifying raw food materials or finished products. In the livestock industry, ear tags are attached to the animal and the label on the tag may contain numbers or their combination with alphabets, which together contain information such as breed, date of birth, farm/paddock, movements, vaccinations, etc. When the animal is slaughtered, additional information may be added to the label, such as date slaughtered, time put in storage, and environmental conditions in storage. In addition to the information contained in the label, the farm record should also document the type and source of feed and other treatments and inputs used to raise the animals. Electronic identification tags are now available which can store large amount of data and also enable data on tags to be read automatically, without contact, using electronic card readers. These cards may be connected to a computer or downloaded later outside the measurement site.

A product can be identified by reading a tag attached to it, by recognizing it using image-processing techniques, or by looking it up from its position. These methods are described below.

Tags

If a product can be sufficiently close to a reader, then reading an identification tag attached to is often an efficient method. There are several tag technologies [49]:

- *Infrared tags*—The tag may be a low-cost, low-power infrared "active badge" worn by a person [50], or a "beacon" attached to a thing. These devices emit the identifier over IrDA, for reception by infrared-equipped devices including PDAs.
- *Optically sensed tags*—These include standard bar codes, already found on many everyday items, and symbols specially designed for easy capture with a digital camera, including "cybercodes" [51] and "glyphs" [52]. Bar codes can be printed and inexpensive readers are becoming available.
- *RFID tags*—Radio frequency identification (RFID) tags can be read at a distance and, since they operate by induction, require no power source of their own [53].
- *Contact tags*—iButtons (Dallas Semiconductor, http://www.ibutton.com) are read by electrical contact with their casing. Like RFID tags, they do not require their own power.

These tagging technologies have relative advantages and disadvantages in terms of cost and suitability for different physical environments. For example, sometimes reading at a distance is desirable (IR, RFID, glyph recognition); in other situations it is preferable that the user should bring the reader up close to make a definite and unambiguous identification, such as by scanning a bar code.

Computer Vision

Stereo computer vision—object recognition—may be used instead of tagging [54]. This has the advantage of eliminating the logistics of tagging but it has the disadvantage of requiring relatively powerful computing resources. Considerable work is needed before this method could be used routinely.

Positioning

In cases where objects move rarely or not at all, or are automatically tracked, a third means of identification is to use a positioning sensor to determine the product's coordinates, and so look them up in a database. By adding an electronic compass, we can also identify remote objects by pointing at them. The GPS is a widely available positioning system, but only outdoors. Short-range radio frequency (RF) triangulation may be deployed indoors or out. Ultrasound techniques can be incorporated for more fine-grained positioning, down to a few centimeters [55].

As the demand for high quality in agricultural products increases, traceability has become an important factor in global agribusiness trade, primarily because of the rising incidence of new regulatory food standards and the concern for environmental sustainability. Traceability enables full backward and forward identification of the product with respect to time and location in the supply chain and thereby facilitates cost-effective withdrawal of products when defects occur and when safety standards are violated [46]. Traceable chains are technology-intensive and information-driven. Current advances in computers and electronics (mechatronics) in agriculture and progress in geospatial science and technology tools for precision agriculture will facilitate successful integration of traceability into existing agricultural mechanization systems.

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