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A SIMULATION ENVIRONMENT FOR THE REDESIGN OF FOOD SUPPLY CHAIN NETWORKS: MODELING QUALITY CONTROLLED LOGISTICS

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ABSTRACT

Nowadays, many industries are confronted with intensified global competition as well as advances in information and process technology. They create both the need and opportunity for a coordinated approach of industrial partners to establish effective and efficient supply chains. Simulation tools are often used for supporting decision-making on supply chain (re)design, building on their inherent modeling flexibility. However, food supply chains set some specific requirements to simulation models. To address these demands a new discrete event simulation environment called ALADIN has been developed. It is based on a generic modeling framework that offers the analyst guidance in modeling, and provides model transparency to problem owners. An essential feature of the new tool concerns the integration of reusable process building blocks and quality decay models enabling "Quality Controlled Logistics". A case example concerning a supply chain for peppers is presented to illustrate the applicability and advantages of the tool.

1 INTRODUCTION

In recent years, Western-European consumers have become more demanding on food attributes such as quality guarantees, integrity, safety, diversity, and associated information services. At the same time, companies in the food industry are acting more and more on a global scale. This is reflected by company size, increasing cross-border flows of livestock and food products and international cooperation, and partnerships. Global competition together with the advances in information technology have stimulated industrial partners to pursue a coordinated approach to establish more effective and efficient supply chains, i.e., *supply chain management* (SCM).

Based on an extensive literature review (Van der Vorst 2000), we define SCM as the integrated planning, coordination, and control of all logistic business processes and activities in the supply chain network to deliver superior consumer value at less cost to the supply chain as a whole while satisfying requirements of other stakeholders in the supply chain (e.g. the government or NGOs). SCM should result in the choice of a *supply chain scenario*, i.e., an internally consistent view on how a supply chain should look like in terms of production and distribution processes and their coordination. This is not an easy task, because of a great variety of policies, conflicting objectives, and the inherent uncertainty of the business environment (Alfieri and Brandimarte 1997).

Food Supply Chain Networks (FSCNs) further complicate the redesign process due to specific product and process characteristics that increase decision-making uncertainty (Van der Vorst 2002). An essential product attribute is *product quality*. The way, in which product quality is controlled and guaranteed in the supply chain, is considered of vital importance for supply chain performance. Apart from being a performance measure of its own, product quality is directly related to other food attributes like integrity and safety. Furthermore, knowing product quality at all stages in the supply chain enables the use of a new concept called "Quality Controlled Logistics", that is, directing goods flows with different quality attributes to different logistical distribution channels (with different environmental conditions) and/or different customers (with different quality demands). In fact one of the keys to SCM for the food industry is an integrative view on logistics and product quality.

Although in a general sense, literature on SCM and SCM modeling studies is becoming comprehensive (see also the recent WSC conferences), several authors (Beamon 1998, Lambert, Cooper, and Pagh 1998, Gunasekaran, Macbeth, and Lamming 2000, Min and Zhou 2002, Gunasekaran 2004) state that there is a need for theory building and developing normative tools and methods for successful SCM practice. They mention in particular, the need for a modeling language for the description and dynamic analysis of supply chain scenarios, to support supply chain decision-making.

In many cases, *discrete event simulation* is a natural approach to study supply chains, as their complexity obstructs analytic evaluation, see e.g. Ridall et al. (2000) and Huang et al. (2003). However, simulation does not guarantee adequate decision support, i.e., feasible mutually accepted candidate supply chain scenarios for which a high performance is to be expected (Van der Zee and Van der Vorst 2005). After all, simulation is not an optimization tool, but assists in a human led search for good quality solutions. Therefore the success of a simulation study largely depends on the joint availability and use of the skills of the analyst and the chain members, as well as the facilities offered by the simulation tool.

In this paper, we will address the previously mentioned issues focusing on a transparent modeling process of FSCNs to support supply-chain decision-making. Specifically, we will introduce a new simulation environment called ALADIN (Agro-Logistic Analysis and Design INstrument). ALADIN is particularly designed to meet the specific modeling needs for the food industry. It does so, starting from a "user focus", i.e., a choice of concepts for modeling that appeals to both analysts and problem owners, while incorporating the specific characteristics of FSCN. Clearly, building such communicative models may contribute to better quality solutions (Balci 1986, Van der Zee and Van der Vorst 2005).

The remainder of the paper is organized as follows. First, in Section 2, we will discuss the essential characteristics of FSCN. In Section 3, we will review current simulation tools, starting from a survey of model capabilities essential for successful FSCN simulation. Next, in section 4, we will introduce the main features of ALADIN. In Section 5, we will present a case study to show the applicability and potential of ALADIN for SCM. Finally, in Section 6, we will summarize our main conclusions, and highlight directions for future research.

2 FOOD SUPPLY CHAIN NETWORKS

This section describes the essential characteristics of FSCNs, the specific process and product characteristics and lists generic FSCN redesign strategies.

2.1 Supply Chain Parties

The food industry is becoming an interconnected system with a large variety of complex relationships. This is reflected in the market place by the formation of (virtual) FSCNs via alliances, horizontal and vertical cooperation, and forward and backward integration in the supply chain (Van der Vorst et al. 2005; see figure 1). Each firm belongs to at least one supply chain in the network, i.e., it usually has multiple suppliers and customers. Supply chains are complex systems due to the presence of multiple (semi)autonomous organizations, functions, and people within a dynamic environment.

A FSCN comprises organizations that are responsible for the production and distribution of vegetable or animal-based products. In general, we distinguish two main types.

1. The FSCN for *fresh agricultural products* (such as fresh vegetables, flowers, fruit). In general, these chains may comprise growers, auctions, wholesalers, importers and exporters, retailers and specialty shops and their logistics service suppliers. Basically, all of these stages leave the intrinsic characteristics of the product grown or produced in the countryside untouched. The main processes are the handling, conditioned storing, packing, transportation, and trading of these goods.
2. FSCN for *processed food products* (such as portioned meats, snacks, desserts, canned food products). In general, these chains comprise growers, importers, food industry, retailers and out-of-home segments and their logistics service suppliers. In these chains, agricultural products are used as raw materials for producing consumer products with higher added value. In most cases, conservation and conditioning processes extend the shelf life of the agricultural and consumer products.

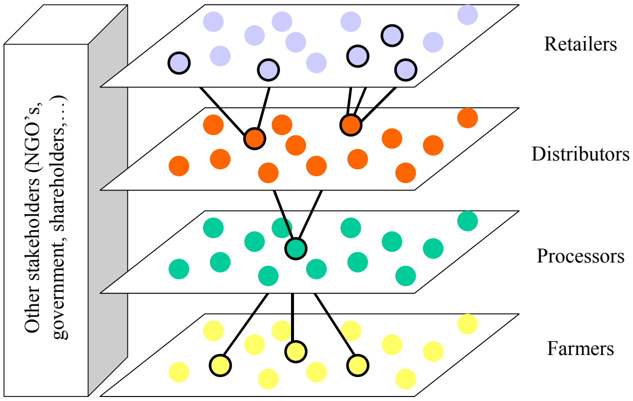

Figure 1: Schematic Diagram of a Supply Chain from the Perspective of the Processor (Bold Flows) within the Total FSCN (Van der Vorst et al. 2005).

2.2 Process and Product Characteristics

Den Ouden et al. (1996) and Van der Vorst (2000) give a list of specific process and product characteristics of agricultural FSCNs, including the following:

- Seasonality in production, requiring global sourcing.

- Variable process yields in quantity and quality due to biological variations, seasonality, and random factors connected with weather, pests, and other biological hazards.
- Shelf life constraints for raw materials, intermediates and finished products, and quality decay while products pass through the supply chain. As a result there is a chance of product shrinkage and stock-outs in retail outlets when product's best-before-dates have passed and/or product quality level has declined too much.
- Requirements for conditioned transportation and storage means (e.g. cooling).
- Necessity for lot traceability of work in process due to quality and environmental requirements and product responsibility.

Due to these specific characteristics of food products, the partnership thoughts of SCM in FSCNs have already received much attention over the past years. It is vital for industrial producers to contract suppliers to guarantee the supply of raw materials in terms of the right volume, quality, place, and time. Furthermore, they coordinate the timing of the supply of goods with suppliers, to match capacity availability. Actors in FSCNs understand that original high quality products are often subject to quality decay during their stay in the supply chain and that the degree of decay depends upon the environmental conditions. For example, exposing a batch of fresh milk to high temperatures for some time will significantly reduce product shelf life. Therefore, supply chain co-ordination is essential to eliminate such incidences.

2.3 Redesign Strategies for FSCN

The SCM literature suggests several strategic, tactical, and operational redesign strategies to improve the efficiency and effectiveness of supply chain processes. An extensive literature review by Van der Vorst and Beulens (2002) identifies a generic list of *SCM redesign strategies* to facilitate the redesign process and attain joint supply chain objectives:

- Redesign the roles and processes performed in the supply chain (e.g., reduce the number of parties involved, reallocate roles such as inventory control, and eliminate non-value-adding activities such as stock keeping).
- Reduce lead times (e.g., implement information and communication technology (ICT) systems for information exchange and decision support, increase manufacturing flexibility or reallocate facilities).
- Create information transparency (e.g., establish an information exchange infrastructure in the supply chain and exchange information on demand/supply/ inventory or work-in-process, standardize product coding).
- Synchronize logistical processes with consumer demand (e.g., increase execution frequencies of production and delivery processes, decrease lot sizes).
- Coordinate and simplify logistical decisions in the supply chain (e.g., coordinate lot sizes, eliminate human interventions, introduce product standardization and modularization).

The above strategies address the general case of SCM. Specifically, for FSCN we can add the redesign strategy to alter the environmental conditions, under which products are (re)packed, stored and transported, in order to improve on food quality. This will result in longer shelf lives, and therefore, provide room for the introduction of innovative logistical concepts.

3 MODELING REQUIREMENTS FOR FSCN

In the previous section we characterized FSCNs in terms of parties involved, processes, products and alternative strategies. Let us now relate these characteristics to requirements to be set on simulation models. We distinguish between requirements that address the general case of SCM and requirements that are specific for the food industry. An overview of these requirements is meant to (i) support our review of current tools for supply chain simulation, and (ii) structure our discussion on the new tool, see Section 4. We conclude this section by stating our research contributions.

3.1 General Requirements on Supply Chain Modeling

A typical supply chain involves multiple (semi)autonomous parties, who may have several, possibly conflicting, objectives. SCM requires, among others, the alignment of partner strategies and interests, high intensity of information sharing, collaborative planning decisions and shared ICT tools. These requirements often represent major hurdles inhibiting the full integration of a logistics chain. Even when there is a strong partnership among logistics nodes, in practice, there are potential conflict areas, such as local versus global interests, and a strong reluctance of sharing common information on production planning and scheduling, such as, for example, inventory and capacity levels (Terzi and Cavalieri 2004). SCM requires *trust* and in-depth insight into each other's processes, which is difficult, since the widely followed competitive model suggests that companies will lose bargaining power, and therefore the ability to control profits, as suppliers or customers gain knowledge (Barratt and Oliveira 2001).

The previous characteristics make clear that an active participation and cooperation of all members are essential ingredients for the success of supply chain modeling. Even more since the complexity of the system and the solution space in terms of the number of alternative chain scenarios are significant. Basically, the members' efforts should result in credible models, active support in the search for better solutions, and last but not least, *acceptance of solutions*. In order to do so, high demands are set on model transparency and completeness. Transparency refers to the insight into model components and their workings, whereas completeness addresses a full overview of design parameters. This results in the following demands, classified by model elements and their relationships, model dynamics, user interface, and ease of (re)use (Van der Zee and Van der Vorst 2005):

1. *Model elements and relationships*: Supply chains assume an integrated approach to physical transformation, data processing, and decision-making. Especially, the allocation of control policies to specific supply chain members, and relationships, such as hierarchy and co-ordination, deserve explicit attention as decision variables. This requires the explicit notion of actors, roles, control policies, processes, and flows in the model.
2. *Model dynamics*: The control of dynamic effects within the supply chain, as reflected in e.g. stock levels, lead times and product quality, is an important issue given the many parties involved. Therefore, the logistics of control, i.e. the timing and execution of decision activities, should be explicit. This requires the ability to determine system state, calculate the values of multiple performance indicators at all times, and even more important, allocate performance indicators to the relevant supply chain stages.
3. *User interface*: The active and joint participation of the problem owners, i.e., the supply chain partners, in the simulation study is required for two reasons (Hurrion 1991, McHaney and Cronan 1998, Bell, Anderson, Staples, and Elder 1999, Robinson 2002). First, as a means to create trust in the solution and among the parties involved, so there is a better chance of acceptance of the outcomes of the study. Second, the quality of the solution may be improved. This refers to model correctness as well as the quality of the chain scenario. Clearly, it is almost impossible for the analyst to have all relevant information on chain dynamics. Therefore, the contribution of the problem owner in terms of alternative solutions is vital to the success of the project.
4. *Ease of modeling scenarios*: Given the complexity of the supply chain, the large number of conceivable scenarios, and the wishes and requirements of the problem owners, "what if" analysis should be transparent. This concerns both the choice of building blocks and the time required for tailoring them to the right format for model adoption. Another demand is model reuse, because of the combination of volatile business environments and the major modeling efforts required. Reusable models may help to increase the speed of modeling and analyzing alternative scenarios, while reducing costs of decision support.

3.2 Specific Requirements on Modeling FSCN

Next to the general requirements on modeling, a number of additional, more specific, requirements for modeling FSCNs should be mentioned. This holds especially true for the model elements and relationships and model dynamics.

First of all, *the model should allow for the trade off between logistical costs, service, and product quality indicators.* Ideally, the agreement on a FSCN scenario is reached based on the evaluation of the consequences of key performance indicators for the FSCN, given the restrictions set by the available resources (Beamon and Chen 2001, Kleijnen and Smits 2003). *Performance indicators* are variables indicating the effectiveness and/or efficiency of a part of or the whole of the processes or systems compared with to a given norm/target or plan (Fortuin 1988). Whereas traditional performance measurement systems are based on costing and accounting systems, measuring performance in FSCN requires a more balanced set of financial and non-financial measures at various points along the supply chain (Lohman et al. 2004). The choice of performance indicators will typically reflect a balancing of investment and operational costs, and customer service in terms of on-time delivery and product quality.

Second, the modeling requirements on performance indicators puts additional demands on modeling elements and dynamics. One of the current top priorities of food retail organizations is the improvement of product availability in retail outlets via the reduction of stock-outs and product waste / shrinkage (i.e. products that have to be disposed of, because its best-before-date has passed). *Quality preservation is therefore a major issue in FSCN, which can be improved via the use of sophisticated environmental conditioning techniques (in transport and warehousing) and the reduction of lead times.* Model elements and dynamics should incorporate these specific characteristics of FSCN, especially the shelf life constraints for products and the occurrence of quality decay while progressing through the supply chain under specific environmental conditions.

Third, the model should be able to deal with the aspect of uncertainty. FSCN deal with biological products that are not homogeneous in product quality and yield. *Control policies in the model should be able to distinguish between batches with different characteristics and make (logistical)* *decisions based on this information.* This will allow for "Quality Controlled Logistics".

3.3 Review of Simulation Tools

In the past, many simulation tools for supply chain analysis have been developed. Van der Zee and Van der Vorst (2005) present a literature review in which they assess the modeling characteristics of these packages given the previous requirements on FSCN modeling. They conclude that current simulation approaches cannot fully cope with the demands on model and tool design for supply chain analysis. Most approaches lack a common *modeling framework*, i.e., a well-defined conceptual view of the field.

Model building is often guided by the analyst's mental reference models and the library of building blocks offered by the given simulation language (see Figure 2). The danger is that key decision variables are left implicit for all or some of the parties involved. An intrinsic weakness of many simulation models and tools is the *lack of explicit modeling of control structures,* i.e., the managers or systems responsible for control, their activities and their mutual attuning of these activities. Most, tool facilities strongly focus on physical transactions, leaving the definition of control structures largely to the analyst. As a net result, control structures are often "hidden", as the analyst's choice of building blocks does not appeal to supply chain partners or because its elements are dispersed all over the model. Clearly, because control structures are intrinsic to SCM, ignoring them may severely harm the quality of decision-making.

Typically, a *modeling framework* would capture essential elements and relationships as well as their dynamics. Such a framework should underlie the library of building blocks of the simulation tool and the mental models of the analyst and the problem owners. The need for such a framework is also acknowledged in the surveys by Beamon (1998), Lambert et al. (1998), Gunasekaran et al. (2000), Min and Zhou (2002), and Gunasekaran (2004). They mention in particular a modeling language for describing and/or dynamic analysis of supply chain scenarios to support supply chain decision-making.

Furthermore, a literature review revealed no simulation tool that deals explicitly with the modeling of specific characteristics of FSCN as discussed in section 3.2. More in particular, the combination of the modeling of logistics processes and product quality degeneration is lacking, preventing the integrated trade-off between both aspects in alternative FSCN scenarios.

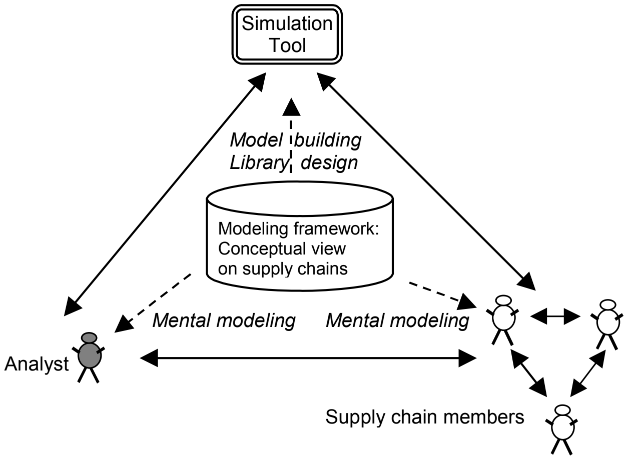

Figure 2. Position of a Modeling Framework (Van der Zee and Van der Vorst, 2005).

3.4 Research Contributions

By introducing the new simulation tool ALADIN, we strive to extend possibilities to use simulation tools for modeling and analyzing alternative FSCN scenarios. More specific, the tool especially addresses:

- the explicit modeling of control structures, and
- the explicit modeling of product quality decay.

The inclusion of the latter feature allows for an integrative view on logistics and product quality enabling 'Quality Controlled Logistics". This enables building higher quality simulation models with respect to transparency and completeness, which enables improved decision support.

4 SIMULATION ENVIRONMENT: ALADIN

In this section we introduce the simulation environment ALADIN in terms of its library of model elements and their relationships guided by the essential qualities of a simulation model, as discussed in Section 3. In the next section we will consider use of the tool in a case study.

4.1 General Description

ALADIN is a visual interactive simulation environment that contains the fundamental modeling components to model the dynamic behavior of FSCN as discussed in the previous section. It is a specific application based on the Logistics Suite of the simulation package Enterprise Dynamics ^{TM}.

4.2 Model Elements and Relationships

Supply chain models are composed of a reusable set of software components (building blocks) that represent types of supply chain entities (e.g., retail outlets, transportation, warehouses, producer), their control policies (e.g. inventory policies, routing policies), and their interaction protocols, i.e., message types that regulate the flow of information, goods, and cash. Besides these supply chain building blocks, ALADIN's core consists of quality decay models. These models describe quality behavior, from say apples to roses, under specified conditions (temperature, relative humidity, modified atmosphere, etc.). They incorporate parameters that reflect stochastic biological variations in product quality decay and are developed by experts in lab-experiments under controlled conditions. Alternative designs of fresh product supply chains (see the redesign strategies in section 2.3) can be simulated, visualized, and analyzed. ALADIN adds the indicator product freshness (remaining shelf life and product waste) to classical performance indicators such as transportation costs, stock levels, and delivery reliability. In this way, ALADIN helps the decision maker, to trade off logistics costs and service (product quality and availability), when assessing specific (re)designs of the FSCN.

ALADIN is based on three key concepts: agents, jobs, and flows. *Agents* represent supply chain entities (such as planners, production departments, and distribution systems) as autonomous objects that are assigned decision-making intelligence. In ALADIN, specific agents have been developed, see Table 1. By introducing a demand controller in ALADIN, physical and information and control layers can be separated (Figure 3). In this way, model transparency is increased, as discussed in Section 3.

Table 1: Specific Agents in ALADIN

Agents	*Representation*
Production unit	Food factory or a grower, who produces products with biological variation in quality and quantity (seasonality).
Transportation unit	Climate controlled truck or vessel with specific temperature and modified atmosphere settings.
Storing and distribution unit	Warehouse or retail outlet with specific climate control characteristics.
Demand unit	Market place with demand for products with specific shelf lives, colors, etc.
Food product	Specific food product (e.g. pepper, cut vegetable) with its specific quality decay model related to the settings of environmental conditions in time.
Demand controller	Explicit modeling of information flow and decision-making activity that activate the goods flow.

All chain activities are defined as *jobs*, including activities related to decision-making. Where physical jobs result in goods, control jobs result in job definitions for agents in the controllers' domain of control. *Flow items* (business entities) constitute the movable objects within a supply chain. We include four types of flow items in the modeling framework: product flows, information flows, resources that facilitate the transformation processes (assignment of capacity), and job definitions. Job definitions specify a job in terms of e.g. its input, processing conditions and the agents to whom the resulting output should be sent.

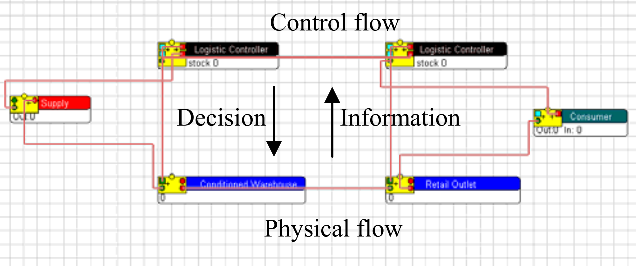

Figure 3: ALADIN improves Modeling Transparency by making a Distinction between the Physical Distribution Flow and The Control Flow.

4.3 Model Dynamics, User Interface and Ease of Modeling

Model dynamics is realized by job execution. We capture the dynamic behavior of the chain processes by modeling the FSCN as a network of agents, jobs, and flows with precedence relationships; the jobs can be triggered by multiple causes and have processing times that depend on the entities processed and available resources. This includes the calculation of (variations in) product qualities related to the specific conditions to which the products have been exposed.

In our choice of concepts we tried to adopt basic logistic terminology and developed recognizable building blocks jointly with the problem owners. Together with our explicit choice and representation of decision variables appealing to the problem owners, we improve the visibility of the supply chain processes. This also increases the model's transparency and acceptance of solutions by the supply chain members.

The specific agents that are built in ALADIN are designed after detailed case analyses. They provide the modeler building blocks that can be reused in an efficient and effective manner. Apart from the modeling efficiencies in terms of re-use, readability, and maintainability, it facilitates a natural one-to-one mapping of real world concepts to modeling constructs, see e.g. Kreutzer (1993).

4.4 Applications of ALADIN

ALADIN represents a flexible and reusable modeling and simulation environment that enables rapid development and customized decision support tools for SCM. Typical case examples of ALADIN are:

- *Designing logistics networks*. Comparing transport by sea and air under different environmental conditions for the export of fresh products such as peppers and tomatoes. And comparing storing fresh products in regional distribution centers to direct or cross-dock delivery. What are the consequences for the remaining shelf life of the product at the retailer?
- *Decreasing fresh product waste*. Most retailers have significant amounts of product losses, caused either by passing product's best before date or by crossing other acceptance limits of customers, e.g. coloring, or loss of firmness. Product waste can be reduced in several ways. For example, by increasing the initial product quality, by applying chilled conditions at the store, or by changing ordering behavior. ALADIN helps to analyze which type of improvement has maximum benefits (bottleneck analysis).
- *Analyzing quality controlled logistics*. Retail outlets may differ with respect to the turnover of fresh products such as meat. In order to minimize product losses, distributing different remaining shelf lives (best before dates) to different retail outlets (with different quality demands) could be a rational approach.

In order to demonstrate the capabilities of ALADIN, we discuss a case study in the next section.

5 CASE STUDY: PEPPER SUPPLY CHAIN

We used ALADIN for modeling and simulating alternative scenarios for the export of Dutch peppers to the USA. The export of peppers from the Netherlands to the USA amounts to about 20.000 tons each year. Much of these peppers reach the USA by costly air transport. This is caused by the fact that so far alternative ways of transport, like over sea, resulted in significant quality decay and product shrinkage, due to lengthy lead times.

Dutch growers and exporters aim to reduce shrinkage and stock-outs in retail outlets in the USA at preferably lower total chain costs, as this would boost sales and profits for all chain participants. Temperature and relative air humidity are important determinants for pepper product quality. Major developments in quality preservation via the use of modified atmosphere packaging and sophisticated chilling techniques provide challenging opportunities to use other logistic concepts. Could transport by sea now be an option?

To study this question a project group was formed that included all supply chain members. The members concerned pepper growers, harbors where products are (un)loaded, exporters and importers, and retailers with multiple retail outlets (Figure 4). Together they identified several alternative FSCN designs.

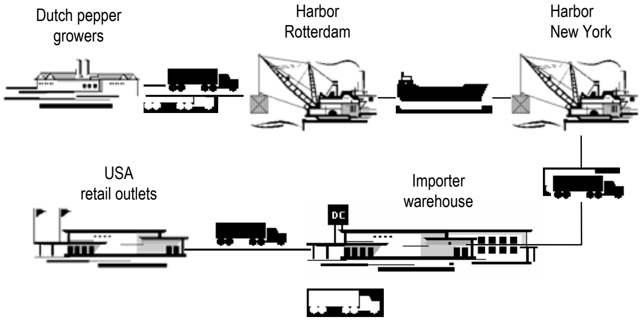

Figure 4: The Supply Chain of Peppers.

Via an iterative process, the scenarios were analyzed. It resulted in the identification of a number of important *design variables*, such as mode of transport, packaging materials, delivery lead-time and frequency, inventory control policy, and order batch size. Each of these factors can be changed to improve supply chain performance. To measure the effectiveness and efficiency of alternative designs, the project team formulated a number of *key performance indicators* for this FSCN, such as logistics costs, stock-outs, product shrinkage, and remaining shelf life.

The project team focused on answering the following research questions:

- Can we extend the shelf life of products in the FSCN of peppers and reduce costs, shrinkage and stock-outs using innovative logistical concepts (other transport modes, distances, control policies, ordering batch size, etc.)?
- What is the potential of Quality Controlled Logistics, using quality decay models to direct flows with different quality attributes to different retail segments (that demand different quality levels)?

To answer these questions, we have to incorporate the statistical (biological) variation in initial product quality and environmental conditions (temperature, humidity) during transport and warehousing.

We modeled this supply chain in ALADIN. As stated before, one of the control policies in the model is the possibility to redirect goods flows to different customers, depending on the quality of the product at a specific stage in the supply chain. For example, in the simulation model the importer can predict the expected remaining shelf life of the peppers via the quality decay models and the collected data on the environmental conditions during the supply (Figure 5). With this information he may decide to ship (part of) a batch with high quality products to a customer who appreciates those products, and the other part with low quality products to customers who demand peppers of reasonable quality at lower cost. Another policy is to decide to ship the products that have the lowest shelf life first (*first-expired-first-out*) instead of using the traditional first-in-first-out principle. The use of historical information related to influencing factors of product quality provides means to control goods flows through the supply chain.

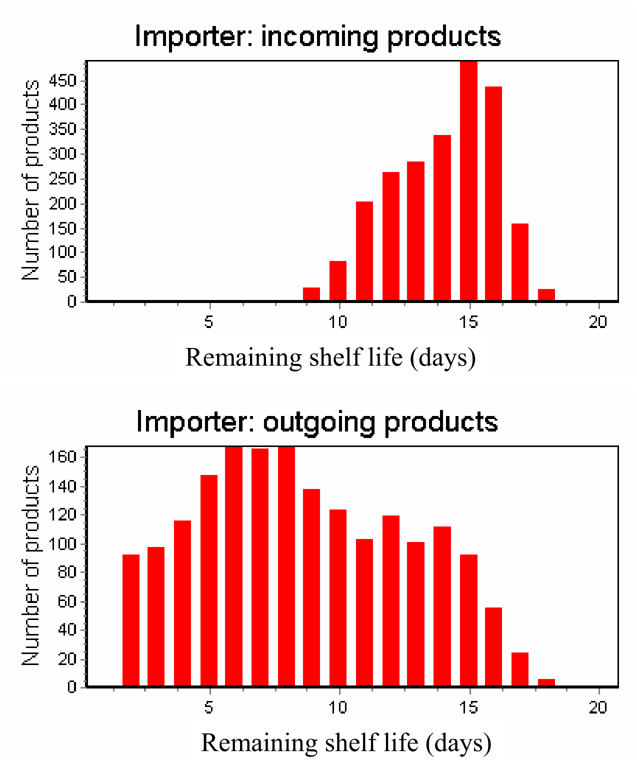

Figure 5: Overview of Variation in Product Quality at the Importer Warehouse. ALADIN allows modeling Product Quality Decay along the Distribution Chain, which enables "Quality Controlled Logistics".

We will not detail the results of the different FSCN scenarios, as we just intend to show the capabilities of the tool. In general, the main results are:

- New packaging and processing technologies provide opportunities to improve chain performance, using innovative logistics concepts. Due to the longer shelf life and quality controlled logistics, peppers can be transported by sea at low cost instead of using expensive and environmentally unfriendly air transport.
- Steering the logistics flows through the FSCN using quality-oriented data can lengthen the shelf life considerably, and reduce shrinkage at importers and retail outlets by 25%.
- Profits caused by reductions in shrinkage fully compensate the costs of technological innovations to managing environmental conditions.

Let us address the added value of ALADIN for supply chain modeling and analysis. Firstly, the integration of facilities for modeling product quality and product logistics provides an improved means for analyzing FSCNs. Instead of studying effects of alternative scenarios on product quality and logistics using separate tools, now only a single tool is needed allowing the studying of interaction effects (see Figure 6). This enables Quality Controlled Logistics, that is, control policies in the model are able to distinguish between batches with different characteristics and make logistical decisions based on this information.

Furthermore, the fundamental modeling components of ALADIN as discussed in section 4 (in particular the explicit distinction between the physical goods flow and the control flow) provided excellent communicative means to problem owners and reduced modeling efforts significantly. Obviously, all these aspects not only contributed to the quality of solutions, but also to the speed of decision making, and the acceptance of solutions.

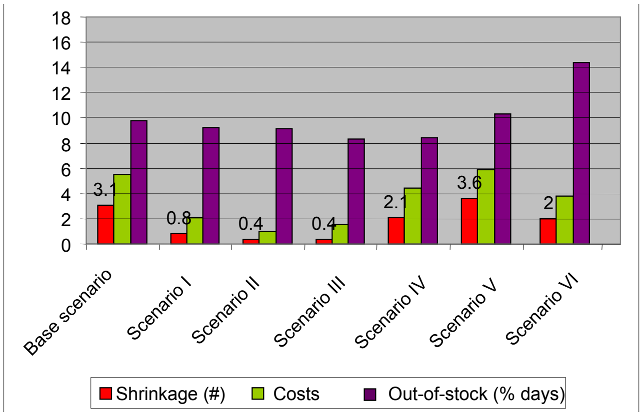

Figure 6: Example of Output Data on Shrinkage, Costs and Stock-outs of Multiple Scenarios.

As we discussed in section 3, acceptance of solutions is related to developing trust among partners. On the other hand, the quality of solutions strongly depends on active involvement of chain members in modeling and analyzing alternative scenarios (see also Van der Zee and Van der Vorst, 2005). The main cause for this is system complexity. In both cases, the extent to which oversight over and insight in candidate decision variables and their settings is obtained by all parties involved is crucial for success. In this respect visual interactive simulation tools turned out to make important contributions as a communicative means. Members of the FSCN got more insight in all processes and were able to follow the modeling process, which significantly improved the discussion about and acceptance of solutions. An important reason for this is model structure, making models not only transparent for the analyst, but also for the supply chain members.

6 CONCLUSIONS

The ultimate success of supply chain simulation is determined by a combination of the analyst's skills, the chain members' involvement and the modeling capabilities of the simulation tool. This combination should provide the basis for a realistic simulation model, which is both transparent and complete. The need for a modeling framework and model transparency is especially strong for FSCNs since they have a number of specific characteristics that put specific demands on modeling these kind of object systems.

In this paper we introduced a discrete event simulation environment called ALADIN. It specifically addresses the modeling and analysis of FSCN. Specific strengths of the tool relate to:

- The integration of logistics modeling and quality decay modeling. The presence of these models make it possible to use simulation for trading off supply chain performance with respect to both logistics and food quality, thereby enabling the modeling and simulation of the concept of "Quality Controlled Logistics".
- The explicit modeling of control structures. Rather than relying on the implicit mental reference models of the analyst and the availability of standard building blocks in the library of Enterprise Dynamics, new building blocks were developed in ALADIN to offer the analyst guidance in modeling specific FSCN. This provides communication means via an explicit and well-defined notion of concepts, and helps in reducing the modeling efforts of the analyst, because of the possibilities for reuse of model classes, i.e., agents, flow items and jobs.

ALADIN's core consists of the combination of reusable process building blocks and quality decay models that facilitate the modeling of FSCN. As such, it contributes to improved decision-making with respect to FSCN design. This has been demonstrated by a case example concerning a pepper supply chain.

Future research will focus on the further development of ALADIN to incorporate more aspects of FSCNs in the modeling process (new building blocks and performance indicators, such as sustainability) and to extend the development and application of the modeling framework concepts in ALADIN. Furthermore, we are researching a promising possibility to transform ALADIN into a gaming/training tool that enables managers to evaluate alternative decision making scenarios in FSCNs on multiple performance indicators, such as costs and product quality.

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