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Information Modelling for Quality and Sustainability

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Abstract

The food sector is confronted with a growing number of public and private requirements, which call for provision of information about the quality and sustainability of food, such as, e.g., its origin, safety and production conditions. This forces enterprises to innovate towards demand-driven and knowledge-based production of food. As a consequence, intra- and inter-enterprise production and information processes have to be integrated and suitable information systems need to be developed to provide information for related decision processes. The present paper introduces a generalized modelling framework for model-based decision support systems (DSS) involving production and information processes across whole supply networks. The different phases of a decision process are supported by the integration of functional, behavioural and informational network models using the Unified Modeling Language (UML) and discrete-event simulation.

Keywords: *Supply chain management, Model-based decision support systems (DSS), Process integration, Unified Modeling Language (UML), Discrete-event simulation*

1. Introduction

During the last decade, consumers in industrialized countries have increasingly raised concerns about food quality, food safety and the sustainability of food production. These concerns, particularly due to sector-wide crises caused by animal diseases (e.g. BSE, swine fever, foot-and-mouth disease and avian influenza) or food contaminations (e.g. dioxin), have initiated increasing consumer interest in the origin, safety, quality, and production of food (Van Plaggenhoef et al., 2007) and, in turn, on the availability of related information and guarantees. Public authorities at national and international levels have reacted by setting up new regulations on the safety and quality of food products, such as the European Union's General Food Law, or by establishing new agencies with food safety responsibilities, such as the European Food Safety Authority (EFSA) (Krieger et al., 2008). Apart from developments in regulatory activities, enterprises in the agri-food sector and especially those in countries with abundance of food usually follow additional non-regulatory food safety and quality assurance schemes that reach beyond compliance with legal requirements to better meet the expectations of their customers and to avoid reputational disasters (Havinga, 2006).

Variations and differences in the food safety and quality interests of regulatory authorities, of enterprise customers at various stages along the food value chain, and of consumers as the final customers may result in a wide range of possible alternatives in the organization and control of processes for food safety and quality assurance an enterprise might have to choose from.

Specific requirements on the implementation of organizational alternatives and controls are frequently clustered as quality assurance schemes. These schemes are usually not static in content but follow their own dynamics in the consideration of requirements. They represent certain levels and ranges of requirements on food safety and quality assurance activities (Krieger et al., 2007). Some of the schemes focus on individual stages of the supply chain only. Examples involve the schemes GlobalGAP which deals with agricultural production or IFS which has its focus on suppliers of retailer enterprises. However, the majority involve requirements for different stages of the supply chain supporting food safety and quality assurance guarantees throughout the chain (Krieger & Schiefer, 2004; Luning et al., 2004).

Whatever the enterprise focus of regulations or food safety and quality assurance schemes, they eventually aim at serving consumers' needs, requiring a demand-driven and knowledge-based production activity along the whole food production value chain (Wolfert et al., 2007). In an open network environment with changing supplier-customer relationships as is the rule and not the exception in the food sector, the multitude of alternatives and the interdependencies between enterprises along the value chain pose a challenge for enterprise decision activities and the design and organization of information systems that could serve the decision activities and allow the appropriate formulation and communication of food safety and quality guarantees along the value chain and towards the consumer. The complexity of the situation is further aggravated by the fact that network activities might not only involve vertical supply chain relationships but horizontal trading activities (Ménard, 1996; Steven, 2005).

As decision processes towards improvements in food safety and quality need to deal with the organization and control of processes along the food value chain, information systems for decision support need to:

a) build on information from intra- and inter-enterprise production processes and their organization and control,
b) link them with needs of decision processes towards improvements in food safety and quality through improvements in the organization and control of processes, and
c) eventually provide the appropriate information that supports the delivery of food safety and quality guarantees.

Within this integrated view, decision processes in enterprises do not only have to deal with the complexity of decision problems (Beulens & Scholten, 2001) but with deficiencies in the information base (Van der Vorst & Beulens, 2002), leading to sub-optimal decision-support and, in consequence, to a sub-optimal decision activity (Wolfert et al., 2007). In the agri-food sector, the integration is not yet well established. Available software solutions for decision support do not adequately represent the intra- and inter-enterprise processes and the information processes based on their organization and control. This describes the modelling challenge, which is scarcely discussed in literature (Jero, 2009).

The modelling challenge is aggravated by some additional complexities. One is due to the fact that requirements on food safety and quality might not only involve process characteristics that are well-defined and accountable at every stage of the food value chain but also process characteristics, such as, e.g. animal welfare, which might not be directly related to well-defined process characteristics and, in addition, could not be linked directly to measurable product characteristics at the final product (Schiefer, 2002). Such requirements need to be linked to process or product characteristics that are accountable and could act as signals for fulfilment of requirements or to virtual information labels (guarantees) attached to processes and products.

Furthermore, as the food sector is characterized by the existence of a high percentage of small and medium-sized enterprises (SMEs) (Fritz & Schiefer, 2008) the linkage between information systems needs to be flexible to allow for different and changing trade relationships and, in turn, different and changing information scenarios (Wolfert et al., 2007).

The focus on food safety and quality is a base on which a wide variety of requirements on sustainability, involving economic, social, and environmental needs can build. Food safety is usually linked to social needs, food quality to economic considerations. The determining factor is the link with process activities.

It is the objective of this paper to develop a generalized modelling framework for model-based decision support in the agri-food sector that links process characteristics and decision activities on the improvement and guarantee of food safety and quality (or other sustainability characteristics with a similar process based view) through an appropriate organization of information system activities that include the collection of information and its organization and appropriate processing through 'applications', usually represented through software solutions. The framework supports the different steps of a decision process by integrating production and information process models throughout the supply chain on the basis of chain and sector requirements.

The models promote process integration on an intra-enterprise level to overcome fragmentation between organizational units and systems, and on an inter-enterprise level to move towards an integrated enterprise in a multi-dimensional network.

The following chapter (chapter 2) introduces into the modelling challenge through a discussion of the characteristics of a decision process and the information flows that potentially could provide support. Chapter 3 introduces into the state of the art in business process modelling which integrates production processes with information processes to support decision activities in the determination of appropriate process organizations and process controls. This is the basis on which in chapter 4 an integrated modelling framework for decision support in the organization and control of processes in agri-food networks can build. Chapter 5 concludes the discussion with a suggestion for further research needs.

2. Decision making and decision support

Decision making in business environments is a complex process involving available information and unstructured, fuzzy reasoning procedures of the decision maker (Drucker et al., 2001). Decision making is highly complex as it needs to take into account (Hammond et al., 1998):

a) uncertainties regarding future developments in the business environment (scenarios);
b) uncertainties regarding the behaviour of actors that might influence the effects of own decision activities;
c) consequences of different decision alternatives including potential risks and expected gains related to the various scenarios.

Levels of decision making in an enterprise can be classified into an operational level, a tactical level and a strategic level. These levels can be defined as follows (Ingalls & Kasales, 1999):

a)operational level: short time horizon with a limited scope; resources and demand are fixed or known; variation, though critical, can usually be dealt with an exception;
b) tactical level: time horizons are longer, up to several months; the range of resources is expanded and demand forecast is difficult;
c) strategic level: time horizons are even longer, up to several years; strategic plan is developed at an aggregated level; decision making is difficult because customer demands are uncertain.

Decision making processes can be structured into several phases, which represent the principle activities of decision making (Drucker et al., 2001; see figure 1). Actual decision activities may involve a variety of feedback loops depending on outcomes of individual phases.

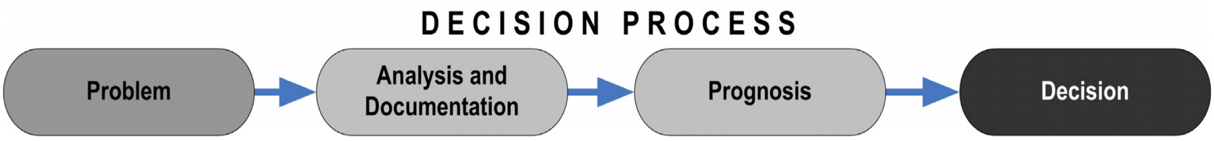

Figure 1. Decision process phases

Each phase of the decision making process needs specific information for support. However, in a network scenario, sources for information are often widely spread involving not only the enterprise a decision maker is linked with but enterprises throughout the network. Davenport and Short (1990) link information sources to business process activities defined as sets of logically related tasks performed to achieve a defined business outcome. In this view business process activities build on a combination of production and information processes where the emphasis may be on one or the other depending on the type of resources (physical or informational; Kim & Rogers, 2005) that are being processed (Luo & Tung, 1999). Within as well as between enterprises, both types of resources are dynamically interacting, which makes an isolated analysis for decision support impossible (Kreische, 2004).

As production processes of each actor of a supply network generate information, information may have a stage-specific character, corresponding to the managerial requirements to be performed at that stage (Turban et al., 2004). Information management within enterprises deals with this information by conceptualizing, developing, introducing, maintaining and utilizing systems for processing of this information (Wigand et al., 2003) and has the objective to effectively (usefully) and efficiently (economically) make use of this information (Picot & Reichwald, 1991).

In agri-food supply networks, some elements of stage-specific information are relevant for actors on other stages, some even for consumers. As a consequence, inter-enterprise information management is necessary for decision support. Moreover, enterprise focused information systems in the agri-food sector are complemented by network or sector focused information systems targeting at traceability and quality (Schiefer, 2006) as well as on food safety, logistics and sustainability (Lehmann et al., 2009a). Among these different systems, information exchange occurs, which can be subdivided into:

a) information exchange among intra-enterprise information systems (vertical and horizontal network dimension),
b) information exchange among intra-enterprise information systems and network/sector focused information systems, and
c) information exchange among network/sector focused information systems.

As a consequence, information can be used by multiple actors during the decision making process, either directly or indirectly. However, in the reality of food supply networks, decision making is aggravated through the fact that information sources are both widely spread and not specifically set-up for supporting a decision making process. Figure 2 illustrates intra-enterprise and network/sector focused information systems in a food supply network as well as an exemplary information exchange among these systems.

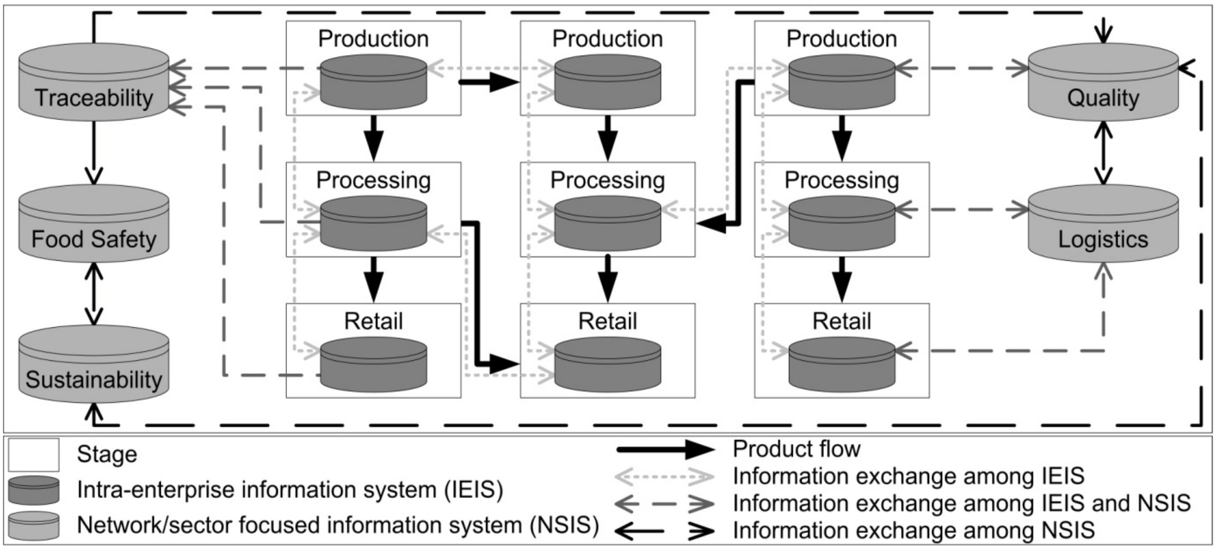

Figure 2. Principle information systems in food supply networks and information exchange

3. State of the art of business process modelling

Any business process model is an abstraction of real processes and allows for analysis and documentation of processes regarding one or more objectives. In most cases, reality consists of much more elements, dependencies and exceptions than included in the model as these are mostly not important for the modelling objectives. A formal model is a set of objects represented according to well-defined rules; it provides advantages with regard to analysis, documentation and communication, in particular as opposed to natural language. E.g., in natural language, it is difficult to analyze processes using different perspectives in a comprehensible way and gathered information is often inconsistent. A model, however, connects the single elements following a clear structure and allows for organizing information at different levels of abstraction. The use of graphical models such as diagrams is often supported by modelling tools. In addition, a model should include precise data as basis for further calculations or simulations. However, a model should not overburden the user with complexity, especially if the target user group has no technical background (Oestereich et al., 2004).

Different categories of business process models for supply chains and networks exist. The basic ideas of these categorization efforts, however, are similar (Kim & Rogers, 2005). E.g., Beamon (1998) classified modelling approaches into deterministic analytical models, stochastic analytical models, economic models and simulation models. Following this, all types of models are either static representing a system's structure at a fixed point in time or dynamic describing the interactions of a system's elements (Eriksson et al., 2004). For decision support it is of particular importance that dynamic models support an estimation of future developments to support decision makers in complex decision processes as described in chapter 2. In addition to the time horizon, models can be characterized according to (Luo & Tung, 1999):

1. Formality (determined by precision of the language and its notation);
2. Scalability (determined by size and complexity of processes to be optimally handled);
3. Ease of use (determined by difficulty to understand and use the method);
4. Enactability (determined by support of automated enaction and process manipulation).

Modelling large and complex systems such as food supply networks requires the possibility to include multiple views. A view is a projection into a model, which is seen from a specific perspective or vantage point and omits entities that are not relevant to this perspective (Booch et al., 1998). Curtis et al. (1992) identified four most common views on process models:

1. Functional;
2. Behavioural;
3. Informational;
4. Organizational.

The functional view is used to divide the system into different functional domains with their functional requirements. As a consequence, the functional view provides a basis for behavioural models and informational models. Behavioural models further specify domains and requirements by adding detailed actions, physical resources and decision points. Informational models include a further specification of informational resources. To solve complex problems, an integration of these different modelling views is required (Beulens & Scholten, 2001). The integration is objective of the organizational view.

The present paper identifies and discusses requirements on business process models for model-based decision support systems (DSS) in food supply networks using the example of the Unified Modeling Language (UML) and discrete-event simulation. First, the UML and discrete-event simulation are introduced, followed by a discussion of their relative advantages and disadvantages for the objective of this paper.

3.1 Business process modelling using the Unified Modeling Language (UML)

The Unified Modeling Language (UML) is the *de facto* modelling language standard for object oriented software design (Kobryn, 1999). Furthermore, it is widely accepted as standard for business process modelling (Berning, 2002; Kreische, 2004). Due to its recognition, a multitude of supporting modelling tools is available varying in functionality, complexity, adaptability and price. To model the different views mentioned above, the UML offers different types of diagrams. The functional view can be modelled by "use case" diagrams, the behavioural view by "activity", "sequence", "collaboration" or "state" diagrams, the structural view by "class" or "object" diagrams and the organizational view by "component" or "deployment" diagrams (Kim & Rogers, 2005). Use case diagrams of the functional view can be the initial point for designing behavioural and informational models. The organizational view can serve for their integration. Depending on the objective of the modeller, particularly if a higher level of detail is needed, the Eriksson-Penker Business Extensions (Eriksson & Penker, 2000) can be helpful.

The Model Driven Architecture (MDA) makes UML models useful for developing software systems and places the model at the centre of the development process by applying UML models for managing complex systems. Thereby MDA makes a fundamental distinction between:

1. Platform Independent Models (PIM);
2. Platform Specific Models (PSM).

A PIM aims to capture implementation-independent information about a system and its business processes, whereas a PSM aims to provide detailed implementation information for a specific deployment environment (Eriksson et al., 2004). Based upon these PSM source code for a software system can be produced. This development process of software systems is a complex task, especially in management environments, which are linked to organizational systems (Pastor & Molina, 2007). However, the focus of this paper is on the organizational challenges in chains and networks rather than on technical challenges in software development, hence, in the remainder of the paper all models are understood and discussed as platform independent.

This paper employs the use case approach to model the functional view, activity diagrams to model the behavioural view and class diagrams to model the structural view. This approach allows for modelling the organizational view without a specific, additional type of diagram. Using the chosen diagram types allows for modelling interrelations as direct connections between the different modelling views throughout the whole supply network. This is of particular importance because production processes of one actor in the network can influence information processes of other actors as well as information processes of one actor can influence production processes of other actors. Decisions which have to be taken in one stage may be influenced by production and information processes across the whole network. Figure 3 illustrates these interrelated modelling views in a supply network using the UML.

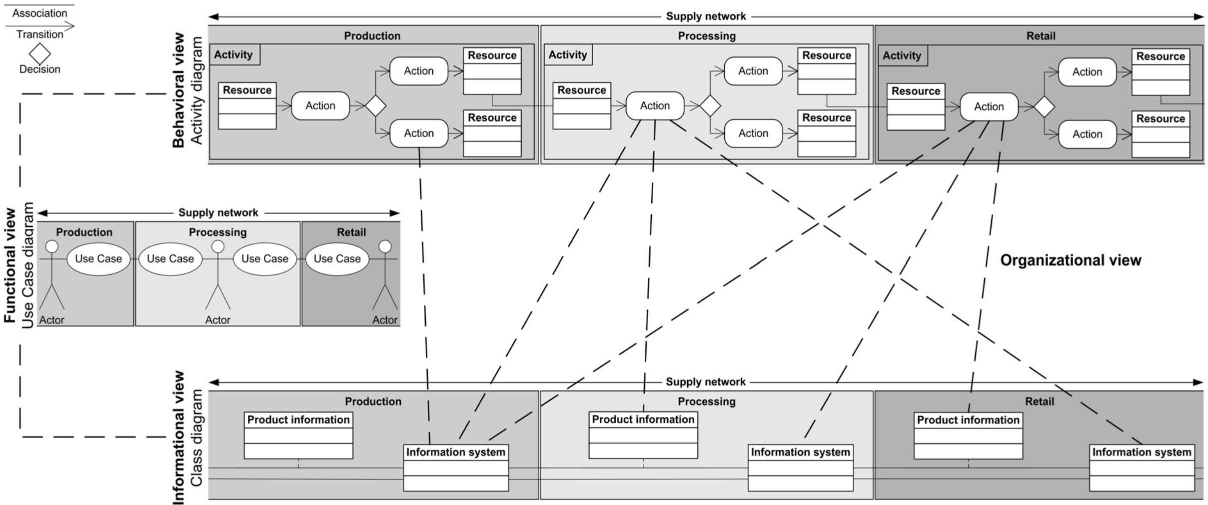

Figure 3. Supply network modelling views using the Unified Modeling Language (UML)

The use case approach is widely employed to discover and record functional domains and requirements. Use case diagrams address a static view of a system and show a set of actors and use cases as well as their relationships (Booch et al., 1998). The general procedure for creating a use case model is the determination of boundaries of the system and of the functional domains considered, the identification of requirements as well as the definition of use cases matching these domains and requirements. These domains could be any stages within a supply network as well as external parties such as, e.g., governmental agencies or quality system providers. A use case could be any activity of an involved actor such as the transaction of a resource (e.g., "buy resource") or requesting specific information (e.g., "request information"). Use cases are usually connected to use cases of other actors and partly complementary (e.g., "sell resource", "provide information").

Identified use cases can serve as basis for modelling the behavioural and informational view representing intra- and inter-enterprise production and information processes. In the behavioural view, using activity diagrams, the functional view can be further specified by adding more detailed actions, resources, transitions and decision points. The informational view, using class diagrams, focuses on information availability and exchange within the supply network. Two types of information can be distinguished: information collected by network actors, i.e. information stored in intra-enterprise or network/sector focused information systems, and information attached to a product by, e.g., delivery notes or ear-tags of animals. The exchange of information can take place either detached from a product (directly from information system to information system) or attached to the product, which is delivered from one actor to another in the supply network.

Any use case can be connected to the respective part of the behavioural and informational model for further specification. While the behavioural view focuses on physical resources, the informational view focuses on informational resources within the network. The organizational view can be modelled through direct connections between the modelling views across the whole network. The organizational view allows for linking informational resources needed for decision making with actions in the behavioural view, which lead to the necessity of a decision. Such a linking is particularly supportive if information required for decision making is spread across the entire system as it is the case in food supply networks.

The proposed approach allows for analyzing and documenting entire supply networks on the basis of network and sector requirements. For more detailed information about modelling techniques for the functional, behavioural, informational and organizational views in food supply networks with the UML see Lehmann et al. (2009b).

3.2 Business Process Modelling using Discrete-event Simulation

Simulation is defined as imitation of the operation of a real-world process or system over time and represents an indispensable problem solving methodology for real-world problems (Banks, 1998). According to Terzi and Cavalieri (2004), the method most commonly used for supply network simulation projects is discrete-event simulation. Discrete-event simulation is highlighted in literature as one of the most powerful tools for process optimization (Beamon, 1998, Law, 2000), design, design-evaluation (Van der Vorst, 2000), decision making, planning (Terzi & Cavalieri, 2004) as well as education and enhancement of discussions for decision making (Holweg & Bicheno, 2002) as it concerns the modelling of a system as it evolves over time (Lee et al., 2002). The majority of models is stochastic and contains components modelled based on probabilistic distributions (Carson, 2003). These distributions have to be modelled using process data or other data sources within the supply network.

Based on the analysis and documentation of processes and related process data as it is described in chapter 3.1, an objective for a discrete-event simulation model can be defined. This focus is needed to define requirements for the model (Maria, 1997; Sánchez, 2006). The model can be used to experiment with, evaluate and compare any number of system alternatives by changing model elements or their configuration. Testing system alternatives in the real world would be risky and expensive (Carson, 2003). Most simulation software products offer a tool for data input and output analysis to observe changes. This functionality can be used for validating and verifying simulation models (Banks, 1998, Centeno & Carillo, 2001). Availability and validity of data are important as wrong information may lead to wrong simulation results. The adaptation of the model to the real world situation has to be verified regularly to ensure model fit with the relevant parts of the real world system.

Discrete-event simulation allows decision makers to evaluate and visualize impacts of a (re-) organization of a system in a “what-if” way. The change of a process configuration or related inputs and outputs can have significant impact on the entire system (Banks, 2000). Figure 4 shows a part of a simulation model based on an enterprise control process. It illustrates the interacting product and information flows in a supply network between production and processing. The information flow includes two feedback loops, one within the processing enterprise (B) and one between the processing enterprise and its supplier (A).

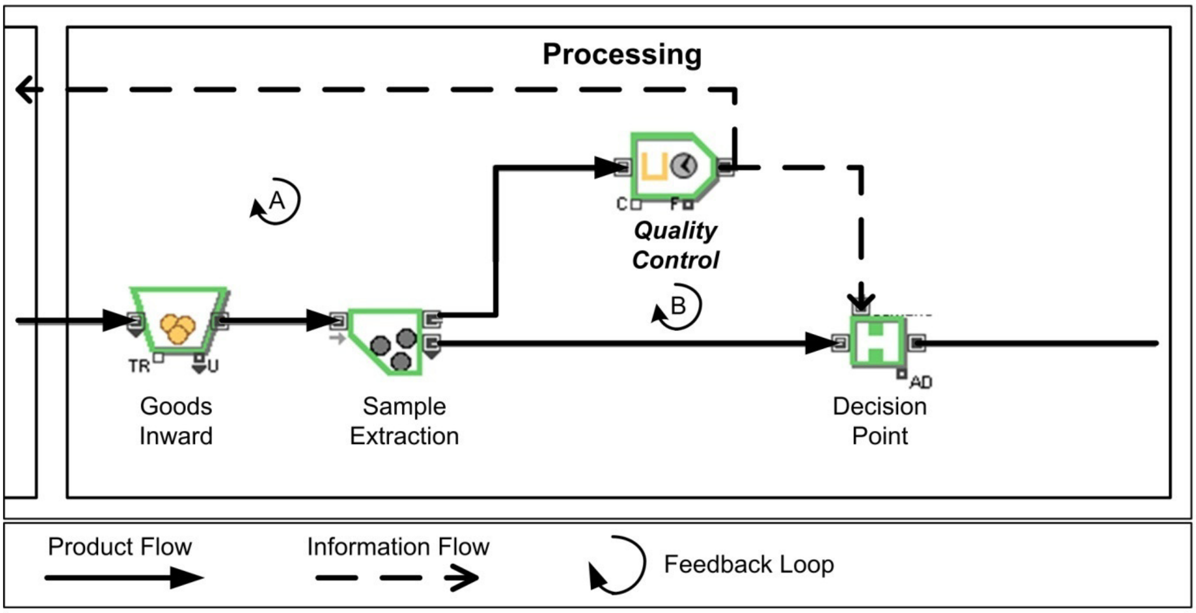

Figure 4. Interacting production and information processes in a discrete-event simulation

In this example, the information flow has an important impact on processes within the enterprise and its network. It is assumed that the product flow is a continuous flow of goods in constant quantity. Goods received from the supplier enter the processing enterprise at goods inward. From this point on, received goods are kept separately until a positive signal from quality control is sent in intra-enterprise feedback loop “B”. A possible negative signal from quality control is sent to the supplier in feedback loop “A”. Hence, the primary tasks of quality control are analyzing received goods and releasing goods to further processing, which are done by sending a signal to the decision point. The signal sent can be either positive or negative. In case of a positive signal at the decision point, goods are released to processing. Due to limited capacity in goods inward, information on the goods status has to be delivered in time by quality control. In the example, information needed for the decision is provided by a unit within the enterprise. However, information often has to be supplied by other actors in the supply network, e.g., identification or animal health information from a producer.

Experimenting with different process scenarios in the quality control department would be risky, expensive and time consuming. In a simulation model as depicted in figure 4, variables for quality control, such as “delay at receiving analysis result” or “laboratory capacity” can be defined individually and scenarios can be developed, which can be used to support a decision process. The response time of quality control can be measured for different process scenarios using different model input parameters. In addition, experiments using a simulation model create results quickly and can be repeated consistently. Time needed for information generation affects the intra-enterprise processes and is a critical information input for suppliers' production processes. The interpretation of results can support decision makers in understanding the impact of single process changes on the system (Van der Zee & Van der Vorst, 2005).

From the conceptual point of view, discrete-event simulation can be defined as simulation with changes in the state of variables only at points in time where events occur (Banks, 1998). In such a model, information has to trigger events such as releasing goods for further processing. According to Banks (1998), events can be differentiated in exogenous or endogenous events. An event is a change of the systems state induced by external (exogenous) or internal (endogenous) impacts. The delivery of raw material from a supplier (exogenous event) and the processing to products (endogenous event) are examples for types of events. Similarly, the provision of information from one enterprise to another and the internal use of this information can be distinguished according to these event types. The implementation of system state variables and functions, which evaluate the impact of information provided on processes, is needed to create interaction patterns based on business rules, such as ordering and planning functions.

3.3 UML and discrete-event simulation models for decision support

The different types of UML models support the static and dynamic modelling of supply network production and information processes but show weaknesses when it comes to forecasting and evaluating possible future developments, which is necessary for decision making. Simulation capabilities of UML (e.g. using the Object Constraint Language) are rather for validating and verifying a model than for forecasting and evaluating future scenarios. To cope with uncertainties regarding future developments in the business environment, regarding the behaviour of actors that might influence the effects of own decision activities, and consequences of different decision alternatives including potential risks and expected gains related to the various scenarios (Hammond et al., 1998; see chapter 2), additional simulation models need to be included into the decision process.

Which type of simulation is most suitable for decision support depends on the level of management being considered. On an operational level with a short time horizon very detailed mathematical models with a small model scale are applicable. On a tactical level with a longer time horizon discrete-event simulation models are better suited because they allow for a larger model scale including fewer details. On a strategic level, with an even longer time horizon even a combination of discrete-event simulation with other simulation methods could be useful (Lee et al., 2002).

Table 1 shows relative advantages and disadvantages of UML and discrete-event simulation models for model-based decision support in food supply networks. Both the UML and discrete-event simulation support the modelling of interrelations between production and information process models. As a consequence, this criterion is not included in table 1.

Table 1. Relative advantages of UML and discrete-event simulation models for decision support

	Functional domains and requirements	Production and information processes	Forecasting and evaluating future developments
UML	+	+	
Discrete-event simulation			+

The UML has relative advantages regarding discrete-event simulation in developing functional, behavioural and informational models, which can be used for defining a problem and describing the processes related to this problem. However, the UML shows relative weaknesses in developing models, which allow for forecasting and evaluating future scenarios needed as a basis for decision making; these can be modelled with discrete-event simulation. These differences may be explained in relation to the background and primary objectives of both modelling methods. The UML has its origins in information technology and, especially, software development where requirements for modelling are mainly technical. Discrete-event simulation is mainly used in operations management for process optimization, planning and decision making.

4. An Integrated Modelling Framework For Decision Support In Agri-food Supply Net works

To support the different phases of a decision process the functional, behavioural and informational views need to be integrated to provide a basis for forecasting and evaluating future developments. Due to the fact that in the agri-food sector production and information processes of different actors within a supply network are mutually interacting, this integration has to include the processes of all involved actors throughout the supply network.

As discussed in section 3, the UML offers different types of diagrams to support these modelling views, but needs to be complemented when it comes to developing and evaluating the future scenarios. For the modelling of supply network and sector requirements as well as for the formulation of production and information models, UML is the approach of choice. Depending on the objective of the modelling, a simulation model, e.g. a discrete-event simulation as described in chapter 3.2, can be used to develop scenarios and evaluate the achievement of the objective for each scenario. On this basis decision alternatives can be developed and recommendations can be given. The integration of the different supply network models in a generalized modelling framework that considers not only the different phases of a decision process but also the vertical and horizontal dimension of the decision scenario is illustrated in figure 5.

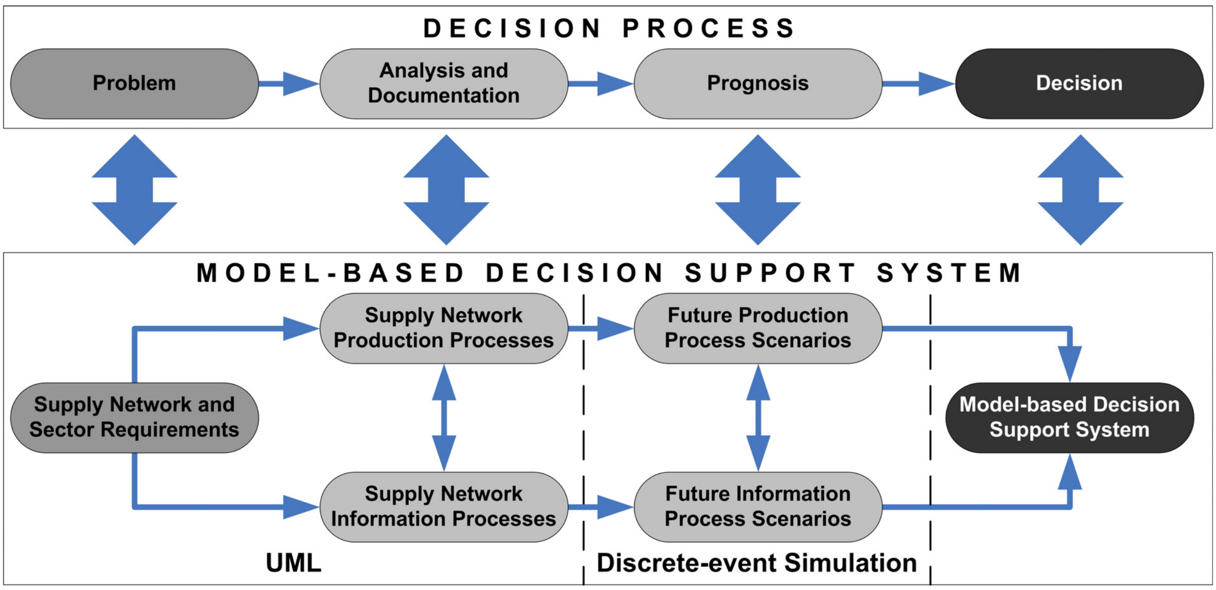

Figure 5. Generalized modelling framework for a model-based DSS, which supports all phases of a decision process

The vertical dimension is determined by the sequence of phases of a decision process, including problem identification, system analysis with documentation, and the determination of consequences of decisions alternatives in various future scenarios (prognosis). Figure 5 includes not only a vertical, but also a horizontal dimension where production and information models are being linked with each other and with the respective decision phase.

Each one of the phases of the decision process needs to be supported by specific modelling diagrams, which provide the basis for a model-based decision support system (DSS). The problem phase needs support by models, which allow the identification of supply network and sector requirements, the analysis and documentation phase needs support by models, which allow an integrated modelling of supply network production and information processes and the prognosis phase needs support by models, which allow for a simulation of different scenarios of these integrated processes to forecast future developments. The last step of the decision process, the decision, is supported by the model-based DSS.

In a decision process, one phase builds the basis for the following. After identification of the problem, the objective for a detailed analysis and documentation of the existing situation can be set. Based on an extensive analysis and documentation, scenarios can be created and a prognosis of future developments can be given, which allows a decision maker in an enterprise to come to a well-founded decision. The sequence of models supporting such a decision process follows a similar logic. The first step is modelling supply network and sector requirements, which set the focus for the following modelling of the processes. The process models allow for a detailed description and analysis of interacting production and information processes, of which parts can be taken as a basis for interrelated production and information simulation models. Whereas the different phases of a decision process result in a decision, the UML and simulation models build the basis for a model-based DSS.

5. Conclusion

Enterprises in the agri-food sector are increasingly challenged by public and private requirements on the sustainability of their products and processes, exemplified by requirements on the safety and quality of food and the delivery of appropriate guarantees for customer enterprises along the food value chain and the consumers. Assuring compliance needs to build on appropriate information systems that could support decision makers at (re)organizing existing production processes to reach compliance and adapt information processes to allow appropriate monitoring and the delivery of guarantees.

However, beyond the availability of appropriate information systems, higher levels of decision support can be reached through the use of model-based DSS that integrate production and information processes throughout whole supply networks. The models on which the systems are based need to (1) allow for an integrated modelling of supply network production and information processes and (2) support the different phases of a decision process.

Both, the proposed UML models and the discrete-event simulation models support an integrated modelling of production and information processes on the basis of supply network and sector requirements. The UML offers different types of diagrams supporting the first two phases of a decision process, namely the problem identification and the analysis and documentation of the existing interacting production and information processes.

However, all models of the UML are mainly focusing on a description and analysis of the production and information processes but show weaknesses when it comes to modelling different scenarios, which would allow for a prognosis of future developments. A prognosis represents the third phase of a decision process and is needed for a well-founded decision. The UML is an open method, which is in continuous improvement to expand its leading global position for business process modelling. However, for the development of supply network information systems, which support all phases of a decision process, the UML needs to be complemented by additional simulation elements, allowing for prognosis of future developments.

The present paper introduces a generalized modelling framework for model-based DSS by integrating UML and discrete-event simulation models of a supply network with the different phases of a decision process. Further research is needed to operationalize this framework for specific situations in the agri-food sector.

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