Reference-data modelling for tracking and tracing

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Preface

Food consumption is not without risk and food safety imposes new requirements on the products. Food should be nice to eat and above all, it should be safe to eat. The latter issue is usually greatly underestimated. Many believe that food generally meets the accepted norms imposed by the government and the control organisations. However, in this Ph.D. thesis, we raise the question as to whether our food is actually safe for consumption, and how any lack of safety can be detected and resolved? Tracking and tracing will provide us with an answer. Modern ICT enables us to follow products through the supply chain and determine the processing history.

Once the topic of my M.Sc. thesis was the exchange of product information within supply chains. An important conclusion of that work was that the exchange of tracking-and-tracing information would soon become increasingly important. Chain actors already then found such information extremely relevant. An explanation of my conclusion was in the desire to prevent and control the occurrence of food incidents, retain the trust of the consumer, and to limit as much as possible any negative exposure on incidents in the press. My M.Sc. thesis delivered the idea to start a Ph.D. thesis on tracking and tracing.

This thesis starts with eleven examples of food incidents, giving the reader a first insight into tracking and tracing. Then, four business cases are investigated for their information-system requirements. From the results we create a general information-system design. We validate the design and its application by three independent business cases. Conclusions are drawn on strengths and weaknesses.

The research described in this thesis may be useful for many organisations. It will assist them in preventing food anomalies from occurring, and in controlling the supply chain as much as possible.

I would like to express my thanks to my supervisors Adrie Beulens and George Beers. In addition to these persons, I would like to thank Jaap van den Herik, director of the Institute for Knowledge and Agent Technology (IKAT). I was most fortunate to have his support, guidance, and encouraging words.

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1. Research description

The thesis describes research on tracking and tracing. It presents the development of a reference-data model for tracking and tracing, and the description of its application. The focus of the thesis is on establishing the tracking-and-tracing functionality within an object system, i.e., establishing the supply chain, and representing this functionality by data models so as to facilitate the development of the information systems suitable for tracking and tracing.

In the first chapter the research description is presented. The objective is to give the reader some insight into the research. The chapter elaborates on the motivation (section 1.1), the challenges (section 1.2), the objectives (section 1.3), and the research questions (section 1.4).

1.1 Research motivation

This section discusses the background of the research. The main motivation lies in the combination of the knowledge on information systems and the concerns on dangers that might occur in daily life, in particular when tracing food. Food is essential to everybody, and therefore it is important that the origin and the way along which the distribution takes place, is traceable. According to a recent policy letter (LNV, 2001), tracking and tracing concerns both government and business. A common concern is the efficient traceability of animals, products and raw materials. Desired and necessary information, both forward and backward in the chain, must become available using modern communication means. According to EZ (2002), appropriate knowledge and competent use of ICT (Information and Communication Technology) within the agricultural chain, in particular with respect to tracking and tracing and food safety, are limited in the Netherlands. EZ (2002) identifies a few specific ICT applications for traceability. This thesis aims at contributing to the knowledge of developing such applications.

We start with providing the overall problem formulation (subsection 1.1.1). Then, tracking and tracing are elaborated upon (subsection 1.1.2). Next, a societal view on food and a scientific view on information systems are presented (subsections 1.1.3 and 1.1.4). Finally, the current tracking-and-tracing information systems are described (subsection 1.1.5).

1.1.1 Problem formulation

A food chain is a chain in which raw materials are transformed into finished products that are fit for consumption. The functioning of food chains is an important topic of study (Trienekens, 1999). For an adequate understanding it is essential to identify the driving forces of food chains. They influence the formation of (new) food chains and may have impact on (existing) food chains in such a way that they will be far more efficient and effective with respect to products and services they supply than the current food chains. In this respect four driving forces are to be distinguished: the consumer (with its demand drive), the (national) government (with its legislation), the technology (with its performance improvement and innovation), and the business community (with its opportunities and new business combinations). When investigating food chains, we need to acknowledge these forces and we should pay explicit attention to the things that can go wrong in food chains. This thesis aims at contributing to the functioning of food chains in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003). This idea is directly translated into our problem statement, which reads:

> *How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?*

Below, we give the reader some insight into tracking and tracing and into the practical problems that exist in tracking and tracing of food products in supply chains.

1.1.2 Tracking and tracing

Food products are generated by what we call supply chains. Supply chains consist of companies that plan, organise and control the processes required to transform initial raw materials into a finished product. The companies within a supply chain are linked by supplier-purchaser relations. Most of the times supply chains operate as they should. Specific problems with products however may occur (Hoyinck and Hentzepeter, 2003). Then, with regard to food safety, the source of that problem should be investigated and its cause should be eliminated as soon as possible. To do this efficiently and effectively, companies should track and trace their products. Below, we explain the problems in the tracking and tracing of food products through the supply chain.

Tracking

When information of a possible product deficiency reaches a company in a chain, it investigates the seriousness of the problem, and assesses whether customers and consumers are at a potential risk. If so, the customers and consumers are informed and all purchased products with the deficiency are recalled. This is not an easy job. To retrieve only the deficient products, a company must be able to determine which product batches are sold, and to whom. It requires product tracking. For product tracking, it is necessary that companies can identify the exact locations where the deficient products are and the quantity of the deficient products in the supply chain. Companies that are unable to track their products in the supply chain are at a loss: they can neither identify the exact locations nor the quantity of the deficient products.

Product tracking is just a part of the solution of the (deficiency) problem. Companies that are faced with a product deficiency must investigate the cause of the problem and eliminate it. The cause of the problem may lie in the company's own resources, but may also lie in the resources of its supplier (or the supplier's supplier).

Tracing

Tracing is needed so as to identify all suppliers in the supply chain, which contributed to the product. Having traced the suppliers, the company asks for the investigation of their product quality and considers any possible anomalies. If the cause of the problem is found, the company investigates whether or not other products might have been subjected to the deficiency. If so, these products must also be recalled from purchasers.

Tracking and tracing

Tracking and tracing provides companies of a supply chain with a possible solution in dealing with product deficiencies. Companies that are equipped with an adequate tracking-and-tracing system have the means to follow and recall their products. Those products, which are potentially harmful to customers, can be located in the chain and be retrieved. Tracking and tracing enables the supply chain to coordinate its efforts with respect to the identification and retrieval of potential harmful products, their location and quantity.

Literature reveals that many food chains are unable to track and trace products appropriately. Wagenberg et al. (2002) investigated the traceability of animal feed, produced by the feed manufacturer and delivered to the farm. Important conclusions of these researchers are: (1) mixing of batches occurs especially in the beginning of the chain, (2) carry-over of feed (batches) takes place throughout the entire chain, (3) traceability of especially the smaller feed components is difficult, (4) traceability time ranges from days to weeks, and (5) traceability is hindered by the (complex) organisation of the chain. Rommens and Mulder (2001) investigated ten meat chains and two fish chains on food safety and traceability. Within these chains only 20% of the meat and fish products could be traced back to its primary producer. Rommens and Buijsman (2001) investigated the traceability of products in fruit and vegetable chains. They attempted to trace 300 products from 12 supermarkets and 6 specialty stores, by their associated product information. Of all the products, 30 % could be traced back to the primary producer, 52% could not be traced back at all, and 18% could be traced back to the supplier, though not to the actual primary producer. Rommens and Buijsman (2001) also investigated the organisation of the system for tracking and tracing within 25 of the organisations from which the products originated. Big differences were found. In general, food chains must overcome the problems concerning the (lack of) product traceability. Moreover, the regulation of the European Parliament and the Council[1] prescribes the traceability of products in food chains by the year 2005. In this respect, Hentzepeter (2002) expects some work for retail to be done, as no Dutch retailer is currently able to guarantee a 100% traceability of its products.

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[1] Regulation (EC) No 178/2002; the General Food Law.

1.1.3 A societal view on food

Food safety and product tracking and tracing have become a concern of our society (Swabe et al., 2001; Rathenau, 2003). Food consumption is not without risk. Every year, many people become sick from food contamination. Regular causes are Salmonella, Campylobacter and E-Coli O 157. The risks of our food consumption can be listed in order of decreasing importance (Gray, 1985; Hummels et al., 1992):

- food poisoning by micro-organisms;
- wrong food consumption, in particular too much sugar, fat, salt and alcohol;
- environmental contaminants such as polychlorinated biphenyls (PCBs), cadmium; and dichlorodiphenyltrichloroethane (DDT);
- the presence of natural toxic substances in food, such as nitrates;
- residues stemming from for example pesticides;
- additives.

An important cause for problems with food products is dynamic quality. The risk of consuming a food product is likely to differ between products of which the shelf life just expired (i.e., insignificant product deterioration) and products of which the shelf life is long overdo (i.e., strong product deterioration). Consumption of the food products, long after expired shelf life, is likely to result in a higher health risk, as opposed to the consumption shortly after expired shelf life. With some product deficiencies, risk and sickness can be differentiated among the various age groups: the young and elderly people, and the people of average age. We mention for example the risks associated with Salmonella.
Certain risks however need not be constant over time. We mention the risks associated with environmental contaminants. The risk assigned to it in the past may be different from the one assigned to it in the present, and also different from the one assigned to it in the future.

Over the years, a variety of food incidents have occurred. We illustrate these incidents by listing the following eleven cases (in chronological order): Planta, Iglo, Perrier, raw eggs, Heineken, Frisolac, Olvarit, Raak Cassis, Brinta, dioxin, and Coca-Cola (see table 1.1). Next, we describe the structure of the table. It is organised into rows and columns. The rows depict the case under discussion (i.e., Planta, Iglo, etc.). The columns depict the case-topic under discussion (i.e., the date of the incident, what happened in the case, how the incident could happen, what the impact of the incident was, and what the consequences attached to the incident were).

The information presented in the table is compiled from (news)paper reports[2]. The cases selected in the overview, are examples of food incidents that occurred. In selecting the cases, we have tried to differentiate on products as much as possible. Another point of attention in selecting the cases has been the media attention received. Further, the cases are neither compiled from any particular viewpoint, nor do they have any predefined order. The order in which they are listed is chronological. A final remark on table 1.1 is on the occurrence of the cases. Two cases are included that occurred before 1990. The case Planta describes an incident that occurred in the 1960s, and the case Iglo describes an incident that occurred in the 1980s. These two cases are taken up for reason of comparison. The other nine cases included in table 1.1, describe food incidents that occurred in the 1990s. The recent cases are taken up because they used improved methods and techniques for tracking and tracing. So the eleven cases provide a good overview of the improvements achieved within forty years. Moreover, with the help of the nine cases we will be able to identify the current information need of the problems to be solved, since we hope to avoid or early detect new cases by means of information and communication technologies.

[2] References: [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11].

Table 1.1: Cases on food incidents.

	Planta	**Iglo**	**Perrier**	**Raw eggs**
Date	Summer 1960	December 1980	February 1990	July 1990
What	Planta was the first vegetable margarine on the market for some seven years, to which the emulgator ME 18 (anti-spatter) was added.	Iglo frozen “nasi" and vegetable products contained nitrite, a carcinogenic substance.	Benzene in mineral water.	Raw eggs contaminated with Salmonella-D bacteria.
How	Over 100,000 Dutch inhabitants got a "blaasjes" disease: a skin disorder that resembled "netelroos" and caused fever. Four people died: hundreds were admitted in hospitals.	The substance originated from the cooling system of the Iglo vans.	Probably the material entered the bottles during cleaning.	The industrial way, in which pigs and chicken were bred. The source of the feed, often third world countries, is a problem because of pollution and contamination (fish meal is a well known example). Where chicken meat is concerned, mechanised slaughter methods have a negative impact. The intestine breaches cause bacteria to spread.
Impact	Two weeks after the discovery a sales ban was pronounced for all 55 margarine brands of Unilever including Zeeuws Meisje and Blue Band. Because of using the same kettles, the emulgator also contaminated them. Within hours after the proclamation, butter was sold out.	At least two people in Maastricht and Venray died after eating the contaminated products. Others got sick.	The mineral water was taken out the shops in the US, followed by Japan and West Germany and the rest of the world. The Dutch distributor Hero recalled one and a half million bottles.	Salmonella is especially dangerous to the weak, elderly and infants. Sixteen elderly people of a nursing home died, after 154 were contaminated with the Salmonella D-bacteria. Of these sixteen, six cases have a direct connection with the Salmonella. Fourteen members of staff also became sick.
Consequences	Unilever paid more than 8,000 people a total amount of 1.25 million guilders, for which the company mentioned that this was not a confession of guilt. Unilever had a loss of 7.5 million guilders. Planta later was called Brio. This still exists.	The cooled vans with the nitrite system were rebuilt in a way that nitrite no longer needed to be applied. Approximately 300 tons of food was taken from the market, from 750 stores in Limburg, which were replenished from stock with possible contaminated cars.	The damage to distributor Hero was estimated two and a half million guilders. Perrier paid. Perrier was praised for its alert reaction. The Perrier share-value did not drop after the affair.	No members of staff were prosecuted. As no legal order against the use of raw eggs existed, no one could be criminally prosecuted, according to the justice of Roermond.

Table 1.1: Cases on food incidents (continued).

	Heineken	**Frisolac**	**Olvarit**	**Raak Cassis**
Date	August 1993	September 1993	November 1993	December 1993
What	In a bottle of Heineken beer (33 cl) meant for export, glass particles were found.	Aluminium particles in at least 30,000 cans of baby and children food of the brand Frisolac of the concern Friesland Frico Domo.	Within cans of Olvarit baby food containing beef and pork, the p- TolueenSulfonAmide (pTSA) was found, a waste product that remains after the de-contamination Halamid has done its work.	A number of 150,000 bottles of Cassis was contaminated with pimaricine: a bacteria and mould killing substance, isolated from bacteria Streptomyces.
How	On the inside of the bottle, during packing or labelling, glass particles came free.	The particles originated from 120 aluminium containers that were used in packing the products. For better regulation of humidity, holes were drilled by which aluminium particles could enter the powder.	The meat supplier, the Gorinchemse firm HVV, had for years deliberately added Halamid to the delivered meat in order to comply with the strong demands of Nutricia. The material pTSA is a bacteria killer and is by the BestrijdingsmiddelenWet not allowed to be in food in doses above one milligram per kilo.	The union FNV suspected that in the production of Cassis pimaricine was used to avoid that the liquid would spray out of the bottle on opening.
Impact	The glass particles were said to lead only sporadically to medical complications. No cases are known. Heineken recalled 3.4 million green export bottles and destroyed another 17 million. Moreover, Bavaria and Oranje Boom also recalled green export bottles, as they had the same bottle supplier of Heineken (which was believed to cause the problem).	The dairy concern Friesland Frico Domo recalled 350,000 cans of baby food. Friesland Frico Domo first could not discover that the cause was in its own production process.	Nutricia recalled two million cans of Olvarit from a stock of ten million. The baby food was destroyed.	Justice took hold of the bottles. No danger would exist for public health, however the Keuringsdienst van Waren would have undertaken action because, pimaricine is illegal on bottling soft drinks. The contamination was noted as a result of a letter from an employee of the company. The letter circulated as of August with local and national governmental institutions.
Consequences	The damage was estimated some tens of millions of guilders. Heineken held accountable for the damage the supplier of the bottles, the Schiedamse firm, de Verenigde Glasfabrieken.	The organisation estimated the direct costs of the recall to be millions.	May 1995, Nutricia announced that the damage estimation was 40 million. In October 1995, the court of the Hague found Nutricia guilty of breaking the Warenwet as a result of lack of process supervision, and a too slow response when the first complaints on pTSA entered. The court ruled that it had not been proven that the public health was at risk. No punishment was given. The two directors of the meat company HVV, got fines of 30,000 guilders and a suspended sentence resulting from the careless way of work.	Only after an investigation of the union FNV, justice decided on action.

Table 1.1: Cases on food incidents (continued).

	Brinta	**Dioxin**	**Coca-Cola**
Date	March 1994	May 1999	June 1999
What	Brinta, wheatmeal for breakfast mush, had been contaminated with the Salmonella bacteria.	In Belgium dioxins were found in chickens, eggs, and products, which included processed chicken and eggs. In July again dioxins were found, this time in pork. Mid June it became apparent that waste of the suspected dioxin chicken, which were recalled from shops in Belgium, had been processed in feed for pork and chicken in Holland.	The carbon dioxide in a Coca Cola soft drink was contaminated with sulphur substances like for example sulphur hydrogen, of the well-known rotten egg smell. Besides it was noticed that in the paint layer of the tins a fungicide, an anti-mould substance, was absorbed. During drinking the freed vapours would be breath in.
How	The contamination probably originated in the factory. It was discovered that the bacteria was present in a roller where the batter of Brinta went through. The contamination then probably did not stem from the used wheatmeal; the problem would then be visible earlier in production. The roller is an enormous cylinder shape tank in which hot air brings the Brinta batter within seconds to boiling temperature so that bacteria are killed. The factory experts did not understand how the Salmonella bacteria could survive the high temperature.	The Belgian chickens were given feed with high concentrations of dioxin. In preparing the feed, contaminated fat of foundry Verkest in Deinze was used. The contaminated fat probably originated from a Waalse company. The contaminated feed was supplied to 1,400 Belgian chicken, pork and beef, feeding companies. The case became apparent when poultry farmers noted unexplainable sickness and dead among the chickens.	During the production of the soft drink in Antwerp, there would be used carbon dioxide with a wrong mixture. The anti-mould substance was used on pallets in the factory of Duinkerken. It would have stuck to the cans and have caused a chemical reaction with the anti-oxidation substance on the bottom of the cans.
Impact	Some people reported intestine complaints after eating Brinta. The production of Brinta was put on hold for some months and 1.5 million packs units of Brinta were recalled from the shops.	The Belgian Minister of Health originally halted the sale of chicken and eggs, and products in which these were processed. Later, also fat products with pork and beef products were taken of the shelf. It included in total hundreds of products.	In Belgium some hundred children were admitted in hospital with sever palpitation and sickness after drinking Coca-Cola and Fanta from soft drink machines at school. With the children "hemolyse" was diagnosed, a disease whereby red blood cells are destroyed and the skin and eyes can turn yellow of colour. Another hundred people reported having complaints of sickness. The supply and sale of products from the same company, like Sprite, Fanta, Aquarius, and Nestea were halted in Belgium and Luxembourg. In Holland all products produced in Belgium were withdrawn from the market. Also France banned a number of Coca-Cola products. The contaminated pallets were destroyed.
Consequences	The damage was estimated to be millions. The Avebe factory invested about four to five million in new equipment.	Angry Belgian farmers protested against the sales ban on their products and the loss of income as a result. They blocked among others important border crossings to Holland, France and Germany with tractors.	The withdrawal of suspected Coca-Cola soft drinks from the market in Europe meant a direct cost of 60 million dollar (about 130 million guilders). The amount of soft drink involved represents almost one percent of the annual turnover of Coca-Cola Enterprises. Part of the damage could be claimed from assurances and third parties. Besides the direct costs, there were negative consequences for business sales and profit.

From the eleven food incidents we attempt to construct an understanding of what precisely tracking and tracing constitutes. We want to be able to describe in detail (1) what tracking and tracing precisely is, e.g., what the requirements for adequate tracking and tracing are, and (2) what actions need to be taken in the supply chain to achieve adequate tracking and tracing.

In general, companies have many quality measures at their disposal, including the monitoring of the quality of processes and products. All these measures together determine how the quality and safety of products is guaranteed, until the moment they leave the factory. Then, the question arises: how to monitor (pro-actively) the quality so as to ensure on a transaction basis that the quality aimed for remains stable? It requires a procedure to track the whereabouts and the status of the quality of the products, as well as their deviation from a predefined specification. In case of a deviation, the source or the origin of the problem will be traced, and all products, which share the properties that caused the identified deviation, are followed by tracking these items downstream in the chain.

Given the notion of tracking and tracing, we introduce three essential components: (1) tracking, (2) forward traceability, and (3) backward traceability. With tracking we are able to follow a product through the supply chain, and register any data considered of any historic or monitoring relevance. With forward traceability we are able to list all the products, having consumed a particular (deficient) material of interest (i.e., products that have some (set of) properties in common). With backward traceability we are able to list all raw materials consumed by manufacturing, for the production of one particular product, and trace these materials further backward.

The complete set of visible and invisible properties that a product (group) has in common and in which we are interested, will be referred to as the generating properties of the product (group). In general, these properties are related to the product itself, to the processes (and the attributes thereof) that produced the product, and to the production means that were used in the production processes.

In developing tracking-and-tracing systems, we require an accurate representation of the object system under discussion. In relation to the eleven cases, the following five items must be accounted for in representing the object system:

(1) the objects present in the object system (physical or abstract);
(2) the type of objects subject to tracking and tracing;
(3) the information of interest on these objects (e.g., the provenance of objects[3]);
(4) the (activated) relations between the objects (e.g., provenance relations[4]);
(5) the integrity requirement.

The integrity requirement is twofold, it includes: (1) the integrity of the representation and (2) the integrity of the object system.

(1) The integrity of the representation states that the representation of the object system must be in accordance with the reality of the object system it represents. It implies that the representation is an accurate and real-time view of the object system or the objects in it.
(2) The integrity of the object system states that the object system itself (i.e., which is represented) must be in a state of being whole or complete. It presupposes that all entities constituting the supply chain are known (for efficient traceability).

Both types of integrity are particularly related to the *performance* of tracking-and-tracing systems. We distinguish them from product integrity. Product integrity refers to natural integrity (natural objects) and artificial integrity (artefacts). Natural integrity represents the fact that a natural object adheres to its supposed natural state of being. Artificial integrity represents the fact that an artificial object adheres to its artefact specification.

1.1.4 A scientific view on information systems

To start the discussion of the scientific view on the information systems suitable for tracking and tracing, we reiterate our problem statement:

[3] Generally translated as origin; in the thesis we particularise it to *first* origin.
[4] Provenance relations: precedence relations between organisations/processes that processed the product.

How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?

This subsection explains two important models: (1) the information model and (2) the reference-information model. Both models have a strong structuring effect on the development of information systems. We will show that, in particular, reference-information models are of importance to the infrastructural dimension of ICT in the supply chain.

Terms of co-operation

A possible way of dealing with uncertainties in the supply chain is the increased co-operation between the constituting organisations. Organisations that are part of a supply chain can work closely together in order to limit, as much as possible, any risks that can be associated with food production, distribution, and consumption. To work effectively together, supply-chain organisations need to agree on the terms on which they wish to co-operate. The exchange of information is a particularly important subject in this respect, especially with regard to tracking and tracing. Agreements can be made on the exchange of certain information in the chain, so as to facilitate tracking-and-tracing. Information models are of help here. They facilitate unambiguous information exchange between the organisations of a supply chain. We explain this below.

Information models

It is learned that information models have a strong structuring effect on the initiation and execution of projects for information systems (Beulens, 1991). Information models describe the information system of an organisation (Beers et al., 1994). Two important components of the information model are: (1) (business) processes and (2) associated data resources. Information models can be used in three ways: (1) the identification of information systems, (2) the standardisation of data for the development of information systems, and (3) the integration of information systems for different organisational functions.

Information planning

The development of an information model is usually targeted on an individual organisation. It is executed as a part of Information Planning (IP). According to Van Dissel (1999): "information planning can be considered a set of broadly-based activities that, within an organisational setting provide direction for the application, development and use of Information and Communication Technology (ICT) and Information systems (IS)". Over the last three decades, the stream of information-system planning has gradually developed. It is now characterised by a fair amount of literature (e.g., Kriebel, 1968; Zani, 1970; Schwartz, 1970; McFarlan, 1971; McLean and Soden, 1977; King, 1978; Lyles, 1979, Martin, 1982, 1989; Aarts and Janssen, 1989). Standard IP methods are stated in table 1.2. The information planning methods given in table 1.2 provide an historical insight into the possibilities that can be used when tracking and tracing are to be performed.

Table 1.2: Information planning methods (Van Dissel, 1999).

Method	**Planning level**	**References**
Business Systems Planning (BSP)	Information architecture and project definition	IBM (1975)
Stage models	Information strategy, development of IS-function	Nolan and Gibson (1974); Nolan (1979)
Critical Success Factors (CSF)	Information architecture, requirements analysis	Rockart (1979); Bullen and Rockart (1981)
Strategic Information systems (SIS)	Information strategy, identification of SIS	Porter and Millar (1985)
System Development Methodology (SDM-0)	Information strategy, information architecture and project definition	Turner et al. (1985, 1990)
Jig-sawing	Information strategy	Hopstaken and Kranendonk (1988, 1989)
Handbook information planning	Information strategy, information architecture and project definition	Aarts and Janssen (1989)
Information Engineering (IE)	Information Strategy Planning (ISP), Business Area Analysis (BAA)	Martin (1989)
Internet strategy	Information strategy	Tiggelaar (1999)

Having investigated the literature on information planning, Van Dissel (1999) concludes that the literature lacks relevant information on the identification, implementation and management of Inter-Organisational Systems (IOS). Yet, there is an overwhelming amount of literature in this area. The systems are regarded ICT-based systems that transcend legal enterprise boundaries (Bakos, 1991; Chismar and Meier, 1992; Konsynski, 1993).

Application of information models

The main use of information models (up to now) has been in the area of identification (and development) of information systems for intra-organisational use. Owing to the structuring effect of information models on the design of information systems for intra-organisational use, Beers et al. (1994) argue that it is logical to develop such models for inter-organisational use in product chains.
In this thesis, we identify the exchange of information and a mutual understanding of that, as a potential key to co-operation and co-ordination of organisations in the agricultural product chain. For a successful information exchange in the chain, however, we need to resolve the issue of information-system integration and standardisation (Beers et al., 1994). In the development process of information systems for product chains, standardisation and integration are considered important factors. They must lead to accessible information systems, and will therefore result in a match between the systems of co-operating organisations.

Reference-information models

Beers et al. (1994) argue that for chains, the process of developing a traditional information model consumes a considerable amount of time and money. They propose a better use of information models, and consider developing models that can be used in more than one situation. Their expectation is that in agricultural product chains the deployment of such models (called: reference-information models) in information-system development, will not only lead to a considerable increase of efficiency but will also lead to increase of mutual understanding. On a branch level, several reference-information models have been developed (Beers et al., 1993). We note that a branch model gives a generalised description of one type of organisation within a certain branch[5] (Beers and Udink ten Cate, 1993).

Reference models

From the above we conclude that the process of developing traditional information models, consumes a considerable amount of time and money. Below, we will focus on reference models, i.e., models that can be re-used for our purpose. Moreover, we expect reference models to be very beneficial to the development process of information systems in chains. In dynamic food chains, reference models can play a major part in connecting the information systems of co-operating organisations. Dynamic chains are chains of which the composition of co-operating organisations frequently changes. The organisations have the management over multiple-information-exchange methods. There, information is exchanged differently, depending on the organisation involved. The variety of exchange methods can be reduced if standardisation and integration of the different information systems are considered. The introduction of reference models has a strong standardising effect on the information systems in these chains.

Provisional conclusions

The key to co-operation between organisations in the agricultural product chain (in the area of tracking and tracing) is the exchange of information. Hence, successful co-operation within chains requires a common vocabulary for inter-organisational communication, and requires the issues of information-system integration and standardisation (i.e., connectivity) to be resolved. Therefore, we tentatively conclude that reference models can provide the required common vocabulary for the information exchange in the chain, and can resolve the problem of information-systems connectivity.

[5] For example: a model of dairy farms.

Three questions on reference models

We accomplish our scientific view on the information systems, suitable for tracking and tracing, by three questions.

(1) What are the advantages of using reference models?
(2) Which examples of reference models can we obtain from the literature?
(3) On which elements of reference models do we focus?

1. What are the advantages of using reference models?

In developing information systems suitable for tracking and tracing, information needs must be identified. This is not without problems. Four important problems in identifying the information needs for information systems are:

(i) the complexity and variety of information needs;
(ii) the difficulties in communication between software developers and users;
(iii) the possible resistance of end users to co-operate (for whatever reason);
(iv) the limited capability of humans in specifying information needs.

The application of reference models in system development deals with these frequently-mentioned problems (Bemelmans, 1994). Having reference models available in the development process, a developer can make use of capitalised design knowledge and experience. Moreover, two additional benefits are identified from using reference models in the information-system development processes (Greveling, 1990):

(i) more correct and complete specifications;
(ii) reduced maintenance efforts and costs afterwards.

Next to these benefits, we mention five explicit advantages of reference models:

(i) reference models are initial tentative design solutions;
(ii) reference models can be instantiated and become enterprise models;
(iii) customised reference models are enterprise-specific products;
(iv) reference models change the design process from a one-of-a-kind activity into a modify-the-template activity;
(v) reference models facilitate information-system integration and standardisation.

2. Which examples of reference models can we obtain from the literature?

We present eight examples of models with the objective of illustrating the rich variety of models for different functions:

(i) environmental reference models, see: Jansen (1998);

(ii) purchasing reference models, see: Porter (1991), Van Stekelenborg (1997);

(iii) manufacturing reference models, see: De Heij (1996), Scheer (1998);

(iv) production logistic reference models, see: Van Rijn (1985);

(v) industrial reference models, see: Hetzel and Köster (1971);

(vi) agricultural reference models, see: Elzas and Simons (1987), Brand et al. (1995);

(vii) hospital reference models, see: Geurts-De Haas et al. (1985), ZIM (1983);

(viii) BIM (BouwInformatie Model), see: Merendonk et al. (1989).

3. On which elements of reference models do we focus?

Reference-information models consist of two models: business-process models and data models. The thesis focuses on (the modelling of) the data part of the reference-information model for tracking and tracing. This implies that, in particular, the data model is examined on its reference capabilities. In the thesis a comprehensive reference-data model is designed in such a way that it can be used in a referential strategy of information-system development. An information-system-development strategy, in which reference models are the main assets, is referred to as a referential strategy of information-system development. The thesis proposes to use the referential strategy as an efficient realisation of information systems for individual organisations in the product chain, thereby benefiting from all the advantages, mentioned previously.

1.1.5 Tracking-and-tracing information systems

In this subsection, we present a review of contemporary ICT applications for tracking and tracing. Thereafter, an overview is given of the typical problems encountered with such applications.

Review of contemporary ICT applications

Below, the functionality of four types of traceability systems is described: (1) fish traceability systems, (2) fresh produce traceability systems, (3) pork traceability systems, and (4) bovine traceability systems.

1. Fish traceability systems

Denton (2003) describes the functionality for Tracefish: a traceability system for the fish industry. Tracefish is a concept of an electronic system for chain traceability. The key to the operation of the system is the labelling of each unit of goods traded, be they raw materials or finished product, with a unique identifier. This is done by food companies that create such units. Companies that transform units such as processors, who convert the units of raw materials received into products dispatched, create new units and must give them a new identification. Each of the companies that creates or physically trades in those units is required to generate and hold the information necessary for traceability. The information is held in computer databases, referenced to by unit identifications. The itemised information includes:

- (i) fundamental information necessary to identify and trace physically the products;
- (ii) specific information required by law, in relation to (a) food safety, (b) quality and (c) labelling, together with (d) commercially desirable information;
- (iii) other and commercial information considered of sufficient relevance to be included.

A technical approach for tracing aquatic animals is described in Håstein et al. (2001). The authors of the article emphasise different tagging methods for tracing fish and fishery products such as: live fish, aquarium fish, fish eggs, and fish for human consumption (fresh or frozen whole fish). With respect to fish for human consumption, they list the information needed in the traceability of crustacean products in trade, and as prescribed by legislative requirements:

(i) name of the food;
(ii) quantitative list of ingredients;
(iii) net contents and drained weight in metric units;
(iv) name and address of the manufacturer, packer, distributor, importer, exporter, and/or vendor of the product;
(v) country of origin;
(vi) lot identification.

NuTrace is described in Joppen (2003). NuTrace is a food quality programme presented by Nutreco; it consist of four pillars:

(i) NuTrace certified quality (e.g., ISO and HACCP);
(ii) auditing/monitoring;
(iii) risk management (e.g., recalls);
(iv) tracking and tracing.

NuTrace experienced a trial period in the Benelux (for agriculture) and in Norway (for aquaculture). Traceability from feed to food is implemented. Relevant information from different parties in a chain is stored in a database. With respect to fish traceability (i.e., salmon production) information storage includes:

(i) feed (e.g., volume and feeding time);
(ii) analysis of water samples (e.g., on toxic metals);
(iii) medication;
(iv) development of population (e.g., body weight development and deviations).

The system provides management information, too. On-line connections between the fish farm and the feed supplier, and between the fish farm and the purchaser (i.e., processing industry) enable a better farm management. The fish farm can obtain information: on the status of the fish as it reaches the processor, and on the quality class assigned to it, by the processor. Quality levels of different generations can thus be compared.

2. Fresh produce traceability systems

Wilson and Clarke (1998) introduce the Internet to deliver traceability in the agricultural chain, with a system called the Food Track system. The implementation of Food Track in the fresh produce sector is discussed. Pilot projects include homegrown potatoes, carrots, onions, salads, peas, top fruit, and imported fresh produce. The system provides current, accurate information on consignments of food and ingredients as they move through the supply chain. Food Track includes the functionality to store consignment data on products (for safety purposes) as well as whole farm or grower data (for quality purposes).

3. Pork traceability systems

Mousavi and Sarhadi (2002) elaborate on the functionality of a traceability solution, which is especially meant for the meat processing industry. They highlight the importance of boning hall activities in the process of tracking meat products within the total supply chain. They propose a practical meat traceability system. The system includes the functionality to trace the individual cuts in the boning hall to the animal of origin. Appropriate information is gathered and stored in a database, which can be accessed and translated into standard commercial formats.

Elbers et al. (2001) elaborate on the Identification and Registration System (IRS) used during the epidemic of classical swine fever in the Netherlands. In this traceability system pig farmers inform a computerised database when live animals are purchased. The registration of the removal of pigs from the farm is included too. In the case of occurrence of outbreaks of a notifiable disease within the country, the sale of pigs to other pig farmers, and the transport of pigs to a slaughterhouse, export-collection centre or livestock market, is registered within the IRS. Carcasses that are collected by the rendering service must be registered also, either by the farm or the rendering plant (when authorised by the farm). The IRS registers each movement of pigs (to and from farms). The following information is included:

(i) unique herd number of the farmer;
(ii) type of pig movement (within the country, import or export);

(iii) unique herd number of destination of the pigs;
(iv) number and type of pigs (breeding pig, finishing piglet or fattener);
(v) date of movement;
(vi) identification number of transport document or import/export certificate number.

The European Union ANImal MOvement system (ANIMO) is a system providing communication of health certificates of consignments of pigs between Member States of the European Union (Elbers et al., 2001). A consignment of animals is accompanied by a standard health certificate or identification document stating the conformity of the consignment with EU regulations. The Member State of origin sends an electronic message via the ANIMO system, to the competent authority of the destination country and to the central competent authority. The message includes:
(i) data of transmission;
(ii) origin;
(iii) destination;
(iv) merchandise;
(v) means of transport;
(vi) observations.

Pig traceability systems in different countries are identified in Madec et al. (2001). The implementations in France, The Netherlands, and Denmark are discussed. Interesting is the discussion on the pig identification systems in the United States of America (USA). There are three ‘layers’ of pig identification systems in the USA: (i) the mandatory system, (ii) the system of the national pork producers association, and (iii) voluntary systems for identity-preserved and value-added quality pork supply chains.
(i) The mandatory system takes care of the required identification of swine in interstate commerce according to the Code of Federal Regulations (CFR). This code contains all the rules governing the movement and handling of animals in interstate commerce for the purpose of controlling or eliminating disease in livestock. The system includes functionality to identify all slaughter pigs back to the last farm of ownership.
(ii) The mandatory system triggered the national pork producers association to start a voluntary system. The association develops pilot-projects for the improvement

of pig production records and pig management, as well as for pig slaughter identification and pig trace back.

(iii) Many pork-producer networks have become part of vertically coordinated and value-added pork-production chains for defined market segments. The pigs are separated for specific groups. To ensure that the identity of these animals is carried beyond cutting the carcasses and processing the meat, the batches are segregated throughout the production chain. These identification systems that trace a single piece of pork or pork product from the retailer back to the farm, are still in development.

4. Bovine traceability systems

Houston (2001) describes a computerised database system for bovine traceability. The systems functionality covers:

(i) herd registration (registration of the holdings that keep cattle);
(ii) unique animal identification (herd number, individual number, and verifier);
(iii) movement control (the establishment of a cattle movement document).

Another bovine traceability initiative is suggested in Calder and Marr (1998). The proposed functionality of the system:

(i) identification of animals and recording of detailed information on date and place of birth, dam, sire, veterinary records, etc.;
(ii) registration of cattle movements with the facility to record purchasing, sales, farm deaths, transfers to or from other holdings, etc.;
(iii) facilitation of official Government department inspections on the farm;
(iv) farm management tool: providing a system to deal with statutory record keeping.

Information systems to trace bovine are applied in different countries or regions of the world. Barcos (2001) describes criteria to assess bovine traceability systems of different countries and regions (Argentina, Canada, Australia, European Union, Egypt, and Cyprus). Functionalities used in the assessment are:

(i) identification of primary production establishments;
(ii) individual identification of animals within each establishment;
(iii) individual identification of animals when leaving establishment;

(iv) identification of herds of animals within or leaving establishment;
(v) carcass with identification of the animal of origin;
(vi) carcass with identification of establishment of origin;
(vii) carcass with identification of herd/manufacturer;
(viii) cut of meat with identification of animal of origin;
(ix) cut of meat with identification of establishment of origin;
(x) cut of meat with identification of herd/manufacturer.

A cattle tracing system in Great Britain is described in Pettitt (2001). It consists of three subsystems: (1) a central database, (2) a passport, and (3) a farm register. The system's overall functionality includes the registration of the birth and the tagging of newborn calves, and the issue of a paper passport, which accompanies the calf throughout its life. Each movement to a new farm, the off- and on-movements, are recorded in the farm register, the database and on the passport. Possible live access to the computerised cattle database must allow the industry to dispense with any possible paper documentation.

A model for pan-European data transfer and a pan-European traceability system is illustrated in McGrann and Wiseman (2001). They propose a system architecture which consists of three components: (1) a central server for Europe, (2) national servers for the countries, and (3) local veterinary units (the computers on the locations in the chain). In the view of the authors, the integrated information system should contain the functionality to register details on:

(i) identification;
(ii) registration;
(iii) movements;
(iv) health tests;
(v) medication;
(vi) residue monitoring;
(vii) welfare;
(viii) complete traceability.

They propose an information infrastructure that ensures:

(i) accuracy of information;
(ii) completeness of information;

(iii) harmonised data standards;

(iv) rapid response on requesting the history of animals.

The applied information systems can be Internet-enabled to permit rapid and economic data collection.

Drawbacks of ICT applications for tracking and tracing

There are few specific ICT applications for traceability available (EZ, 2002). Software vendors do not sell 'traceability' as a standard module. In organisations, traceability is often supported manually. Some organisations obtain traceability through a mix of registrations on paper (forms, packing bills, etc.) and electronically (databases). The cases that describe the electronic exchange of traceability information within an entire chain are scarce. Moreover, the diversity of specific characteristics of business processes in the agricultural sector is so big that the way an organisation deals with its traceability is almost unique. Individual choices seem to determine the organisation of the system. EZ (2002) lists the following ICT drawbacks:

(1) Internal systems and registrations

Basic functionality for traceability requires that an organisation's internal systems and registrations be coupled. Traceability requires data from systems and registrations, which have initially not been set up for product traceability but for other purposes, such as sales, purchasing, production, and laboratory management. The manual gathering of these data is inefficient.

(2) The use of ICT systems is not uniform within the chain

Production-oriented organisations apply Laboratory Management Information Systems (LIMS) and Enterprise Resource Planning systems (ERP). Trade organisations and retail emphasise logistic efficiency and use Warehouse Management Systems (WMS). Controlling agencies apply ICT mostly for data registration and archiving so as to determine historical effectiveness for policy planning.

(3) Lack of standardisation of barcodes and scanning

An important bottleneck to apply ICT for traceability is the lack of standardisation. The lack of standards hinders the automated communication between chain links, and hence the traceability in chains. Although the most relevant information is stored by organisations, proprietary coding and computer systems make the coupling of this information an almost impossible task.

(4) Financial obstacles

Another bottleneck for traceability with ICT is one concerning money. Many complex technologies, such as ERP, only lie within reach of the big players (e.g., the manufacturers). For the smaller players in the field (e.g., the farmers) these systems are financially not feasible.

Given *specific* circumstances, tracking-and-tracing systems are not difficult to deploy at all. According to Van Kooten (2002), tracking-and-tracing systems can be easily implemented in those parts of chains, which are completely transparent. It implies that all the information, which is needed to satisfy the objectives of the participants in the chain, is available with integrity and adequacy. In these chains, we expect a similar ease of implementation for *automated* information systems. The subject of transparency is presented in Beulens and Spaans (2002) and Hofstede (2002, 2003). An overview of transparency requirements for supply chains and networks is given in Beulens (2003).

1.2 Research challenges

For our research on the development of reference-data models for tracking and tracing we distinguish six research challenges:

(1) views on tracking and tracing (subsection 1.2.1);
(2) data involved in tracking and tracing (subsection 1.2.2);
(3) contextual requirements (subsection 1.2.3);
(4) performance requirements (subsection 1.2.4);
(5) a referential approach for system and infrastructure (subsection 1.2.5);
(6) implementation issues (subsection 1.2.6).

Below, we elaborate on the challenges.

1.2.1 Views on tracking and tracing

Stakeholders like retail, manufacture, product board, and government all hold their own view and interpretation of tracking and tracing. As of the different views and interpretations, tracking and tracing is not properly defined. Formulations of tracking and tracing strongly depend on the type of people discussing the topic, along with the objectives that these people have. The challenge is to provide a definition of tracking and tracing which is satisfactory to everyone.

1.2.2 Data involved in tracking and tracing

If we want to develop proper tracking-and-tracing information systems, we must establish the types of data, which are involved in these systems. We distinguish in this respect, data on the following five elements:

(1) the inherent properties of products;
(2) the properties assigned by the processes in which they were made;
(3) the properties of the production means that were used during the processes;
(4) the provenance properties and origin properties (in part dependent on the former properties);
(5) the relations between them.

The properties themselves concern three types:

(1) the properties that a group of products has in common, i.e., the generating properties of the group;
(2) the properties that products have uniquely;
(3) the type of attributes (e.g., chemical, biological).

1.2.3 Contextual requirements

The context in which tracking and tracing is placed must be investigated. We expect that a context has implications on: (i) architecture, (ii) infrastructure, and (iii) performance. The four aspects of concern are:

(1) the object system: (i) a network of autonomous actors, (ii) actors operating internationally, and (iii) actors involved in multiple networks;
(2) autonomous actors have different commercial, logistical, and quality approaches;
(3) actors are positioned within different legal contexts (e.g., European Union and United States of America) with different implementations of product responsibility and product liability;
(4) actors have their own Enterprise Resource Planning (ERP) systems and quality systems; a tracking-and-tracing infrastructure must cooperate with systems and infrastructures on company level.

1.2.4 Performance requirements

Tracking-and-tracing systems must operate properly. Performance requirements for the systems must be established in relation to the performance of the infrastructure. Especially in divergent chains, performance is an important issue; for then it is essential that a recall be executed efficiently so as to limit the scope and the effect of the problem encountered. Next to the integrity requirement described in subsection 1.1.3, we mention (Beulens, 2003):

(1) access rights and user rights;
(2) depending on the situation and the objective;
(3) considering the protection of privacy, autonomy, commercial interests, and legal protection in case of responsibility.

1.2.5 A referential approach for system and infrastructure

When we are able to investigate the described problems from a referential viewpoint, we can commence to work on the design of information systems and associated infrastructures. Reference designs on systems and infrastructures should deal with the subjects discussed previously. Reference designs for tracking-and-tracing information systems are not at hand. The development of specific reference designs is described in this thesis. With regard to the development of infrastructures, specifications for different food chains emerge (EAN, 2003, 2003a).

1.2.6 Implementation issues

The implementation of tracking and tracing must not be underestimated. It is a problem of considerable size. Tielemans (2003) identifies two factors regarding the implementation of tracking-and-tracing systems: (1) the change in the way of working, and (2) the awareness of the necessity of the extended registrations.

(1) On implementing tracking-and-tracing information systems, administrative burdens increase. For an implementation to become successful, all employees working with the tracking-and-tracing system must receive proper education.

(2) Besides learning a new way of working, the necessity of all extended registrations should be known to everybody. A simple way of registration with barcode equipment or radiofrequency equipment may increase the level of acceptance and decrease the possibility of mistakes.

1.3 Research objectives

The thesis aims at contributing to the functioning of food chains in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003). The idea is directly translated into our problem statement, which reads:

> *How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?*

The objective of the research is twofold:

(1) establishing the tracking-and-tracing functionality within an object system, i.e., establishing the supply chain, and

(2) representing the functionality by data models so as to facilitate the development of information systems suitable for tracking and tracing.

1.4 Research questions

To obtain the research objective, the following five questions are addressed:

(1) which elements characterise tracking and tracing, in relation to (i) an enterprise in the chain, (ii) its objective, and (iii) its administration?

(2) which functionality and performance with regard to tracking and tracing can be derived from the enterprise in the chain?

(3) which data models are fit for an adequate representation of the functionality?

(4) which reference-data model can be successfully constructed?, and

(5) what is the evaluation of the application of the reference model?

Chapter 2
Research approach

Chapter contents

2. Research approach

This chapter outlines our research approach in general. We distinguish four steps: (1) presenting the view of the thesis on the empirical reality, (2) describing the factors that are investigated, i.e., the variables, constructs and concepts, (3) presenting the inter-relations between the factors, and (4) discussing the representation and the validation of the research findings.
The approach is put in a research framework that is presented first (section 2.1). Then, the method of research is described (section 2.2). Subsequently, the method of data gathering is elaborated on (section 2.3). Thereafter, the representation of the research results is given (section 2.4). Following, the data conceptualisation is discussed (section 2.5). Finally, the organisation of the thesis is outlined (section 2.6).

2.1 Research framework

Our point of departure is the aim of contributing to the improvement of the tracking and tracing of products by means of business requirements, constraints, and modern ICT support. The five research questions of chapter one call for a closer investigation of the concept of tracking and tracing (i.e., we should emphasise certain knowledge questions). Moreover, we should obtain an accurate representation of the functionality, which is essential to tracking and tracing (i.e., we should emphasise certain design questions). In this section, we discuss in particular how we deal with the design questions.

We start with developing a view on the empirical reality and with selecting a theory so as to establish what different factors (i.e., variables, constructs and concepts) must be considered. Moreover, we wish to determine how these factors are related (Whetten, 1989). Porter (1991a) stresses the usability of frameworks: ”Frameworks identify the relevant variables and the questions which the user must answer to develop conclusions tailored to a particular industry and company. The theory embodied in frameworks is contained in the choices of included variables, the way variables are organised, the interactions among variables and the way in which alternative patterns of variables and company choices affect outcomes”.

In answering our problem statement and establishing the requirements for ICT support for tracking and tracing, we consider how production is organised, what management control is exercised and what information requirements are imposed; we use a specific *framework* developed by Bemelmans (1994, 1998). The theory of the framework is developed out of ideas by Blumenthal (1969, 1974) and De Leeuw (1982). Bemelmans distinguishes three concepts: (1) the production process, (2) the control concept, and (3) the information concept. He references the environment as first denoted by Blumenthal (1969, 1974) and De Leeuw (1982). No notion is included of the fact that information provision within a chain exceeds the level of a single actor so as to include multiple actors in the chain. In figure 2.1, we depict the framework of Bemelmans. Figure 2.2 depicts the extension. In the extended framework, the communication with other enterprises in the chain is considered for the case that the production is organised in such a manner so as to include several independent enterprises.

Figure 2.1 depicts the Process-Control-Information framework (the PCI framework) with the three layers: the production process, the control concept, and the information concept. The framework states that the requirements for information systems depend on the characteristics of the production processes, their control concept, and the associated reporting requirements. The layers are mutually dependent. They are explained below.

1. The figure depicts the dependency between the production process and the control concept. Given the characteristics of the production process, requirements are imposed on the control concept (arrow 1).
2. Vice versa, given the characteristics of the control concept, requirements are formulated for the production process (arrow 2).
3. The figure depicts the dependency between the control concept and the information concept. Given the characteristics of the control concept, requirements are imposed on the information concept (arrow 3).
4. Vice versa, given the characteristics of the information concept, requirements are formulated for the control concept (arrow 4).

The figure implies that the information concept is based on the requirements of the control concept, which in turn are derived from the requirements of the production process (*and, vice versa*). It acknowledges any interactions with the environment, as first denoted by Blumenthal (1969, 1974) and De Leeuw (1982).

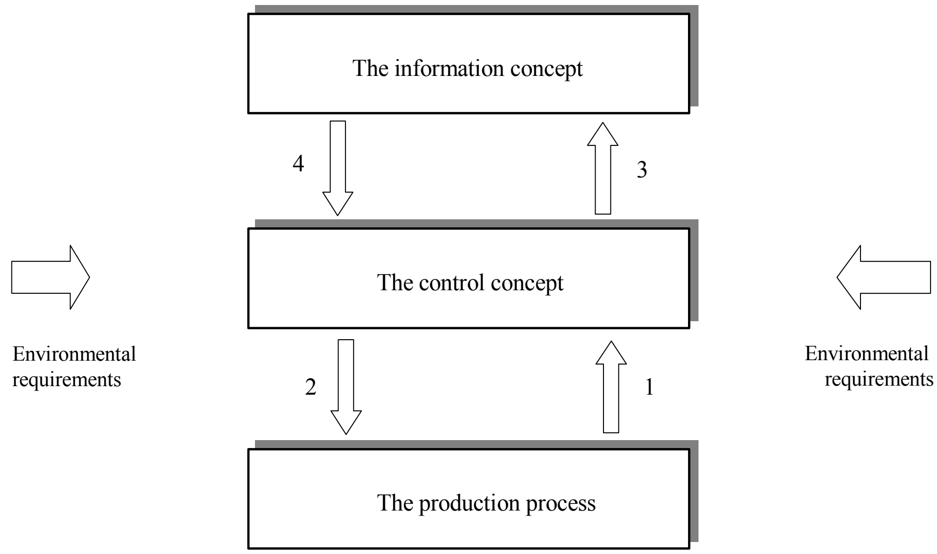

Figure 2.1: PCI framework (derived from Bemelmans, 1998).

Much standard software is based on assumptions of the production process to be controlled, the control concept, and the associated information concept (Van Rijn, 1985). With respect to the PCI framework, different control concepts and associated information concepts have been developed. Examples of control concepts embedded in standard (logistical) software are: Make To Stock (MTS), Assemble To Order (ATO), and Produce To Order (PTO). Different control concepts lead to differentiated information needs. Control over production processes is most effective when the information provision has been tailored to the specific situation under discussion.

The variety of functions supported by standard software is not only related to the control situation, it depends on the required interfaces between the enterprise information system and other systems that control processes elsewhere in the enterprise, too (Van Rijn, 1985).

For contemporary supply-chain applications such as tracking and tracing, software should include also the functionality to enable interfacing between a main production-information system and other information systems, *in a chain*. In facilitating interfacing between enterprise systems in a chain, interchange standards are required. It implies a need to represent information infrastructure in the PCI framework[6]. In figure 2.2 we see the information-infrastructure concept added (as compared to figure 2.1). The idea of figure 2.2 is that any enterprise must be able to connect to the information infrastructure so as to exchange information in the supply chain. The figure indicates the dependency between the information-infrastructure concept and the information concept.

5. Given the information concept(s), interface requirements are imposed on the information-infrastructure concept (arrow 5).
6. Vice versa, given an information-infrastructure concept, interface requirements are formulated for the information concept(s) (arrow 6).

Accordingly, requirements of inter-organisational interface standards (i.e., non-proprietary) are located in the information-infrastructure layer. For example, the requirements for data exchange with EAN-128 (by the international Article Numbering Association) are located on the infrastructure level.

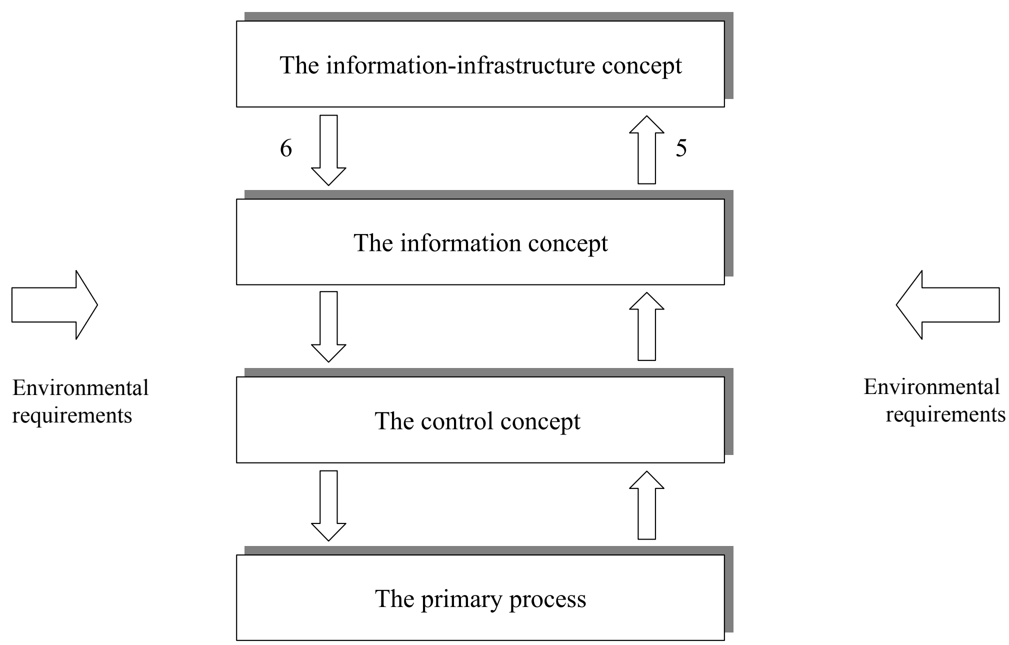

Figure 2.2: Extended PCI framework (Jansen-Vullers et al., 2003).

[6] Information infrastructure: technical infrastructure, data infrastructure, generic applications, (inter-)organisational provisions and standards.

The (extended) PCI framework helps us to find an answer to our problem statement. In answering the problem statement we propose to follow the philosophy of the (extended) PCI framework. This means that we start investigating the organisation of the production processes in the chain, then seek out the desired concept of control, and subsequently derive an appropriate information concept. From the study of production processes in the chain, we want to become aware of the product properties to be controlled. Finally, we want to determine the concept for controlling these properties on behalf of tracking and tracing. In chapter one, we mentioned generating properties. They are the properties we wish to control. For them we wish to establish an information concept. The properties are related to (1) the product itself, (2) the processes (and the attributes thereof) that produced the product, (3) the production means that were used in the production processes, and (4) the relationships between (1), (2) and (3).

2.2 Research method

Below, we discuss the research method. It should portray the anchoring of our investigations in the 'design' science. Therefore, we first discuss the characteristics of the 'design' science. Then, we show how our thesis relates to theory-oriented research and how theory is actually developed in the thesis. Moreover, we describe the role of case studies. We finish the section by explaining the explicit relation on the level of each research question.

Design science

A 'design' science has the mission to develop knowledge on behalf of the design process itself and on the behalf of future improvements (Van Aken, 1994). The knowledge is primarily meant for use by professionals in the area under investigation. A professional is a person from a clearly described profession, who uses scientific knowledge to solve value problems. Van Aken (1994) has built a theory on 'design' science in which he refers to Freidson (1973), Schön (1983) and Van Aken (1991). He states that a professional can be an architect, an aeroplane constructor or a business manager. Value problems refer to problems in reality: the knowledge obtained is of business value. This clearly contrasts with knowledge problems, which are characterised as truth problems: the knowledge obtained there is less likely to be of direct value to business (Van Aken, 1994). Basically, two types of research are distinguished: theory-oriented and design-oriented research (Van Eijnatten, 1992). In theory-oriented research, knowledge is the result to be obtained; in design-oriented research the result to be obtained is a design (Florusse and Wouters, 1991). In design-oriented research, the essence of the professionals work consists of designing (Van Aken, 1994).

Design science is one of the topics of the thesis. Design science has been accepted as such in a part of the scientific community. Van Eijnatten (1992) refers to a conducted study, assigned by the ‘Technology, Labour and Organisation Programme’ (in Dutch: Technologie, Arbeid en Organisatie, TAO). The TAO committee considered the methodological aspects of design science. The Parliament brought the program into being in 1985. Resulting from the study on design science, a list of important points-of-departure for design-oriented research is produced.

The main characteristics of design science are: the prescriptive nature, the design process itself, the scientific nature, the organisational nature, the multidisciplinary aspects, and the consequences of design (and potentially its prevention). Below, we give the contents of these six characteristics by enumerating some factors, which support the characteristics.

Design-oriented research is prescriptive, since:

- it constitutes a knowledge base for improving the design;
- it supplies insights by which better choices can be made;
- it provides a correspondingly better control on actions;
- it applies knowledge for a means-end analysis;
- it applies a general method of abstraction.

Design-oriented research focuses on the design process, since:

- it puts emphasis on organisation diagnosis;
- it emphasises targeted intervention and evaluation of effects;

- it applies the regulative cycle[7];
- it uses theory of development when shaping the design.

Design-oriented research is scientific, since:

- the major part of investigation goes to internal and external validity;
- emphasis is put on generalisation;
- there is attention for verification and reliability;
- it accordingly applies accepted research methods and techniques of other sciences.

Design-oriented research focuses on the organisation as a whole, since:

- all aspects are studied in relation to each other;
- a systems approach is applied in its context;
- a synthesis is aimed at within the research framework;
- the research applies an integral view.

Design-oriented research is multidisciplinary, since:

- a problem-oriented approach is applied by technical and organisational sciences;
- an interdisciplinary collaboration can be deployed.

Design-oriented research focuses on consequences (and therefore on prevention), since:

- any researcher takes into account the work-related and organisational consequences;
- the role of the researcher is characterised by active involvement and co-participation in the solution.

As stated earlier, the research of the thesis deals with the design of reference-data models for tracking and tracing. The research method we will follow is the regulative cycle. Figure 2.3 depicts the cycle. The regulative cycle consists of a problem phase, a diagnosis phase, a planning phase, an intervention phase, and an evaluation phase. In the problem phase, bottlenecks within the area of interest are listed and addressed. In

[7] Van Strien (1975, 1997).

the diagnosis phase, the analysis of the problem takes place. In the planning phase, a design is proposed to solve the problem. In the intervention phase, an attempt is made to try the design in practice. In the evaluation phase, the failures and successes of the design are evaluated. In our thesis we follow main phases of the regulative cycle. In several distinct phases of the regulative cycle, we have investigated multiple cases for obtaining reliable assumptions on the construction of our design. Moreover, we needed several cases to make generalisation (i.e., the reference aspect) possible.

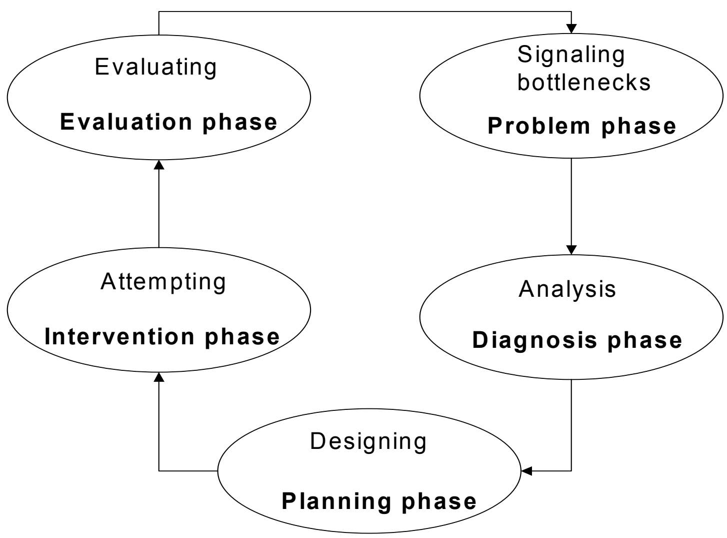

Figure 2.3: Regulative cycle (Van Strien, 1975; Van Eijnatten, 1992).

Obviously, several views on the designing process are possible. For instance, Sarlemijn (1989) signals that designing is viewed as the application and trial of research results. As such it fits to the theory-oriented research methodology. Developed designs (of which a reference-data model is an example) are considered the carriers of the recorded theory. Below, we explain how our design-oriented research is connected with theory development and theory testing.

We start providing a regular definition of theory: a theory is the whole of propositions about some part of reality, which are coherent and not conflicting, and which have been formulated in such a way that at least one empirical testable hypothesis is derived

(Baarda and De Goede, 1990). Porter (1991a) denotes that theory is contained in the choices of the included variables, the way variables are organised, the interactions among variables, and the way in which alternative patterns of variables and company choices affect the outcomes.
We explain two important theory-oriented concepts (induction and deduction), and their relation to the thesis.

Induction

The derivation of a theory, from a finite number of empirical facts, is referred to as induction (Van der Zwaan, 1995; De Leeuw, 1993; De Leeuw, 1996). According to Whetten (1989), a first step in theory building is the constitution of propositions, which involves an initial exploration and formulation of concepts concerning the empirical domain. Eisenhardt (1989) stresses the importance of an a-priori specification of theory components in the first steps of theory building. He states that a-priori specification of theory components helps to shape the initial design of theory building research. To answer the knowledge questions in the thesis we present theory components on tracking and tracing. To answer the design questions in the thesis we formulate design requirements from case-study research (i.e., an initial design theory).

Deduction

The formulation of research results by the derivation of specific statements from general ones is referred to as deduction (Van der Zwaan, 1995; De Leeuw, 1993; De Leeuw, 1996). In the thesis, we apply deduction by testing a prototype. The design of the prototype is considered the carrier of the theory described previously. It comprises of a set of design requirements. By formulating the prototype we validate our design theory. In the thesis the prototype is tested on practicability and usefulness.

The function of unfolding and testing theories with case studies, is acknowledged by Van der Zwaan (1990), Yin (1989) and De Leeuw (1993).

The role of the case studies

Different research methods, their workings, and primary goals are compared to make plausible that a specific research conduct leads to reliable and valid research results. Below, we describe five important conducts of research in general, and focus in particular on the conduct chosen for the thesis: the case study. We subsequently elaborate on the case-study conduct and describe four factors that require our specific attention in this respect (Yin, 1994): (1) concept validity, (2) external validity, (3) internal validity, and (4) reliability.

Below, five research methods, their workings, and primary goals, are explained: field experiment, survey, case study, action research, and ethnography[8].

Table 2.1 provides the methods, the workings and the primary goals, along with some examples. With each method a specific conduct is associated. It should lead to reliable and valid research results (Den Hertog and Van Sluijs, 1995).

[8] Non-exhaustive.

Table 2.1: Research conduct (Den Hertog and Van Sluijs, 1995; supplemented).

Main routes	**Workings**	**Primary goals**	**Example**
Field experiment	Groups submitted to intervention are monitored before and afterwards; they are compared to groups not submitted to intervention.	Supply evidence, trying something new	Functioning of autonomous production groups (Den Hertog, 1978)
Survey	A set of factors measured in the same manner for a number of individuals or groups	Generalised assumptions on groups (exploration)	Success factors in product development (Cooper, 1980)
Case study	Study of a contemporary phenomenon in its natural context	Exploration, reflection, supply evidence	Design of an expert system (Leonard-Barton, 1990)
Action research	Research is designed and executed with members of an organisation	Organisational development and knowledge development	A program for democratic management (Gustavsen, 1992; Checkland and Scholes, 1990)
Ethnography	The researcher mingles with a group and observes carefully	Exploration, reflection	Social tragedy in organisations (Rosen, 1988)

The research conduct of the thesis is the case study. Below, we present some arguments as to why a case study has been chosen. The case study is the most important research type in the design paradigm (Van Aken, 1994). As seen from the point of view of the conduct, the designer does not assess the truth but attempts to learn effectively from the various problem approaches. Yin (1989) argues that case studies are favoured when contemporary events are examined and little or no control is exercised over these events by the researcher. In the different research phases of the thesis this is precisely the case, as in the thesis the focus is on the description and analysis of contemporary events and situations, without the researcher *influencing* them. By using case studies, the contemporary events are studied in their natural context, so as to facilitate the understanding of the researcher and the interpretation of the results. According to Van der Zwaan (1990), case studies are very suitable to overcome the relative novel aspects and new issues of the cases involved. In summary, case studies provide us with the means of investigating the “as-is” (tracking and tracing) within the real-life context of the organisations, with respect to information and communication technology.

For each case study, four main factors require attention (Yin, 1994): (1) concept validity, (2) external validity, (3) internal validity, and (4) reliability. Below, we present the definition of the factors and how the thesis deals with them.

1. Concept validity: establishing correct and accurate ways of measuring the concepts being studied.
   Chapter 3 investigates the concept tracking and tracing. The appearances and characteristics of tracking and tracing are described. A definition of tracking and tracing is consolidated and is taken into account by the empirical data gathered.

2. External validity: establishing the domain within which a case study takes place and how its findings are generalised.
   A general modelling solution captures the tracking-and-tracing requirements in the thesis. The solution may be analytically generalised in the manufacturing domain, with special reference to logistic and quality. A strengthening of external validity has been exercised, by selecting four case studies to obtain tracking-and-tracing solutions for manufacturing. Moreover, a non-food case was included for the purpose of differentiation within the manufacturing domain.

3. Internal validity: establishing a causal relationship between experimental variables and dependent variables; certain conditions are to lead to other conditions by means of an accurate data analysis.
   We emphasise the exclusiveness of interpretation, i.e., are the results truly caused by the identified variables, or are any data overlooked, possibly identifying other variables? In light of the internal validity (the exclusiveness of interpretation of the results), we would like to avoid any error(s) by whatever data bias. Different variables and independent factors as well as data sources are used in the research.

4. Reliability: demonstrating that the conduct of a study can be repeated and will achieve the same results.
   Reliability describes the extent to which a repeated measurement of the same variables will lead to the same result. The thesis deals with reliability by describing as closely as possible: the object system, the research questions, the method(s) applied and the research instruments used.

The conduct on the level of each research question

Below, we elaborate on the comprehensive conduct of investigation, encompassing all individual research questions. For this purposes, we repeat our five research questions.

1. Which elements characterise tracking and tracing, in relation to (i) an enterprise in the chain, (ii) its objective, and (iii) its administration?
2. Which functionality and performance with regard to tracking and tracing can be derived from the enterprise in the chain?
3. Which data models are fit for an adequate representation of the functionality?
4. Which reference-data model can be successfully constructed?
5. What is the evaluation of the application of the reference model?

The method of investigation used to answer the first question, i.e. the knowledge question, is the drafting of an initial proposition on tracking and tracing and the exploration of the proposition by an extensive literature study. First, a survey is made of tracking-and-tracing literature so as to present operational tracking-and-tracing definitions. Then, the findings of the literature survey are used to describe tracking and tracing more precisely by its appearance and characteristics.

The method of investigation used to answer the second, third and fourth (design) question relies primarily on case-study research, which was elaborated on previously. The method of case study will be used in the problem and diagnosis phase and in the planning phase of the research. In the problem and diagnosis phase, the main objective is the derivation and establishment of a finite number of sets of tracking-and-tracing requirements. In the planning phase, the main objective is the generation of a general set of tracking-and-tracing requirements and the modelling of a general solution: a reference-data model.

The method of investigation used to answer the fifth question is also the case study. There, the method of case-study research is used in the evaluation phase of the research. In this phase the objective is twofold: to obtain feedback on the design and to get feedback on its materialisation. With regard to the first part: the case participants should assess whether the reference model covers *their* tracking-and-tracing requirements. With regard to the second part: the case participants should assess the presentation of the prototype. An actual intervention as recorded in the regulative cycle has neither been conducted nor was it the objective of the case participants at the time of the research.

2.3 Method of data gathering

Below, we discuss how the data from the investigation(s) are collected from the object system. Fundamentally, five different ways of data acquisition are used in our research:

1. data acquisition through documented material;
2. data acquisition through documented feedback;
3. data acquisition through face-to-face questionnaires;
4. data acquisition through observation;
5. data acquisition through group meetings.

The relation between the data acquisition used and the research questions under investigation is described below.

The method of data gathering used in answering the first research question of the thesis is the collection of data from well-established and documented material (literature) so as to perform a homogenisation of the different views and perspectives on tracking and tracing. The method of gathering data used in answering the three following research questions is collecting data from three sources: (1) documented business sources (literature), (2) face-to-face questionnaires (qualitative), and (3) (process) observation.

The method of gathering data used in answering the fifth research question, is collecting data from again three sources, viz.: (1) data are obtained from face-to-face questionnaires (qualitative), (2) group meetings, and (3) documented feedback.

2.4 Representation of results

Below, we describe the representation techniques applied in the research process in relation to the approaches used. The approaches are discussed per research question.

The representation technique applied for the representation of the results of the first research question is *natural language*. Structured natural language is used as a representation means to describe the main results of conducted literature study on tracking and tracing. Functionality of tracking and tracing is precisely and coherently described.

The representation technique applied for the representation of the results of the second research question is *systems modelling*. Researched enterprises are represented as (black-box) systems of which their process organisation is depicted by schematics. The sets of tracking-and-tracing requirements derived from studying the enterprises are represented by *structured natural language*.

The representation technique applied for the representation of the results of the third and fourth research question is the representation by the *Entity Relationship Model (ERM).* The sets of specific tracking-and-tracing requirements, represented by natural language, are subsequently translated into one set of general design requirements. For the set of general design requirements, part-models are developed and represented by entity relationship modelling. An entity relationship model represents the comprehensive modelling solution too: the reference-data model. The model concisely describes the entity (relationship) type(s) and the semantic(s).

The representation technique applied for the representation of the results of the fifth research question is *natural language*. Spoken and written feedback will be given on the reference-data model and on its materialisation. The reference-data model (itself) is represented by entity relationship modelling. The materialisation (thereof) is represented by a *software prototype*.

The representation of modelling solutions constitutes a large part of the thesis. The representation of modelling solutions has not been discussed extensively. No description has yet been given of the concepts that are used nor has the meaning of concepts been explained explicitly. Below, we therefore finish with an elaboration on the data conceptualisation.

2.5 Data conceptualisation

Reference models are designed with the objective to be re-used. To facilitate the re-use of reference models, their conceptualisation must be specified explicitly. This is referred to by the term ontology. An ontology is an explicit (formal) specification of a conceptualisation (Gruber, 1994, Borst 1997). A conceptualisation is a structured interpretation of a part of the world that people use, to think and communicate about the world (Borst, 1997). Genesereth and Nilsson (1987) refer to conceptualisation as the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold them.
Kusters (2001) identifies a broad stream of approaches for ontologies that vary from predicate-logic-based languages, via data models, up to structured textual descriptions. Advantages of using ontologies are: (1) they support the design of information systems and (2) they facilitate the unambiguous communication between people, between information systems, and between people and information systems.

In selecting an ontology for tracking and tracing, we ask ourselves, what are the main representation needs? In chapter one, we mentioned the representation of the object system. On behalf of tracking and tracing, we need to account for the representation of the different objects that are found within the object system. Of special interest are the objects that are subject to (any) transaction. We especially need to account for the representation of their processing history, including their (past) relations with other objects within the object system. For tracking and tracing, we accordingly infer a need for three satisfying data concepts (De Heij, 1996; Bertrand et al., 1990): (1) standing data, (2) transaction data, and (3) associative data. Below, these data concepts are explained.

First, we deal with the representation of standing data. They are directly found in a certain company: such as departments, suppliers, customers, machines, etc. These standing data are also called state-independent data (De Heij, 1996). The state-independent prefix denotes that the state of the data objects under discussion does not change, during the flow of the goods through the company. State-independent data are master data with a relatively permanent character. In fact, a company is able to function relatively good without creating new master data for a while. The state-independent data or master data are stored in so-called master files.

Second, we need to represent transaction data. These data are basically created dynamically in time and usually in association with other entity types. Transaction data are referred to as state-dependent data (De Heij, 1996). The state-dependent data are created in the daily interactions of the enterprise with its environment. The state dependent prefix denotes that the state of the data objects under discussion changes during the flow of the goods through the company. Typical examples of transaction data are: quotations, orders, and stock movements.

Third, we need to represent associative data. Associative data describe the diversity of relationships possible between (1) the standing data, (2) the transaction data, and (3) the standing data (or transaction data) and (other) associative data. Examples of associative data are: the bill of materials, routings, and the bill of lots. Although enterprise-information systems have similar standing data, their associative data are modelled very differently depending on the configuration of the business process. Information on standing data, transaction data and associative data is found in Bertrand et al. (1990).

Having discussed our main representation needs, we now turn to the question of what ontology holds the expression power, so as to satisfy our representation needs? Sufficient coverage for our representation needs is found in the Entity Relationship Model (ERM). The ERM is available to model schematically the object system according to our main requirements. As of the initial introduction of ERM by Chen (1976), the modelling method has evolved, so as to capture comprehensive meaning. As of the extension with semantic modelling concepts, the ER model turned into the Enhanced or Extended-ER (EER) model (Elmasri and Navathe, 2000). The extension with semantic concepts (to capture meaning of the object system) enables the representation of complex requirements and makes ERM at least suitable for our modelling objective.

In conclusion, we propose to use in this thesis, the notation of ERM. Figure 2.4 illustrates how the data of the data structure are related. The figure indicates the degree of complexity of a relationship by specifying how many other entities are assigned to a certain entity of a certain entity type. Stated differently: the number of instances of one object type, which are associated with an instance of another type. The notation is used throughout the thesis for representing the data of the object system.

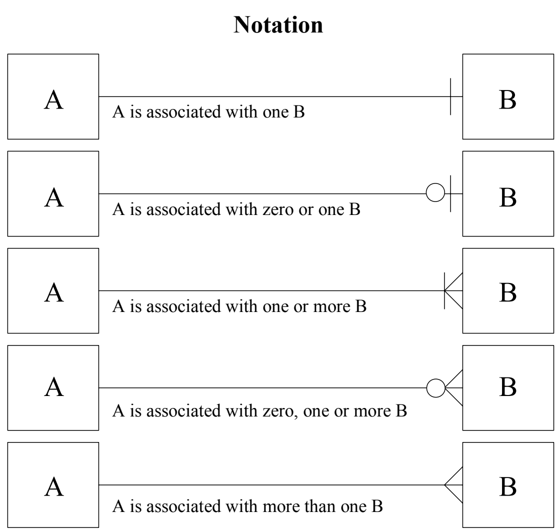

Figure 2.4: The applied ERM notation.

Next to the identification of the entity types, we identify the important attribute class types, which characterise the entity types. In the thesis, they are represented by (structured) natural language.

2.6 Organisation of the thesis

The thesis is divided into six chapters. The chapters discuss the research description (chapter 1), the research approach (chapter 2), tracking and tracing (chapter 3), the reference-data model (chapter 4), the evaluation of the reference-data model (chapter 5), and the conclusions (chapter 6). Below, we describe the chapters. In figure 2.5 we schematically depict the organisation of the thesis.

Chapter 1 presents the research motivation by describing the problem statement, an introduction of tracking and tracing, a societal view on food, a scientific view on information systems, and an overview of contemporary systems. Following, the research challenges are presented. Finally, the research objectives and the research questions are listed.

Chapter 2 presents the research framework and elaborates on the conduct of research by discussing: the research method, the method of data gathering, the representation of the results, the data conceptualisation, and the organisation of the thesis.

Chapter 3 represents the object system with a special reference to the logistic and the quality infrastructure. The chapter describes the literature on tracking and tracing, and presents the functionality of tracking and tracing required by the object system. Finally, the role of stakeholders to tracking and tracing is elaborated on.

Chapter 4 introduces four case studies and describes the tracking-and-tracing requirements. The cases are taken from: the agri-industry, the food industry, the non-food industry, and the pharmaceutical industry. The case requirements are generalised so as to enable the construction of a general modelling solution: a reference-data model.

Chapter 5 describes the evaluation of the reference-data model and the application. A description of three test cases is presented, and requirements are discussed. A description of the prototype application is given. Further, the reference-data model is evaluated. Subsequently, the main functionality of the prototype and the desired extra functionality of the prototype are evaluated.

Chapter 6 formulates the conclusions of the research. The problem statement is reiterated first. Then, the five research questions are answered. Following, we draw a final conclusion on the research. Finally, recommendations for future research are given.

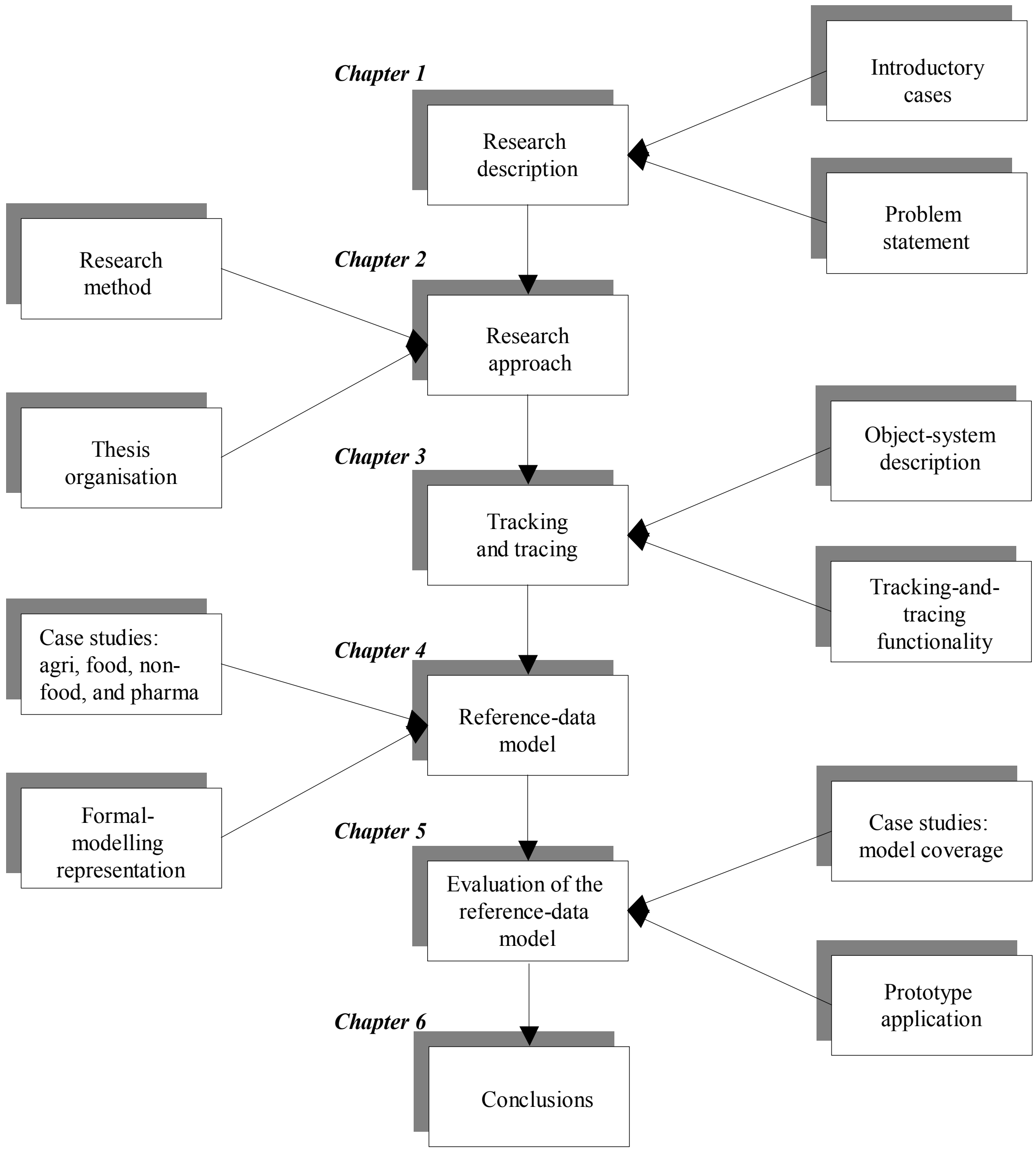

Figure 2.5: Organisation of the thesis.

Chapter 3

Tracking and tracing

Chapter contents

3. Tracking and tracing

In this chapter we examine the scientific literature to sharpen our initial statement on tracking and tracing, as made in chapter one[9]. We investigate (1) available theories and models that describe (the properties of) the object system, and (2) the desired tracking-and-tracing functionality within the object system.
We start the chapter with background information (section 3.1) and the properties of the object system (section 3.2). Following, we discuss functionality within the object system (section 3.3). Subsequently, we present the role of the stakeholders (section 3.4). We finish with a chapter summary (section 3.5).

3.1 Background information

We reiterate our problem statement:

> *How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?*

For adequate tracking and tracing it is necessary to know what the nature of tracking and tracing is in a particular case, and what actions need to be taken. In chapter 1 we described for each of the eleven case studies, the date of the incident, what happened in the case, how the incident could happen, what the impact of the incident was, and what the consequences attached to the case were. This information enabled us to formulate what tracking and tracing (initially) constitutes and what representation requirements (initially) are needed for information-system development.

In chapter one, we acknowledged the need for a consolidated notion of the tracking-and-tracing functionality within the object system. We formulated a first notion of what tracking and tracing constitutes. We explained that companies have many quality systems and measures in place, including the monitoring of the quality of processes and

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[9] Parts of this chapter have been published in Van Dorp (2002).

products. Together they determine how the safety of products is guaranteed. Subsequently, we posed the question: how do we monitor (pro-actively) the quality so as to ensure on a transaction basis that for each product quantity, the quality aimed for remains stable? This would require a procedure to track the whereabouts and the status of the quality of the products, as well as the deviation from a predefined specification. We explained that in case of a deviation, the source or origin of the problem must be traced as good as possible, and all products that may share the properties that caused the identified deviation should be followed, by tracking these items downstream in the chain.

Hence, tracking and tracing must at least support: (1) tracking, (2) forward traceability, and (3) backward traceability. With tracking we would be able to follow a product through the supply chain, and registering any data considered of any historic or monitoring relevance. With forward traceability we would be able to list all the products, having consumed a particular (deficient) material of interest (i.e., products that have a (set of) properties in common). With backward traceability we would be able to list all the raw materials, consumed by manufacturing for the production of the one particular product, and trace these materials (and associated properties) further backward. The complete set of visible and invisible (associated) properties that a product (group) has in common and in which we are interested, are referred to as the generating properties of the product (group). In general, the properties may be related to the product itself, to the processes that produced the product and to the production means, used in the production processes.

Finally, from the eleven cases discussed in chapter 1, we derived that the following five items must be accounted for in representing the object system:

(1) the objects present in the object system (physical or abstract);
(2) the type of objects subject to tracking and tracing;
(3) the information of interest on these objects (e.g., the provenance of objects[10]);
(4) the (activated) relations between the objects (e.g., provenance relations[11]);
(5) the integrity requirement.

[10] Generally translated as origin; in the thesis we particularise it to *first* origin.
[11] Provenance relations: precedence relations between organisations/processes that processed the product.

The integrity requirement is twofold, it includes: (1) the integrity of the representation and (2) the integrity of the object system.

(1) The integrity of the representation states that the representation of the object system must be in accordance with the reality of the object system it represents. It implies that the representation is an accurate and real-time view of the object system.
(2) The integrity of the object system states that the object system itself (i.e., which is represented) must be in a state of being whole or complete. It presupposes that all entities constituting the supply chain are known (for efficient traceability).

Both types of integrity are particularly related to the *performance* of tracking-and-tracing systems. We distinguish them from product integrity. Product integrity refers to natural integrity (natural objects) and artificial integrity (artefacts). Natural integrity represents the fact that a natural object adheres to its supposed natural state of being. Artificial integrity represents the fact that an artificial object adheres to its artefact specification.

In section 3.2 we investigate the logistic and quality properties of the object system. Section 3.3 examines the functionality of tracking and tracing. Then, in section 3.4, we discuss the role of stakeholders. A chapter summary is provided in section 3.5.

3.2 Properties of the object system

In this section we investigate the representation of the object system. Over the years, different models of an object system have been developed. We mention two of them. Logistic models conceptualised the object system for logistic control and detailed the associated information needs. Likewise, quality models conceptualised the object system for quality control and detailed its associated information needs. Over the years, a variety of logistic and quality models and their associated information needs were described in the literature. Since tracking and tracing include both a logistic and a quality view of the object system, these models are helpful in representing the object system for tracking and tracing, accurately. The models give us insight into what to represent of the object system and how to represent it. To establish a tracking-and-tracing control and information concept, it is imperative to know what properties to represent and how to represent them. For this purpose we discuss a subset of the available logistic and quality models, viz. those that can be used for the object system. The object system we aim at will have two types of infrastructures: a logistic infrastructure and a quality infrastructure. The logistic infrastructure is described with logistic models (of subsection 3.2.1). The quality infrastructure is described with quality models (of subsection 3.2.2).

3.2.1 Logistic infrastructure

On our object system we consider two infrastructures: a logistic infrastructure and a quality infrastructure. In each infrastructure a set of models is investigated so as to be applied if a case requires it. Below, we discuss the logistic models. Logistic models conceptualise the object system for logistic control. The models represent the information needs of the object system, from a logistic perspective. Quite frequently, there are representation differences caused by the specific variables within the object system and the control exercised over them. Below, we provide a general overview of variables and control. In passing, we remark that one of the first authors who did so was Bemelmans (1986). The variables of the object system are classified into three categories: (1) product/market characteristics, (2) production means, and (3) production process characteristics.

(1) Examples of variables of the product/market category:
complexity of end products, demand dynamic, demand predictability, economic value (stock provisions yes/no), and quality level (stock provisions yes/no).

(2) Examples of variables of the production means category:
number of different production means, multi deployment of production means, dynamic (fluctuations) of the supply of production means, supply predictability of the means, economic value of means (keep stock provisions yes/no), and quality level of means (keep stock provisions yes/no).

(3) Examples of variables of the production process category:
number of different production operations, relation between different operations (routing), operation time and quality (machine change losses and start-up losses,

specification-changes), predictability of dynamic(s), economic value of operations, and quality level of operations.

The way, in which control is exercised over these variables, indicates how the object system is actually to be represented. The manner, in which the object system is configured and is represented, depends on four matters: (1) the implemented organisation of the production means, (2) the implemented organisation of control (integral versus decoupled), (3) the implemented objectives, and (4) the implemented control functions and characteristics.

(1) Examples of implemented organisation of production means:
process, line, flow, shop, job-shop, and project organisation.

(2) Examples of implemented organisation of control:
produce to stock (anonymous production) and produce to order (customer production).

(3) Examples of implemented objectives:
cost minimisation, delivery time, throughput time, and quality levels.

(4) Examples of implemented control functions and characteristics:
who does what, methods of control, including speed, frequency, level of detail, and adaptability.

We have now described a variety of variables and control possibilities for the object system. What we have omitted, however, is a description of how variables and control are actually related for different models. Below, we therefore investigate those models of the object system that provide us with a more *coherent* description of logistic variables and control. We distinguish: models for logistic control and models for distribution control.

Models for logistic control

The configuration of variables and the control exercised over the variables by companies in the chain, determines the span of control that companies have over their goods. Moreover it determines to what extent companies can *track and trace* their goods efficiently and effectively. Below, we present in this respect five differently configured models. The models (*coherently*) conceptualise the object system for logistic control. They are: (1) make and ship to stock, (2) make to stock, (3) assemble to order, (4) make to order, and (5) purchase and make to order (Van Goor et al., 1996; Hoekstra and Romme, 1992; 1993).

The different models are characterised by the Customer Order De-coupling Point (CODP), which indicates to what point in the supply chain (upstream) a customer order penetrates the production process of a product or service supplier. To the right of the CODP (i.e., downstream), production is executed on the basis of known and noted customer orders. To the left of the CODP (i.e., upstream), production is executed based on prediction (anonymous production). The CODP concept and its associated information needs are important in the logistic control of the object system (Trienekens and Beulens, 2002).

(1) In the model make and ship to stock, products are manufactured and distributed to stock points that are decentralised and located in the proximity of the customer.
(2) In the model make to stock, end products are contained in stock at the end of the manufacturing process. From there products are being shipped directly to geographically dispersed customers.
(3) In the model assemble to order, a product for one specific customer is assembled. Only system elements are in stock in the production facility and the assembly takes place on specific customer order.
(4) In the model make to order only raw materials and parts are maintained at the production facility and no other stock is kept. Every order for a customer is a specific project.
(5) Finally, in the model purchase and make to order no stock of finished product is kept at all, purchase is related to a specific customer order and the whole project is accounted for by one specific customer.

Below, we show the advantages and disadvantages of the position of the CODP within the models. Insight into the relation with the CODP is best obtained by discussing two extremes: model 1 and model 5.

Model 1:

- The advantage of the first de-coupling structure is its short delivery time.
- The disadvantage is its high stock and risks of obsolescence. For the food supply chain, the latter is very important with respect to perishablility.

Model 5:

- The advantage of the last de-coupling structure is that no stocks are kept.
- The disadvantage is the relatively long throughput time as raw materials are ordered only when the customer has set his order.

A recent development in fresh food supply chains is the shifting of the CODP upstream in the chain (Van der Vorst, 2000). As of the detection of inefficiencies in the chain due to the packing and (multiple) re-packing of products, information on the consumer's wishes is routed directly to initial primary producers and suppliers to improve performance. Nowadays, the Greenery tries to connect suppliers and customers directly, to pack products at their production source according to customer wishes. Trienekens (1999) and Trienekens and Beulens (2002) refer to the Chain De-coupling Point and extends the notion of the (traditional) CODP to a supply chain scope.

In conclusion, the place of the CODP within an object system (i.e., the configuration of variables and the control exercised over these variables) gives us an idea of the control that is exercised by a company over its goods flow. It is an important indicator of the extent to which a company is initially able to track and trace its goods, efficiently and effectively in the supply chain. On this topic, we discussed five models. All models have a specific concept of control and consequently, have an information concept that matches that. For the designs on the associated information concepts, we refer to the reference models mentioned in chapter 1: production logistic reference models (Van Rijn, 1985) and manufacturing reference models (De Heij, 1996; Scheer, 1998). By studying these reference models, we obtain an initial idea of the data models useful to tracking and tracing.

Models for distribution control

Better control over the good flow and improved possibilities for tracking and tracing can be obtained also with the application of distribution models. If companies exercise control over the distribution organisation and the grouping of products in the chain, their ability to track and trace products through the supply chain, increases, too[12]. We present in this respect two models. The models (*coherently*) conceptualise the object system for distribution control (Trienekens, 1999):

(1) models for the organisation of distribution processes;
(2) models for the organisation of products into logistic categories.

The object system is represented differently in these models. With respect to the control over the goods flow, different information needs are formulated. The two models complete our discussion.

(1) Models for the organisation of distribution processes

We distinguish four models for the organisation of distribution processes: (i) distribution from stock, (ii) distribution from the distribution centre, (iii) cross docking, and (iv) transito. Below, we describe the main aspect of each model.

(i) With distribution from stock, products are routed directly from the manufacturer facility to the retail outlets.
(ii) With distribution from the distribution centre, products are kept in stock at the distribution centres.
(iii) With cross docking, products are passed through the distribution centre just to be assembled with other products into one delivery and are passed on directly to the customer.
(iv) With transito, products are simply transferred to the customer via the distribution centre. The manufacturer assembled the products on the level of the retail outlet.

The distribution process configuration is considered an important infrastructure component of the object system under discussion. As with the CODP, the configuration of distribution processes is related to the desired control over the goods flow.

[12] Hentzepeter (2002) refers to Intelligent Tracking and Tracing (ITT).

The control that is to be exercised over the goods flow must be supported by an adequate information concept. Hence, the application of a particular distribution concept implies establishing an information concept that enables this control.

(2) Models for the organisation of products into logistic categories

Products are grouped into logistic categories. A logistic category is subdivision of products into a class of products that share the same method of ordering, delivery, and stock keeping. Eight properties that enable the classification of products into logistic categories are (Vermunt, 1993):

- (i) perishability;
- (ii) conditioning;
- (iii) value density;
- (iv) form;
- (v) weight/volume relation;
- (vi) packaging density;
- (vii) discontinuity (seasonal character);
- (viii) country-specificity.

When products are ordered in logistic categories, they share the same method of ordering, delivery, and stock keeping. The ordering, assigns the products with specific generating[13] properties (of the category ordered upon). Especially perishability and conditioning are important properties of logistic categories in a food chain. However, we remark that, as the method of ordering, delivery, and stock keeping for the different actors in the chain is not the same, products may be regrouped into (other) assembly units, and their generating properties may be extended. Vermunt (1993) distinguishes five assembly units for regrouping:

- (i) the modality unit (train, ship, aeroplane, truck);
- (ii) the transportation unit (container, truck container, trailer);

[13] The complete set of visible and invisible properties that a product (group) has in common and in which we are interested, are called the generating properties of the product (group). In general, the properties may be related to the product itself, to the processes that produced the product, and to the production means that are used in the production processes.

(iii) the loading unit (pallet, roller, container);
(iv) the packaging unit (box, tray, crate);
(v) the product unit (article).

In case of regrouping the products in the food chain by different assembly units, generating properties of products may be extended on the basis of the generating properties of the product category onto which they were initially assigned (e.g., with regard to perishability and conditioning).

In as far as one wishes to trace the grouping of products with their generating properties in the chain, there is a need for an information concept that enables this. Similar to the control over the distribution process (discussed previously), the control over the regrouping of products in the chain requires a dedicated information concept.

3.2.2 Quality infrastructure

Quality models conceptualise the object system for quality control. The models represent the information needs of the object system from a quality perspective. The object system is represented differently depending on the configuration of certain object system variables. Before elaborating on possible quality models, we discuss the variety of variables responsible for such representations.

An explanation of quality variability within the object system is found in the characteristics of: (1) products, (2) processes, and (3) processors. Den Ouden et al. (1996), Trienekens and Trienekens (1993), Trienekens (1999), and Van Rijn et al. (1993) describe these characteristics. We discuss the three groups below.

(1) Characteristics of products

The quality variability of products can be characterised by their underlying causes (Den Ouden et al., 1996; Trienekens and Trienekens, 1993). We distinguish:

(i) lack of predictability of supply of product due to, e.g., weather conditions;
(ii) quality variation between different producers and between different lots of producers, which leads, e.g., to variable recipes;

(iii) perishability of (fresh) products, which limits the possibility of using stock as a tool to balance supply and demand;
(iv) unpredictable production yields due to quality variation within and between lots.

Quality characteristics usually vary at successive companies of the supply chain, starting with raw materials (highly perishable: quality variation in and between lots) to semi-finished products (less perishable and homogenised goods) and end products (non-perishable to little perishable and diversified products).

(2) Characteristics of processes

With regard to the processes of production and distribution, explaining factors for quality variability are (Trienekens, 1999):

(i) unpredictable production yields;
(ii) long production times (e.g., growing vegetables, fattening pigs);
(iii) short throughput times;
(iv) the distance to the market (a limiting factor with respect to transportation time);
(v) special demands with respect to the production and transportation (e.g., hygienic measures and cleaning);
(vi) conditioning of products such as cooling and freezing (many food chains have a dominant role for chilling technology);
(vii) diverging production processes;
(viii) the recycling of products.

(3) Characteristics of processors

With regard to the explaining factors of quality variability for processors, we refer to table 3.1. It describes the characteristics of the processors.

Table 3.1: Processor characteristics (Van Rijn et al., 1993).

Characteristics	Description
Timing constraints (shelf life)	For certain materials, shelf life constraints apply. Raw materials can only be kept for a short period of time (e.g., milk), intermediates are to be processed within a certain period of time or the finished product itself can only be kept for a limited period of time (e.g., cheese). Using up materials according to first in first out may not apply and different batches of the same product, but of different age, cannot be grouped and must be handled separately.
Variable yield	Variable yield may result from variations in production. Lead times, material consumption, and quantitative yield may deviate from planned. Variable operation time may occur, because of the time required to come to a sufficient quality level when materials of different quality are merged. Succeeding operations can be affected.
Work in progress	In branches like food and pharmaceutics external regulation or factors may induce the need for traceability of work in progress. This implies that each lot is treated individually and separately through the production process. In pharmacy it usually is necessary to track a lot from operation to operation. A file with process data is created and needs to be held for a certain period after delivery to the customer.
Diverging product structures	Diverging product structures can yield multiple products of different and ambiguous quality. Often catalysts are used in the process. Yoghurt is an example of a product that is regained after the process and fed back into the process. The ingredient yoghurt is used to initiate the production process.
Order dependency	The sequence of production orders can depend on product and process characteristics. Multiple orders cannot be planned independently from each order. Colouring operations for example can be scheduled from light to dark to reduce cleaning costs. Cross contamination also is an issue with certain materials.
Machine configurations	High volume capacity units are rigid and pose a major constraint to planning and scheduling of orders. Different production phases must be synchronised carefully as little flexibility is obtained from inventory (also holds rigid boundaries). Machine configurations must be defined for this purpose.

Table 3.1: Processor characteristics (continued).

Alternatives	Alternatives of installation usage and material usage are possible. A product can sometimes be made in different ways making a choice between available installations (throughput and material consumption may then differ). The product composition may also be subject to change: this depends on cost price of materials, quality levels of materials supplied or on quantitative availability.
Waste	Waste is related to the diverging product feature. Waste is the unavoidable by-product with a negative value. Its disposal has a price tag. Some waste disposal must be reported to the proper authorities.
Output driven execution	The output of an intermediate process step may determine which operations need to be executed next and in what way. For example cleaning or filtering may be an optional operation that is required after a certain process.
Quality tests	Quality tests often need to be done either in processing or as a separate operation. It can be the case that final inspection may take up more time than the actual production time. Goods under inspection are in stock, though cannot be used by production.
Restricted storage capacity	Storage is restricted when materials, semi-finished products or end products can only be contained in specific containers or tanks. This can especially be the case under regulation where batches may not be mixed and must be treated separately. Of course, this also is a capacity-planning problem.
Active material	Active material, such as protein, determines the value of end products as cattle food. The active material component is contained in other material components in the product. The concentration, amount or percentage of the active component can vary. Registration of the total product quantity therefore is not sufficient for planning. The active component needs to be taken into consideration separately.
Product quality levels	When using natural materials like crops or sorts, different product quality levels need to be accounted for. Apples for instance need to be sorted out into the quality levels. Some may go to direct sales, other apples that do not stand the quality level can be used to make apple juice.

We have now described a wide variety of variables and control possibilities for the object system, from the viewpoint of quality. We should be able to present an initial answer to an important question: What specific representation requirements do we identify from the previous descriptions on the characteristics of (1) products, (2) processes, and (3) processors, and what modelling concepts are needed in representing the requirements, appropriately? From the previous descriptions, we are able to infer three categories of representation needs, with associated concepts for modelling.

(i) Objects present in the object system:
e.g., finished products, semi-finished products, intermediates, raw materials, production orders, capacity units, operations, intermediate process outputs, active materials, material batches, and material lots.

The associated concepts for modelling are: entity types.

(ii) Information of interest on objects:
e.g., product and process characteristics, product quality levels, material consumption, quality inspection results, component concentrations, and amount/percentage of (active) materials.

The associated concepts for modelling are: attribute (class) types.

(iii) Complex relations between objects:
e.g., input-output process relations, lot-separation relations, lot-mixing relations, product structures, and product compositions.

The associated concepts for modelling are: entity relationship types.

It is clear that (i) entity types, (ii) attribute (class) types, and (iii) entity relationship types, are important to the modelling of tracking and tracing.

Above, we presented the variety of variables and control possibilities for the object system from the viewpoint of quality. We omitted, however, a description of how variables and control are actually related to each other in different models. Below, we therefore investigate those models of the object system that provide us with a more *coherent* description of quality variables and control.

Ten quality models

Below, we present (quality) models that *coherently* conceptualise the object system for quality control. An overview of ten models is presented: (1) International Standardisation Organisation (ISO), (2) Codex Alimentarius, (3) minimal food system, (4) Hazard Analysis of Critical Control Points (HACCP), (5) Good Manufacturing Practice (GMP), (6) Good Agricultural Practice (GAP), (7) Integral Chain Control (ICC), (8) British Retail Consortium (BRC), (9) Safe Quality Food (SQF), and (10) Global Food Safety Initiative (GFSI).

The ten models mentioned above give an account as of what is needed when systematically delivering quality, for a specific part of the object system. Not all quality models are described. The quality initiatives Keten Kwaliteit Melk for dairy products (KKM), Milieu Bewuste Teelt for fruits and vegetables (MBT), and Milieu Project Sierteelt for ornamentals (MPS), are not discussed as they are regarded to have a higher sector specificity.

1. International Standardisation Organisation (ISO)

The (general) norms for quality have been included in the ISO 9000 series. This quality system has a broad organisational scope. ISO 9000 covers many functional areas and contains norms, which are aimed at obtaining control over the quality of the business process. By formulation of criteria for the way in which the control of business processes should take place in the organisation, one is able to guarantee that products and services are generated of specified quality. An organisation is able to meet customer requirements, and requirements of industry and government in general, in a better way. Depending on the activities performed by an organisation, the organisation may deploy ISO standards accordingly. This means that standards may apply to organisations with a broader span of activities. Table 3.2 summarises the ISO 9000 series (ISO, 2001). As a means of controlling quality in the food industry, ISO 9000 unfortunately is not sufficiently elaborated. The most important disadvantage of ISO is that it is viewed too general for coverage of the food industry. In the control of food-quality dedicated criteria seemed desirable, particularly from a viewpoint of legislation.

Table 3.2: ISO (2001).

Standards and guidelines	Purpose
ISO 9000:2000, Quality management systems – Fundamentals and vocabulary	Establishes a starting point for understanding the standards and defines the fundamental terms and definitions used in the ISO 9000 family which are needed to avoid misunderstandings in their use.
ISO 9001:2000, Quality management systems – Requirements	This is the requirement standard one uses to assess one's ability to meet customer and applicable regulatory requirements and thereby address customer satisfaction. It is now the only standard in the ISO 9000 family for which third-party certification can be executed.
ISO 9004:2000, Quality management systems – Guidelines for performance improvements	This guideline standard provides guidance for continual improvement of one's quality management system to benefit all parties through sustained customer satisfaction.
ISO 19011, Guidelines on Quality and/or Environmental Management Systems Auditing (currently under development)	Provides guidelines for verifying the system's ability to achieve defined quality objectives. One can use this standard internally or for auditing the suppliers.
ISO 10005:1995, Quality management – Guidelines for quality plans	Provides guidelines to assist in the preparation, review, acceptance, and revision of quality plans.
ISO 10006:1997, Quality management – Guidelines to quality in project management	Guidelines to help ensure the quality of both the project processes and the project products.
ISO 10007:1995, Quality management – Guidelines for configuration management	Gives the guidelines to ensure that a complex product continues to function when components are changed individually.
ISO/DIS 10012, Quality assurance requirements for measuring equipment – Part 1: Metrological confirmation system for measuring equipment	Gives guidelines on the main features of a calibration system to ensure that measurements are made with the intended accuracy.

Table 3.2: ISO (continued).

ISO 10012-2:1997, Quality assurance for measuring equipment– Part 2: Guidelines for control of measurement of processes	Provides supplementary guidance on the application of statistical process control when this is appropriate for achieving the objectives of Part 1.
ISO 10013:1995, Guidelines for developing quality manuals	Provides guidelines for the development, and maintenance of quality manuals, tailored to specific needs.
ISO/TR 10014:1998, Guidelines for managing the economics of quality	Provides guidance on how to achieve economic benefits from the application of quality management.
ISO 10015:1999, Quality management – Guidelines for training	Provides guidance on the development, implementation, maintenance, and improvement of strategies and systems for training that affects the quality of products.
ISO/TS 16949:1999, Quality systems – Automotive suppliers – Particular requirements for the application of ISO 9001:1994	Sector specific guidance to the application of ISO 9001 in the automotive industry.

2. Codex Alimentarius

Nowadays many contemporary norms for the control of food quality in particular, are known to have a legal basis. World-wide the legislative basis is formed by the Codex Alimentarius: a global reference for countries in drafting legislation for quality control. The Codex Alimentarius is a food code developed by two organisations of the United Nations (UN): the FAO (Food and Agriculture Organisation) and the WHO (World Health Organisation). The FAO is concerned with agriculture and food production. The WHO is concerned with public health and consumer protection in relation to health. The Codex Alimentarius is comprised of food standards for commodities, codes of hygienic or technological practice, evaluation of pesticides, limits for pesticide residues, guidelines for contaminants, evaluation of food additives and evaluation of veterinary drugs.
Resulting from the creation of the Codex, a major accomplishment has been to sensitise the global community to the danger of food hazards as well as to the importance of food quality and therefore the need for food standards. By providing an international focal

point and forum for informed dialogue on food issues, the Codex Alimentarius Commission fulfils a crucial role. In support of its work on food standards and codes of practice, it generates reputable scientific texts, convenes numerous expert committees and consultations as well as international meetings attended by the best-informed individuals and organisations concerned with food and related fields. Countries have responded by introducing long-overdue food legislation and Codex-based standards and by establishing or strengthening food control agencies to monitor compliance with such regulations. The Codex Alimentarius now has a well-established reputation as an international reference (FAO/WHO, 1999).

3. Minimal food system

Food standards and codes of practice from the Codex Alimentarius are considered an important starting point for the development of quality systems in the food industry. In the development of any quality system however, one would like to know what requirements need incorporation. In other words, what requirements need to be considered in drafting a quality system? A description of a minimal quality system for the food is found in Vonk (1996). He describes what requirements are to be included for a minimal quality system for the food industry. A concise description of those requirements is presented below. We focus on: (1) quality recordings, (2) quality control, (3) hygiene plan, and (4) responsibility recordings.

Quality recordings

> A quality system should include the recording of the required quality level of products, using specifications of end products, including the packaging. Typically should be included: requirements on composition, shape and size, organoleptic requirements, physical requirements, such as pH, viscosity and temperature, microbiological requirements, the shelf life and the product's related temperature of storage. A quality system should include the recording of the required quality level of raw materials, using similar specifications as described with the recording of the quality level of end products. Additional concern must go to potential pollution by, e.g., dirt, vermin, hairs, stones, metal pollution or mould. Further, the system must include requirements on packaging, labels and re-packaging.

Quality control

A quality system should assure the required quality level of raw materials on entrance, by accompanying certificates or by delivery of certified suppliers (who comply with specifications). However, a minimal visual identification inspection on entrance must be present. If a supplier is not able to guarantee sufficient certainty, the inspection on entrance must be elaborated. In this respect one must render thought on inspection of the packaging material. A quality system must describe requirements on production control and should include the registration of process data in a previously determined frequency. In the control over production, sufficient attention must be paid to workings according to recipes, in which temperatures and mixing or stirring times are registered. What should be included too are indications for hygiene: e.g., first washing a can before opening it. Taken that the production is organised in multiple steps, one includes requirements for admitting semi-finished products to subsequent production steps. A quality system must include requirements on the end control of a product: the product itself being inspected. End control concerns the control of the product itself before packaging, and the control of the product after packaging. It is important that the products conform to the specification. It may not be required to inspect all points of the specification when critical control points of production have been secured.

Hygiene plan

A quality system must include a hygiene plan. The plan is particularly important when products are microbiologically vulnerable. Such a plan describes the use of cleaning products and disinfectants, the type of cleaning product, who is to clean and on what time, who is to check that the hygiene measures are actually performed, how the registration takes place, how cleaning products and disinfectants are labelled and whether they are stored separately, where the brooms and cloths are to be stored (ventilated cupboards), how to perform the inspection of the premises and the organisation surroundings, and how the fight against vermin is organised. Other (hygiene) requirements include: chemical and physical material and equipment requirements, requirements concerning the water used, the disposal of waste, typical critical control points and transportation concerns.

Responsibility recordings

There must be an unambiguous recording of assignments, responsibilities and authorities. Oral agreements must be formalised and registered in function descriptions, organisation charts and in procedures and instructions.

The minimal system for the food industry is a very limited one. As food organisations usually wish to extend the functionality of their quality systems, the minimal system with its quality recordings, quality control, hygiene plan, and responsibility recordings, is not sufficient. The minimal system however is the springboard for discussing the contemporary quality (reference) models of the food industry. Below, we discuss these models.

4. Hazard Analysis of Critical Control Points (HACCP)

The quality system HACCP would fit part of the description of the minimal system described above. HACCP however, is not a full or complete quality system. In order to benefit from HACCP one should integrate the system within a broader quality framework. It is not effective to implement HACCP without a general scope (Vonk, 1996). HACCP plays a leading part in the development of quality systems for the food industry. HACCP however has a specific focus on the food production process. In contrast, ISO has the disadvantage, of being too general to serve the food industry accurately. From the fact that ISO and HACCP cannot completely satisfy the requirements of quality management in the food industry, other systems have emerged, filling up blank gaps in the requirements. Illustrative hereof is the quality system Good Manufacturing Practice (GMP), dedicated to serving manufacturing organisations (discussed next).
We describe the general features of HACCP, below (Early, 1995). HACCP is a logical and structured method of assessing hazards and risks associated with manufacturing of food products, enabling the identification of CCP (Critical Control Points) in the manufacturing process and the application of monitoring, control and verification requirements. HACCP augments and refines codes of GMP in that it concentrates effort and priorities for control on those requirements that are essential for safety. HACCP did initially not ensure compliance with non-food safety aspects of quality and compliance with specifications, other than those associated with microbiological spoilage. HACCP was originally concerned with hazards of microbiology, but the scope has expanded to other components such as chemical and foreign body contamination. HACCP adheres to typical definitions, such as: hazard, risk, control, target value, tolerance, verification, and corrective action. A hazard is defined as the potential to cause permanent or temporary injury to a consumer. A risk is defined as an estimate of the probability of a hazard occurring. Control is defined as actions taken or conditions applied either to reduce to

accepted levels or to eliminate a hazard. A target value is the value that is to be achieved at a CCP if the hazard is to be reduced to acceptable levels or eliminated. The tolerance is the acceptable degree of variation of the target value. Verification concerns the procedures carried out to validate the effectiveness of the HACCP system. Corrective action concerns the actions taken when monitoring indicates the potential loss of control.

5. Good Manufacturing Practice (GMP)

GMP standards document the management responsibility for the production of foods, which meet quality and safety requirements. GMP standards express specific requirements, and enable the integration with other systems. It is possible to combine different quality systems. GMP provides a framework for the development and implementation of quality management systems with the possibility of subsequent registration to ISO 9000 and integration with HACCP systems. Analogously, other quality systems may be developed and combined, in order to enable the food industry (like other industries) to obtain the best results in quality.

We describe the general features of GMP (Early, 1995). GMP describes requirements on premises, facilities, manufacture, storage and distribution operations, hygiene, food safety, management responsibility, and audits. Requirements on premises include, the suitability of the manufacturing environment, the buildings, the roadways, and, e.g., the surface drainage. Requirements on facilities are concerned with, e.g., the provision of factory space, lighting/ventilation and personnel facilities. Requirements on manufacture, storage and distribution operations include descriptions on purchased products, identification and storage, suitability of plant equipment, ingredients, packaging materials, handling, storage and packaging of products, labelling and product presentation, product warehousing, transport and distribution, reworking of products, product specifications, inspections and testing and Good Laboratory Practice (GLP). Requirements on hygiene and food safety include preservation requirements, cleaning requirements, personnel hygiene practices, foreign body control and metal, glass and chemical control. Management responsibility is concerned with the provision of resources, production and hygiene procedures, training, complaint procedure, and product-recall. Audits should assess GMP compliance and should identify non-compliance, which should be rectified by appropriate corrective action.

6. Good Agricultural Practice (GAP)

Whereas GMP is aimed at manufacturing organisations, GAP is aimed at organisations concerned with primary production. GAP stands for Good Agricultural Practice and aims to develop sustainable production methods and safe food chains by which the consumer maintains trust in the safety and quality of agricultural products. The Euro Retailer Produce working group / Good Agricultural Practice (The EUREP GAP), the European organisation of retail organisations, has developed norms which primary producers should consider in order to get their products accepted by the supermarkets involved. Supermarkets however, are not obliged to buy products from GAP certified agricultural organisations. On top of the GAP code, certain supermarkets formulate additional requirements in order to free one self of liability claims on calamity. Below, we describe the essentials of GAP (EUREP GAP, 1999).

GAP on farms defines essential elements for the development of best practice for the global production of horticultural products (e.g., fruits, vegetables, potatoes, salads, cut flowers, and nursery stock). GAP defines the minimum standard acceptable to the leading retail groups in Europe. However, standards for individual retailers and those adopted by growers may exceed those described. GAP is a means of incorporating Integrated Pest Management (IPM) and Integrated Crop Management (ICM) practices within the framework of commercial agricultural production. Adoption of IPM/ICM is regarded by EUREP members as essential for the long-term improvement and sustainability of agricultural production. EUREP supports the principles of and encourages the use of HACCP (Hazard Analysis Critical Control Points). General principles are formulated: all growers must demonstrate their compliance with national or international law and all growers should be able to demonstrate their commitment to:

(1) maintaining consumer confidence in food quality and safety;
(2) minimising detrimental impact on the environment, whilst conserving nature and wildlife;
(3) reducing the use of agrochemicals;
(4) improving the efficiency of natural resource use; and
(5) ensuring a responsible attitude towards worker health and safety.

7. Integral Chain Control (ICC)

The ICC model is concerned with integral control of animal chains. Different ICC requirements exist for the different organisations of the chain. Representatives of the sectors concerned, united in the management team of the Productschap Vee en Vlees (PVV) and the Productschap Pluimvee en Eieren (PPE) formulate ICC regulations. The PVV is the product board for livestock and meat, the PPE is the product board for poultry and eggs. Farmers and organisations participate in the ICC schemes on a voluntary basis. Once they have agreed to participate however, they are obliged to ensure compliance with the requirements to which they have committed themselves via the ICC agreement.
Below, we describe which requirements are included in ICC schemes. The requirements are differentiated to requirements for (1) livestock and poultry farmers and to requirements for (2) slaughterhouses, meat cutting plants and egg packing stations.

Requirements for livestock and poultry farmers

All livestock farmers must comply with the Identification and Registration (I&R) regulation to ensure that the origin of animals is traced. The I&R system used for poultry is called KIP: Koppel Identificatiesysteem Pluimvee (Poultry Batch Identification System). The success of a system with extra quality guarantees depends on the use of good feed. All ICC livestock and poultry farmers must therefore give their animals feed, which is produced according to the Good Manufacturing Practice (GMP). The Productschap Diervoeder (Industrial Board for Animal Feed) grants GMP accreditation to feed suppliers who prove that they manage their production process in accordance with the code's requirements. The feed suppliers are to this end regularly inspected. Veterinarians must in their own work and in all the work they do for ICC livestock and poultry farmers adhere to the regulations of the code for Good Veterinary Practice (GVP). The GVP was formulated by the Koninklijke Nederlandse Maatschappij voor Diergeneeskunde (Royal Dutch Veterinary Society). The veterinary surgeons are checked for compliance every year.

Requirements for slaughterhouses, meat cutting plants, and egg packing stations

ICC-accredited slaughterhouses, meat cutting plants and egg-packing stations must adhere to the regulations of a hygiene code. The Dutch egg packing stations already employ HACCP principles. This means that they must identify and control all critical food safety points at their premises. The rules for red-meat slaughterhouses and cutting plants are laid down in a special Hygiene Code Manual. The slaughterhouses and cutting plants must be able to prove that they employ hygienic working methods. They must comply with regulations relating to the design and layout of their premises, carcass inspections, cleaning and disinfecting. Slaughterhouses, meat cutting plants and egg packing stations must perform canalisation. Next to ICC animals, meat and eggs, certain ICC-accredited slaughterhouses, meat cutting plants and egg packing stations, process non-ICC products. These companies must ensure that all ICC animals and products are kept strictly separated from other animals or products in all parts of the premises. This is what is known as canalisation. They must be able to prove this on paper and in practice.

8. British Retail Consortium (BRC)

The British Retail Consortium (BRC) or the International Technical Standard for Food Suppliers (ITS Food) is a technical standard for companies supplying private label food products (Luning et al., 2002). BRC was founded as a reaction on the increased number of discount retailers (using private labels) in combination with poor economic perspectives in the United Kingdom (UK). The BRC includes clear criteria for the assessment of private label suppliers, contracts out the auditing of these suppliers to third party inspection, and aims at cost reduction for retailers as well as suppliers. BRC is a checklist that combines the HACCP principles with specific parts of GMP (e.g., pest control and facility layout) and parts of ISO (system control).

9. Safe Quality Food (SQF)

Safe Quality Food (SQF) offers guarantees on the safety and the quality of food products throughout the supply chain (Van Delst and Hendriks, 2002). The Australian government, a number of farm organisations and companies, developed one system with which to secure an entire chain. The system is based on the chain scan: Safe Quality Food (SQF). SQF is divided into three levels with associated norms (Van Dooren, 2003):

(1) SQF1000: aimed at the primary sector, small processors and service providers;
(2) SQF2000: aimed at the processing industry and large suppliers;
(3) SQF3000: aimed at organisations in retail.

The basis of SQF consists of the HACCP-guidelines, the Codex Alimentarius, and the ISO-9000 series. SQF includes the identification and the tracking and tracing of products (Van Dooren, 2003).

10. Global Food Safety Initiative (GFSI)

The Global Food Safety Initiative (GFSI) co-ordinated by CIES - The Food Business Forum, was launched in May 2000. It is a retail-led network of food safety experts and their trade associations worldwide. In all, more than 200 retailer and supplier companies in over 50 countries are part of the international CIES network.

The GFSI establishes and implements food safety norms, develops early warning systems, and informs the consumer. The objectives of the GFSI are to (CIES, 2003):

(1) enhance food safety;
(2) ensure consumer protection;
(3) strengthen consumer confidence;
(4) benchmark requirements of food safety schemes;
(5) improve cost efficiency throughout the food supply chain.

Organisations with food safety systems or standards can submit a request for approval to the GFSI (e.g., BRC and SQF). On approval of the submitted standards, producers and suppliers can use them in the food chain.

With the coherent quality models now described, we continue with answering our question on the accurate representation of the object system.

We have been able to extract from the discussed quality-model descriptions, specific representation requirements and modelling concepts (needed to represent these requirements). For the discussed quality models, we describe the categories of representation needs and the associated concepts for modelling.

(i) Objects present in the object system:

e.g., plant equipment and facilities (e.g., manufacture and storage equipment), operations (e.g., manufacture and storage operations), products, semi-finished products, and raw materials.

The associated concepts for modelling are: entity types.

(ii) Information of interest on objects:

e.g., physical product features (e.g., pH, viscosity, and temperature), microbiological product features, product shelf life, product storage temperature, product pollution (e.g., dirt, vermin, hairs, stones, metal pollution, and mould), product processing (e.g., temperatures, stirring and mixing times), and results of product inspections.

The associated concepts for modelling are: attribute (class) types.

(iii) Complex relations between objects:

e.g., product composition relations (such as chemical and microbiological composition relations between products and product components), and product and material (batch) mixing and separation relations.

The associated concepts for modelling are: entity relationship types.

We have obtained a better idea of as to what (i) entity types, (ii) attribute (class) types, and (iii) entity relationship types, in particular, are important with respect to the modelling of the quality (system) demands.

Logistic and quality infrastructure conclusion

Having discussed the descriptions of the quality systems, we now reiterate our research objectives. We stated that we needed an accurate representation of the object system under discussion. As tracking and tracing (in the thesis) includes both a logistic and a quality view of the object system, logistic and quality models were selected so as to represent the object system accurately for tracking and tracing. Logistic models conceptualised the object system for logistic control, and quality models conceptualised the object system for quality control. The models gave us the insight into the different information needs of the object system with regard to tracking and tracing. As of the desire to establish a tracking-and-tracing information concept, it was imperative to elaborate on the different properties of the object system. The different models discussed gave an account of what is needed in obtaining systematic control over quality and logistics, with a reference to specific parts of the object system.

3.3 Functionality within the object system

Below, we investigate our assumptions on tracing and tracing. We do so by investigating the literature. We compare our ideas with available data from literature, and investigate the actual functionality.
The section starts with a literature overview on tracking-and-tracing definitions (subsection 3.3.1). Then, the actual functionality of tracking and tracing is described (subsection 3.3.2).

3.3.1 Literature on tracking and tracing

We investigate below, from literature, the definitions on tracking and tracing. Table 3.3 lists them. We present these descriptions along with the associated author(s).

Table 3.3: Literature definitions.

Author(s)	Definition
Eads and Undhein (1984)	Lot traceability can be likened to a bill of material explosion or implosion (where-used) process. The traceability process explodes from end use to an earlier state and then implodes from an earlier state to all end uses.
Clement et al. (1992)	Lot traceability systems make it possible to track the lots of material used in the manufacture of a particular item based on items such as lot number, serial number, or date/time of manufacture. This is similar to the bill of material explosion. Similarly, a lot where-used facility may also be available that permits tracking up to the items produced from a given lot of material.
Van Rijn et al. (1993)	Traceability relates to WIP (Work In Progress), defining it as the identification of a lot or batch of material, the tracking information (location and quantity), and the tracing information (where-from and where-used) of material.
ISO (1994)	Traceability is the ability to trace the history, application or location of an entity by means of recorded identification. ISO relates traceability to the origin of materials and parts, the product processing history and the distribution and location of the product after delivery. According to ISO, traceability includes the set of interrelated resources and activities, which transform inputs into outputs.
Kim et al. (1995)	Traceability is referred to as clear knowledge of ancestry whereby the entities to trace (in this reference: ISO 9000 products and activities), depend on unique identification; traceability relations are commented on by a graphical notation of ancestry.
Steele (1995)	With lot tracing, one identifies suspect items once faulty component material or processes are uncovered.
MESA (1997)	Traceability comes down to product tracking and genealogy. It provides the visibility to where work is at all times and its disposition. Status information can include who is working on it, components, materials, batch, supplier, lot, serial number, current production conditions, any alarms, rework or exceptions related to products. Besides visibility, an on-line tracking function creates a historic record, allowing the traceability of components and usage of each end product.
Weigand (1997)	Tracking and tracing is considered a modern tool that gives insight into the origin of products to all links of the supply chain, insight which is used to optimise the processes in the separate links and to enhance the total supply chain.
APICS (1998)	A twofold view on traceability is put forward: traceability is (1) the attribute that allows the ongoing location of a shipment to be determined, and traceability is (2) the registering and tracking of parts, processes and materials used in production, by lot or serial number.

Table 3.3: Literature definitions (continued).

Jansen (1998)	A distinction exists between product tracking and product tracing. Product tracking originates from product value or risk, whereby one wishes to locate the products. Product tracing originates from exception handling, whereby one wishes to establish the source of (bad) quality.
Moe (1998)	Traceability is viewed as an ability by which one may track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales (read: ‘chain traceability’), or internally in one of the steps in the chain, for example the production step (read: ‘internal traceability’).
Wilson and Clarke (1998)	Food traceability can be defined as the kind of information necessary to describe the production history of a food crop and any subsequent transformations or processes that the crop might be subject to, on its journey from the grower to the consumer plate.
Beulens et al. (1999)	Traceability is the ability to document the history of delivered goods and services and to prove conformance to specifications. Moreover, with respect to tracking and tracing it is indicated that long after closing a particular business transaction, the customer and supplier still are subject to a relationship.
Töyrylä (1999)	Traceability is an ability to preserve and access the identity and attributes of a physical supply chain's objects.
Van Twillert (1999)	Tracking and tracing may be subdivided into a tracking part and a forward and backward traceability part. The tracking part consists of the determination of the ongoing location of items during their way through the supply chain. The forward traceability part refers to the determination of the location of items in the supply chain, which were produced together, using for example a contaminated batch of raw materials. The backward traceability part refers to the determination of the history of a certain item. Backward tracing is used to determine the source of the problem of a defective item. Tracking-and-tracing information could be used for optimisation of processes in and between links of the supply chain.
Elbers et al. (2001)	Tracing, a procedure that begins with a known infected individual, herd or flock and which traces all possible locational and interactive exposures in both directions; back towards the source and forward to contacts.
McKean (2001)	Traceability of a product requires a transparent chain of custody to achieve credibility and to complete the desired information transfer functions. Product traceability has two components: unique animal or product identification systems and credible and verifiable chain of custody or identity.
LNV (2002)	The possibility to trace and follow food, feed, food producing animal, or substance, meant for processing in a food or feed, through all stages (of production, processing, and distribution).

We compare the literature definitions of tracking and tracing with our assumptions on tracking and tracing. We previously described a definition of tracking and tracing, which distinguished three parts: tracking, backward traceability and forward traceability.
With tracking we would be able to follow a product through the supply chain, and registering any data considered of any historic or monitoring relevance. This is acknowledged by some of the table definitions.
With backward traceability we would be able to list all the raw materials, consumed by manufacturing for the production of the one particular product, and trace these materials further backward. Table definitions acknowledge this view, too.
With forward traceability we would be able to list all the products, having consumed a particular (deficient) material of interest. Several table definitions express this view.
One important aspect of traceability is merely included implicitly in the table definitions: the generating properties. The complete set of visible and invisible properties that a product (group) has in common and in which we are interested, are called the generating properties of the product (group); in general, the properties may be related to the product itself, to the processes that produced the product, and to the production means that are used in the production processes. We recognise aspects of the definition on generating properties, implicitly, in the table. However, as of its importance, we prefer to position it as an explicit concept.

Having discussed the notion of generating properties within the definition of tracking and tracing, we turn our attention to a detailed description of tracking and tracing. The subsection below describes the functionality of tracking and tracing within the object system. Again, literature is leading. We elaborate on backward and forward traceability, and on the active and passive use of tracking and tracing.

3.3.2 Functionality of tracking and tracing

Having established the concept of tracking and tracing, we now investigate the technical details. In the subsection are investigated: forward and backward traceability and the active and passive use of tracking and tracing. We start with the ‘technical’ descriptions of (1) tracking, (2) backward traceability, and (3) forward traceability:

(1) Tracking describes the method of following an object through the supply chain and registering any data considered of any historic or monitoring relevance.
(2) Backward traceability describes the exploration of where-from relations between objects. These relations depict the raw materials consumed by manufacturing (process) operations for the production of a particular product.
(3) Forward traceability describes the exploration of where-used relations between objects. These relations depict all the end products having consumed a particular raw material of interest via certain (process) operations.

We continue with the mechanisms behind backward and forward traceability. Then, we deal with the mechanisms of active and passive tracking and tracing.

Backward traceability

Backward traceability determines the composition of an item (in terms of the contributing component lots), through exploring the where-from relations. Backward traceability is also referred to as a material lot explosion. Figure 3.1 depicts backward traceability graphically. It displays the lots for traceability, which are represented by squares.
We distinguish in the figure, the final production lot (the super-ordinate lot) and the processing lots (the sub-ordinate lots). The arrows depict the (where-from) traceability relations. The super-ordinate lot (the final production lot) is traced back to its sub-ordinate lots (the processing lots) via the where-from relations. The process (operation) level is depicted too and represented in the figure by a horizontal (dashed) line.

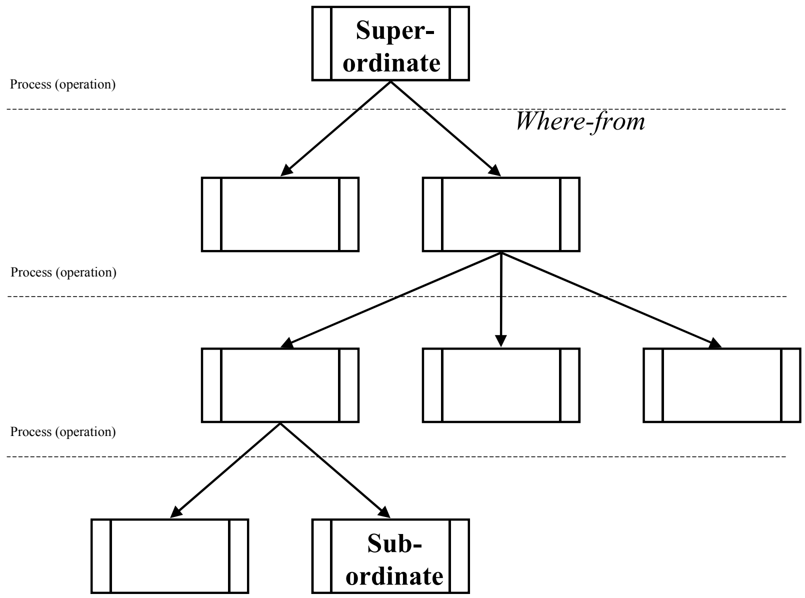

Figure 3.1: Material lot explosion.

A visualisation of the information obtained from exploring where-from relations between lots is given in table 3.4 (Petroff and Hill, 1991). The table shows all of the components contributing to a certain parent, including their associated lot numbers. An operator keys in the item number and the lot number of the parent and the system responds with the details. The *heading* shows the item number and the lot number as entered, plus the description, unit of measure, original quantity, remaining quantity and the order type (manufacturing or purchasing). The *body* of the table shows the component items and the lot numbers, the issued quantity, the unit of measurement, the date of issue, and the order type of the components.

Table 3.4: Where-from (Petroff and Hill, 1991).

Item number: 5692600 Lot number: 9615 Description: Codeine syrup, 10% Unit of measure: kg Original qty: 100 Remaining qty: 63 Order type: MFG					
Component Item number	Component Lot number	ISS Qty	U/M	Issue Date	Order Type
4881309	4272 Codeine	2	Kg	10/17/89	PUR
4881309	1251 Codeine	1	Kg	10/18/89	PUR
6905070	2504 Cough syrup base	35	Kg	10/17/89	PUR
6905070	2540 Cough syrup base	60	Kg	10/17/89	MFG
8410128	6542 cherry flavouring	2	Kg	10/17/89	PUR

Forward traceability

Forward traceability determines all end products having consumed a component of particular interest (actually meaning that a certain component lot was used), through exploring the where-used relations. Forward traceability is also referred to as a material lot implosion. Figure 3.2 depicts forward traceability graphically. It displays the lots for traceability, which are represented by squares.

We distinguish in the figure, the final production lots (the super-ordinate lots) and the processing lot (the sub-ordinate lot). The arrows depict the (where-used) traceability relations. The processing lot (the sub-ordinate lot) is traced forward to the super-ordinate lots (the final production lots) via the where-used relations. The process (operation) level is depicted too and represented in the figure by a horizontal (dashed) line.

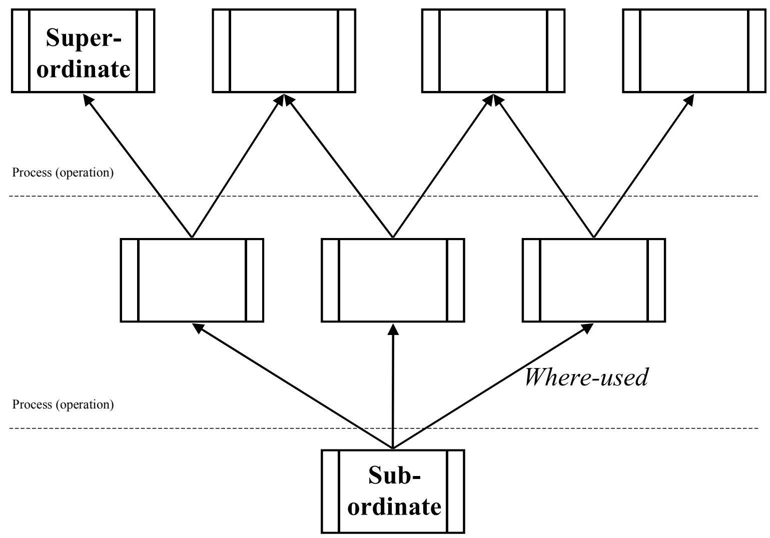

Figure 3.2: Material lot implosion.

A visualisation of the information obtained from exploring where-used relations between lots is given in table 3.5 (Petroff and Hill, 1991). The table shows all the parents having consumed a certain component, including their associated lot numbers. The operator keys in the item number and lot number of the component in question and the system responds with the details. The *heading* shows the component item and lot number as entered, plus the description, unit of measure, original and remaining quantity, and the order type that produced it. The *body* of the table shows the parent items and the lot numbers, the issued quantity, the unit of measurement, the date of issue, and the order type of the parents.

Table 3.5: Where-used (Petroff and Hill, 1991).

Item number: 8410128 Lot number: 6542 Description: Cherry flavouring Unit of measure: kg Original qty: 25 Remaining qty: 16 Order type: PUR					
Parent Item number	Parent Lot number	ISS Qty	U/M	Issue Date	Order Type
5692600	4855 Codeine syrup, 10%	2	Kg	10/21/89	MFG
5692600	9615 Codeine syrup, 10%	2	Kg	10/17/89	MFG
9344144	6586 Cough drop, deluxe	1	Kg	09/05/89	MFG
7556905	5264 Santa's chewing gum	2	Kg	09/13/89	MFG
1888860	2963 Bubble nummy	2	Kg	08/30/89	MFG

In summary, we have now investigated the functionality of tracking and tracing for the object system. We discussed backward and forward traceability and explained that through the exploration of where-from and where-used relations, products with all features of concern, can be traced (in conjunction with process operations), in two different directions: upstream and downstream.

For both types of exploration, we described the mechanisms behind the trace, and presented a visualisation of the tracking-and-tracing information. The results of the examination in this subsection are considered important references for the actual development of tracking-and-tracing functionality. This development is further elaborated on in chapter 4.

The use of tracking and tracing

Tracking and tracing can be used actively or passively. Van Twillert (1999) and Weigand (1997) mention in table 3.3 that tracking and tracing is used as a tool, to optimise processes in separate links, and to enhance the total supply chain. They refer here to an active use of tracking and tracing. The other authors refer to a passive use of tracking and tracing. We explain the distinction.

In the passive sense, tracking and tracing provides the visibility to where items are at all times and their disposition. An on-line tracking function creates a historical record by means of recorded identification, and allows for the traceability of items and their usage in each end product. Tracking and tracing in the passive sense is applied for forward and backward traceability of items, on calamity.

Tracking and tracing in the active sense however encompasses tracking and tracing in the passive sense. The on-line tracking-and-tracing information is additionally used for the optimisation and enhancement of processes in and between organisations. The active approach considers tracking and tracing a tool to manage quality and quality information for the purpose of process optimisation and chain enhancement. Tracking and tracing in the active sense may be used to decrease failure costs, increase productivity and better guarantee quality.

With active tracking and tracing, the registering of data on items during tracking, is not only applied to be able to carry out backward and forward traceability, moreover, is applied to be able to optimise processes in and between organisations of the supply chain. Below, we discuss two examples in which tracking and tracing is used actively, i.e., on behalf of process optimisation:

(1) recipe optimisation (Rutten, 1993, 1995);
(2) lot-based production (Van Rijn et al., 1993).

(1) Recipe optimisation

In the food industry, the outcome of production is variable. Production variations emerge when process control is not standardised, and non-coherence in process operations or usage of ingredients, exists (Early, 1995). Production variations however must be dealt with. Recipes are material usage and process control instructions and include work instructions, equipment instructions, operator instructions, machine instructions and scheduling instructions (MESA, 1995). On allocating materials to production, recipe optimisation limits the variation of actual production, as both the properties of lots and the number of production-items required, are taken into consideration. Depending on the quality variance found, sufficient allocation adjustments are made to quantity usage of these materials. Recipe optimisation has many advantages, ranging from better anticipation of changes in lot quality and increased production responsiveness (supplying high quality products in the shortest possible time) to, increased margins and higher revenues due to waste elimination, decreased inventory and optimised order fulfilment. Recipe optimisation enables production control to continuously follow the properties that are accumulated in the process.

Recipe optimisation focuses on short term events (the daily operations control level).

(2) Lot-based production

In food, quality characteristics of raw materials and semi-finished products are subject to variation. In general, many yields in food industry are subject to qualitative variation. With lot-based production, production calculations are not solely based on material quantity but on material quality too. The material characteristics are taken into account when determining what lots to use for a certain production order. The allocation of material (lots) to production then is made on the basis of the quality characteristics of the lots and on the desired quality of the end product. The potencies, i.e., active material components (like % fat or protein) vary with materials in the food chain. To be able to reach a certain percentage of fat or protein in the end product, a particular mix of lots is required. Consequently, production calculations are not based solely on the material quantity of the lots, moreover, production calculations are optimised by taken into consideration the material quality of the lots, too.

Lot-based production focuses on the mid-term optimisation of production formulae (the weekly/monthly operations control level). It differs from recipe optimisation in that recipe optimisation focuses on the operational co-ordination of lots in the supply chain (the daily operations control level).

3.4 The role of stakeholders

The object system includes many stakeholders, of which the requirements with respect to tracking and trading have been left undiscussed, thus far. Below, we present an overview of important stakeholders of the object system and we describe their role in the development of tracking-and-tracing functionality. A stakeholder overview is given and the (tracking-and-tracing) requirements are elaborated on. We discuss three types of stakeholders:

(1) stakeholders inside the company of a chain;
(2) stakeholders outside the company of a chain;
(3) stakeholders outside the chain.

By the latter two stakeholders, we extend our tracking-and-tracing analysis of requirements, so as to include the external environment of a company, too.

(1) Stakeholders inside the company of a chain

Stakeholders internal to a company of a chain, state requirements and exercise power with respect to tracking and tracing. They may wish to state their tracking-and-tracing requirements, as tracking-and-tracing data generated at different functions of the organisation, are of business value. Much tracking-and-tracing data of the organisation are of value to internal stakeholders. Below, we discuss important business functions and their data, from the viewpoint of tracking and tracing. Successively we discuss, (i) the marketing function, (ii) the purchasing function, (iii) the production function, (iv) the quality control function, (v) the materials management function, and (vi) additional functions. The overview is compiled from Dale and Oakland, (1994), Early (1995) and Zwietering and Van ‘t Riet (1994).

(i) The marketing function

The marketing business function is a main collector of tracking-and-tracing data of products. Such data include performance and sensory specifications, standards, materials processed and packaging applied. The marketing business function is the customer interface, in that it functions like a continuous quality monitoring and feedback system.

(ii) The purchasing function

The purchasing function is important from the viewpoint of tracking and tracing, too. Materials purchased will become a direct part of the end product and consequently determine its quality. Stated differently, the quality of raw materials influences the output. Information on the (properties of) purchased goods therefore is important, and should be made available for tracking and tracing.

(iii) The production function

Data generated by the production function are also considered important to tracking and tracing, as these data are to state that all successive steps of production have been taken under controlled conditions, and in a specified and verifiable way. Therefore, a documented standard should describe how data registration ensures verification of production steps. Production records must register the identification of raw material lots and the actual processing by production.

(iv) The quality control function

The quality control function also has a strong relation to tracking and tracing. Quality control inspects the quality of products within different business functions. Quality control takes place on purchased materials, materials in process and on end products. Clearly, the unique identification of products and materials is important in retrieving all registered quality aspects from the viewpoint of tracking and tracing.

(v) The materials management function

The materials management function is an example of a business function, which is important to tracking and tracing, too. Materials management of food products is often concerned with strict regulations. Food products must be treated with care, have to be separated from others or be protected in a special way. Moreover, if the organisation is to guarantee product quality, volatile and dynamic properties of food materials make it a necessity for products to be monitored throughout different functions of the organisation.

(vi) Additional functions

An additional function, of importance to tracking and tracing, is cleaning. Chemicals combined with food contact surfaces, are often a cause of cross-contamination. Other important functions are: storage, packaging and delivery. We conclude by saying that in identifying and resolving quality problems, nearly every functional area within the company of the chain, plays a part.

(2) Stakeholders outside the company of a chain

Besides the requirements stemming from stakeholders inside the company of a chain, as tracking-and-tracing information is of internal business value to certain business functions, we distinguish the requirements of stakeholders from outside the company of a chain, too. We mention in this respect: chain (internal) customers.
A chain customer exercises power over (1) a single chain-company or over (2) multiple chain companies. The power is exercised over a single chain-company when a single company is responsible for the product under discussion. The power is exercised over multiple chain companies when the responsibility for the product is distributed over different companies within a chain.
Chain-companies may close contractual agreements with respect to specific responsibilities, on calamity. In that such contractual agreements are made, the tracking-and-tracing systems of the individual companies should be assessed, so as to ascertain that they can provide for the proper functional support.

(3) Stakeholders outside the chain

Requirements of tracking and tracing stem from outside a chain, too. Stakeholders outside a chain impose requirements on the supply chain, on the chain product. The most obvious stakeholder is the consumer. Much power from consumers is imposed on the chain by the execution or withholding of a transaction at the supermarket. Clearly, it is an effective means of influencing the requirements on - and the supply of - products (product assortment). Products that do not obey traceability requirements and are not labelled sufficiently may drop in sales as they are banned from the customer's shopping list. Several other stakeholders exercise power and impose requirements on the supply chain. We discuss eight stakeholders below: (i) governing bodies, (ii) controlling agencies, (iii) insurance companies, (iv) consumer organisations, (v) shareholders, (vi) branch organisations, (vii) the global market, and (viii) the local community.

(i) Governing bodies

Governing bodies are external stakeholders affecting the internal functioning of the supply chain. Although government is considered ‘external’ to the supply chain, it is nevertheless an important and influential factor of the environment in which the supply chain operates. Many requirements of national (European) governments are instructed by EU legislation. Typical EU legislation is contained in European Economic Community (EEC) directives. These directives are implemented by the member states. A complex of directives exists. We discuss six directives, so as to be exemplary with respect to the influence of government(s) on tracking and tracing. We discuss: (a) the general food law (EC 178/2002), (b) the compulsory labelling system[14] (EC 1760/2000; EC 1825/2000), (c) the packaging and packaging waste (94/62/EEC), (d) the official control of foodstuffs (89/397/EEC), (e) the functional labelling of products (79/112/EEC), and (f) the liability for defect products (85/374/EEC).

a. General food law (EC 178/2002): states that traceability of food, feed, feed-producing animals and any other substance intended to be, or expected to be, incorporated into a food or feed, shall be established at all stages of production, processing and distribution, as of January 1st, 2005.
b. Compulsory labelling system (EC 1760/2000; EC 1825/2000): On September 1st 2000, a compulsory EC labelling system came into effect, under rules adopted in Brussels on July 17th, 2000. The system required obligatory information to be indicated on the labelling of all fresh and frozen beef and veal products. The labelling system is a European Community (EC) wide system, which informs customers of the origin of beef and provides reference numbers to trace beef back to its origin. This compulsory system features two separate stages. The first stage was initiated on September 1st 2000 and gives information on where beef is slaughtered and where cutting operations are performed. The second stage was initiated on January 1st 2002 and gives information on the countries of birth and rearing. With respect to the first stage, a transition period from September 1st 2000 to January 1st 2001 was included in the sanction rules of the EC. In this period beef could only to be taken of the market if the label displayed information that was misleading to consumers or which did not correspond with product specification. The arrangement was to account for difficulties of operators in implementing the labelling system.
c. Packaging and packaging waste (94/62/EEC): This directive concerns the management of packaging and packaging waste to prevent any impact thereof on the environment or

[14] For more information on the system: Van Dorp (2003a).

to reduce such impact, providing a high level of environmental protection. The total quantity of packaging material used should decrease, while the percentage of recycled packaging material should increase. Return and collection systems, and reuse and recovery systems must guarantee a maximum return of packaging and packaging waste. Tracking and tracing monitors the quantity and the type (*recycled* or *non-recycled*) of packaging material in the supply chain, in order to reduce environmental impact as much as possible.

d. The official control of foodstuffs (89/397/EEC): This directive verifies compliance with foodstuff legislation and rules on composition and quality. The focus is on the inspection of foodstuffs, food additives, vitamins, mineral salts, trace elements (and other additives, intended to be sold as such) and materials and articles intended to come in contact with foodstuffs (e.g., packaging material). The inspections are carried out (without warning) regularly or when violation or non-compliance is suspected. The inspections are carried out using means proportionate to the end to be observed. Competent authorities perform the inspections and protect the consumers' interests.

e. The functional labelling of products (79/112/EEC): Functional labelling is to ensure that consumers are provided with the essential information with regard to the composition of the product, its manufacturer and the methods of storage and preparation which are necessary to ensure consumer safety. In this respect, labelling of minimum durability and any special conditions of storage or use, enhances (quality) traceability. Labelling information must not mislead the consumer.

f. Liability for defect products (85/374/EEC): Product liability is concerned with the liability of the producer for damages caused by the defectiveness of his products. In this respect, the consumer is protected against damage to his health or property caused by a defective product. When a producer cannot be identified, each supplier of the product shall be treated as its producer unless he informs the injured person, within a reasonable time, of the identity of the producer or the person who supplied him with the product. In this respect, tracking-and-tracing systems may pass on ‘the bug’.

(ii) Controlling agencies

Controlling agencies hold power over the supply chain. Controlling agencies establish whether the requirements of product tracking and tracing are actually satisfied in practice and whether financial measures, or other measures, are to be taken against companies in the chain that do not comply with the requirements of tracking and tracing. The PVV (the product board for livestock and meat) and the PPE (the product board for poultry and eggs (or the delegated parties) hold watch over the requirements included in the ICC schemes.

(iii) Insurance companies

Insurance companies are (also) confronted with tracking and tracing: how to insure food manufacturers for calamities that may affect the entire supply chain as well as a part of the public (having consumed a defect product)? When food manufacturers submit their request for insurance against calamities, they are faced with stringent requirements from insurance companies. To obtain a reasonable insurance, manufacturers must oblige to hold certain quality standards or the insurance will not cover. Consequently, it is in the interest of the manufacturer to implement quality systems and their associated mechanisms of tracking and tracing. They must make sure that no improper (quality) practices are held against them.

(iv) Consumer organisations

Consumer organisations hold an influence over companies of a chain. Companies that are under scrutiny of consumer organisations may have got a problem. Consumer organisations have a great influence over the buying public, as they represent the voice of the customer. Clearly, demands posed by consumer organisations must not be reluctantly dealt with or the company suffers financial consequences. Companies acknowledge this and are most often open and willing to co-operate with consumer organisations in order to retain the loyalty of the buying public. It results in increased transparency on the provenance of our food. Besides well-established consumer organisations, contemporary Non-Governmental Organisations (NGOs) represent the consumer’s voice (e.g., Greenpeace), too.

(v) Shareholders

Shareholders also hold an important position as external entities. Shareholders, who by means of transaction obtain an asset of the company, influence the present worth of such company to the point that it may influence its continuity and prime existence. In case of calamity, share values may drop so as to generate a disaster for the company's financial situation. Clearly, to maintain shareholder trust and prevent mood swings on the stock exchange, food deficiencies with public impact must be prevented. Pro-active quality management is required for shareholders to maintain trust in the organisation's responsiveness and maintain the demand of shares.

(vi) Branch organisations

Branch organisations play an important role in disseminating state-of-the-art method and techniques for the business. With respect to tracking and tracing, particular working conventions are drawn up by branch organisations which are best followed by an organisation, as it enables him to connect easily to the practices of actors in the chain. An example is the application of barcode standards in business, e.g., EAN-128. Implementing such common practices as recommended by the branch organisation, may prevent exclusion from the business community.

(vii) The global market

The global market also influences the organisation. The global market has brought social-economic and market change. Markets are currently open to global players. Many of these markets quickly saturate. A growing and fast changing product assortment is put forward to increase product choice in the battle for the consumer. The supply of all these various products however has led to stringent demands from the consumer with respect to the composition and the production method of products, e.g., where food safety, usability, animal friendliness and environmental load are concerned. Apparently the consumer asks for a fast changing product assortment that must obey a growing number, and also stringent, constraints while further, products in that assortment must be priced competitively. Positioned in a global market, organisations must acknowledge these influences and be able to grant such wishes of the consumer.

(viii) The local community.

A local community in direct vicinity of a company may hold a great influence. The company can be a good neighbour to the community or town in which it is situated. As many producing organisations depend on the local labour force, adequate thought must go to local requirements. The organisation is required to deploy a socially acceptable production and, e.g., not apply heavy metals, chemicals or radioactive materials. Repercussions may follow when organisations do not grant the wishes and demands of their local stakeholders with respect to the materials processed.

3.5 Chapter summary

Below, we summarise the results on (1) the representation of the object system, (2) the desired tracking-and-tracing functionality within the object system, and (3) the role of stakeholders.

(1) The representation of the object system

Literature on products, processes and processors, enabled us a first inference of representation needs and associated concepts for modelling (these needs). We distinguish three categories:

(i) Objects present in the object system:
e.g., finished products, semi-finished products, intermediates, raw materials, production orders, capacity units, operations, intermediate process outputs, active materials, material batches and material lots.
The associated concepts for modelling are: entity types.

(ii) Information of interest on objects:
e.g., product and process characteristics, product quality levels, material consumption, quality inspection results, component concentrations, and amount/percentage of (active) materials.
The associated concepts for modelling are: attribute (class) types.

(iii) Complex relations between objects:
e.g., input-output process relations, lot-separation relations, lot-mixing relations, product structures and product compositions.
The associated concepts for modelling are: entity relationship types.

Additionally, we presented quality models. These models gave us the consolidation of the representation needs inferred, above. Below, we present the results from the examination of the quality models:

(i) Objects present in the object system

e.g., plant equipment and facilities (e.g., manufacture and storage equipment), operations (e.g., manufacture and storage operations), products, semi-finished products, and raw materials.

The associated concepts for modelling are: entity types.

(ii) Information of interest on objects

e.g., physical product features (e.g., pH, viscosity, and temperature), microbiological product features, product shelf life, product storage temperature, product pollution (e.g., dirt, vermin, hairs, stones, metal pollution, and mould), product processing (e.g., temperatures, stirring and mixing times), and results of product inspections.

The associated concepts for modelling are: attribute (class) types.

(iii) Complex relations between objects:

e.g., product composition relations (such as chemical and microbiological composition relations between products and product components), and product and material (batch) mixing and separation relations.

The associated concepts for modelling are: entity relationship types.

We conclude that the ERM ontology for representing the object system, which was presented in chapter one, is able to support the identified representation needs with associated concepts for modelling.

(2) The tracking-and-tracing functionality

We distinguished four items in the review of tracking-and-tracing functionality: (i) tracking, (ii) backward traceability, (iii) forward traceability, and (iv) generating properties.

(i) Tracking is the method of following an object through the supply chain and registering any data considered of any historic or monitoring relevance.
(ii) Backward traceability is the exploration of where-from relations between objects (these relations depict the raw materials having certain properties of interest, and which are consumed by manufacturing operations for the production of a particular product).

(iii) Forward traceability is the exploration of where-used relations between objects (these relations depict all the end products having consumed a particular raw material with certain properties of interest, through the processing of operations).

(iv) The complete set of visible and invisible properties that a product (group) has in common and in which we are interested, are called the generating properties of the product (group); in general, the properties may be related to the product itself, to the processes that produced the product, and to the production means that are used in the production processes.

With respect to the objective of tracking and tracing as an instrument, we distinguished two possibilities: active traceability and passive traceability. When the objective is quality enhancement within and between enterprises, active traceability is referred to; when the objective is (mere) recall management, passive traceability is referred to. Administration differs in both cases. In choosing the 'active strategy', the administration requirements are more complex.

(3) The role of stakeholders

In conclusion, the role of stakeholders in the development of tracking and tracing was described. We discussed: (i) stakeholders inside the company of a chain, (ii) stakeholders outside the company of a chain, and (iii) stakeholders outside the chain.

(i) Stakeholders inside the company of a chain are representatives of different (internal) business functions. They wish to state tracking-and-tracing requirements, as tracking-and-tracing data generated at different functions are of business value.

(ii) Chain customers, i.e., stakeholders outside the company of a chain, exercise power. Power is exercised over a single chain-company when a single company is responsible for the product under discussion. Power is exercised over multiple chain companies when the responsibility for the product is distributed over different companies within a chain.

(iii) The most obvious stakeholder outside the chain is the consumer: its power is imposed by the execution or withholding of a transaction at the supermarket. Next to the consumer, we identified: governing bodies, controlling agencies, insurance companies, consumer organisations, shareholders, branch organisations, the global market, and the local community.

Chapter 4

Reference-data model

Chapter contents

4. Reference-data model

The chapter describes the tracking-and-tracing requirements derived from case-study research and the modelling of a general tracking-and-tracing solution[15]. The chapter supplies evidence to sustain our ideas on traceability. For each case, we use the method of describing the process flow and determining the (tracking-and-tracing) information requirements. The description of the method is embedded in many information-system development methods. For four cases, a systematic overview is presented of the production steps and the traceability considerations. The tracking-and-tracing requirements are described in (structured) natural language. Through induction, a general model is developed, viz.: a reference-data model.
The chapter first introduces the four case studies and discusses their findings (section 4.1). Then, the modelling of the reference-data model is elaborated on (section 4.2). Finally, a chapter summary is presented (section 4.3).

4.1 Contents of the cases

The chapter presents four case studies. The case studies are an indication of whether our initial ideas on tracking and tracing, are correct. The ideas on tracking and tracing were twofold: on the representation of the object system, and on the desired tracking-and-tracing functionality within that object system.

In more popular terms, we need a representation of the object system that enables us to list information on raw materials[16], parts, intermediates and subassemblies, and enables us to review the transformation thereof into an end product, via the execution of operations by general capacity units. It is this representation that will enable us to perform the tracking-and-tracing functions and will help us to retrieve any generating properties that are of concern to us, in a certain case.

[15] Parts of this chapter have been published in Van Dijk et al. (1999), Van Dorp et al. (2001, 2001a, 2002), and Van Dorp (2002a, 2002b).
[16] Purchased or extracted materials that are converted via the manufacturing process into (other) products.

Below, the case studies are elaborated on. The research includes the analysis of four distinct production cases: (1) a slaughter facility, (2) a food processor, (3) a leather producer, and (4) a pharmaceutical manufacturer.

Of all cases, the leather producer does not generate a product for consumption; though it can be considered to have strong ties to the agri-industry. The case is included for strengthening the external validity[17] of the research i.e., analytic generalisation to non-food manufacturing.

The cases are described in two main steps, an approach derived from information-system methodology: (1) analysis of the process flow (referred to as production steps in the case descriptions), and (2) analysis of the information requirements (referred to as traceability considerations in the case descriptions).

[17] For more information on external validity, please refer to the second chapter: the research approach.

4.1.1 Case 1: a slaughter facility

The first enterprise investigated on tracking-and-tracing requirements, produces beef products. The enterprise under discussion is a slaughter facility. It supplies customers with such beef products as quarters with bone, technical parts (no bone) and snits.

Production steps

In figure 4.1 we provide an overview of the production steps and the control system. A transportation company brings the animals from the farm location to the slaughterhouse. (1) At receipt, the animals get an entrée inspection. (2) They can be directed to a certain stable section or hall section. For instance, animals with specific quality certificates are to be separated from the others. (3) Successively, the animals are slaughtered batch-wise. The slaughter process includes, amongst others: a neck stain, bleeding, de-skinning, organ removal, weighing and classification and assignment of a slaughter label. The label includes a sequence number that relates the carcass to the animal identification of entrée. (4) Then, the carcass is chilled. Chilling is a method of speed-cooling carcasses before, (5) they enter the actual cooling room. Once in the cooling room, the carcasses are assigned to customer orders (i.e., become designated products). They are allocated based on their quality properties. (6) When the destination of the carcasses is known, they are disassembled into quarters. Quarters are meat parts with bone. Depending on the allocation made, quarters can be cut further into technical parts, (7) these are meat parts without bone, and also, (8) into the smaller parts, snits. (9) Successively, quarters are packed or wrapped while technical parts and snits are put into crates and boxes. All products are assigned product labels (representing merely the generating properties of the product type and not the product instance), and are put in a storage room. (10) In the storage room, the products are grouped and the crates and boxes are palletised. (11) Thereafter, the expedition to the customer commences. The orders are then picked and delivered.

The production control situation of the slaughter facility is Assemble To Order (ATO); as the assignment of customer orders takes place in the cooling room (5), the Customer Order De-Coupling Point (CODP) lies here.

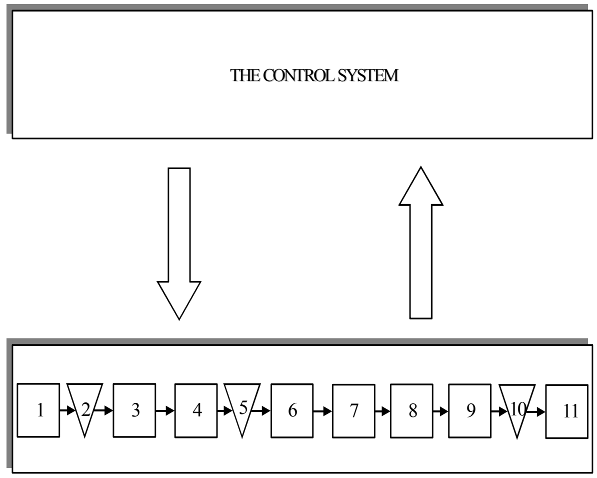

Figure 4.1: Production chain of beef products.

Traceability considerations

Cattle batches are supplied to the slaughter facility. The animals carry unique identification. The identification is coded on the ear-tag of the animals. The code gives access to identification data stored on the animal, in a national database. The chain actors enter these data, in different stages of the supply chain (for instance, on the import of cattle and on the farming of cattle). On processing cattle into beef products, slaughterhouses must take notice of legislation. Contemporary legislation states that product batches is not to include animal parts of a different country: cattle processed should have homogeneous country properties (Van Dijk et al., 1999). If the processed cattle do not have the (set of) properties in common, which is of interest to us, we consider the batch integrity violated[18]. To ascertain the integrity for the first production step (the slaughter process), the ear-tag of cattle must be scanned so as to acquire verification from the central computer system on the provenance of the cattle. Cattle are joined into larger (economic) processing batches, as long as the prescribed batch integrity is maintained.

In the cooling room all carcasses remain identified by a label. These carcasses are then assigned to customer orders, based on quality selection. The carcasses are further cut

[18] The complete set of visible and invisible properties that a product (group) has in common, and that we are interested in, are called the generating properties of the product (group); in general, the properties may be related to the product itself, to the processes that produced the product and to the production means that are used in the production processes.

into technical parts and snits. In these successive production steps, proper registration must be accounted for. Depending on the product amount and the required quality, the associated production steps may mix parts from different animals into crates or boxes. This is no problem, as long as the crates or boxes remain traceable to their constituting cattle parts and maintain their homogeneous country properties. The batch identification placed on boxes and crates is to disclose any information on the cattle processed. The identification should maintain a relationship with the actual identification numbers of the processed cattle (or their associated slaughter sequence number).

Contemporary legislation demands that the cattle supply chain successively registers the cattle's country of birth, country of rearing, country of slaughter, country of cutting, and a traceability reference number. For verification of cattle provenance in successive steps of the supply chain, data from a (national) computer system is retrieved. Cattle data, made available by a central computer system, enables a slaughterhouse not only to realise printing of product specifications on the consumer products (i.e., the provenance) but also to determine cattle quality on entrée (e.g., supplier quality certificates) and optimise internal slaughterhouse control activities.

Cattle data may additionally help the slaughterhouse to optimise the planning and control of the allocation of cattle carcasses to customer orders. In this respect, an advance notice on the animals for slaughter and the expected classification of the animals is thought of. Farmers can send such information to the slaughterhouse. The information enables the slaughterhouse to optimise planning and control over supply (quality). Analogously, such information as the actual time of slaughter and the assigned classification to animals can be sent (back) from the slaughterhouse to the farmer, so as to enable the farmer to assess his own performance, the performance of the transportation company, and that of the slaughterhouse. The farmer can then trace any quality anomaly (e.g., caused by animal stress on delays).

Explication of requirements

We have presented the traceability considerations for the slaughter facility. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 4.1 gives this set.

Table 4.1: Main requirements case 1.

Slaughter facility	- Registration of cattle numbers
	- Registration of cattle batches
	- Registration of data on cattle batches (generating properties):
	  - Country (provenance)
	  - Quality (supplier certificates)
	- Registration of cattle operations, per production step
	- Identification of cattle batches processed
	- Identification of cattle end-products (crate and box identification)
	- Registration of generating properties on the level of crates and boxes
	- Optimisation of slaughterhouse performance

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. We distinguish in this respect: (1) entity (relationship) types and (2) attribute (class) types. The appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. The attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the country of origin, the quality, etc.

1. For the slaughter facility we identify six *entity (relationship) types*[19]:

(i) a material lot and batch (identified in production);

(ii) a production relation (or association) (activated between lots or batches);

(iii) a capacity unit (responsible for a particular production step);

(iv) an actual production operation (executed by a specific capacity unit);

(v) an actual production operation variable (registered for a specific operation);

(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a cattle batch;
a product batch.

Ad. (ii) mixing relations between beef parts;
relations between processed cattle and end products;
composition relations.

Ad. (iii) slaughter equipment;
storage room;
cooling room.

Ad. (iv) entrée inspection;
slaughter;
chilling;
disassembly;
packing;
wrapping;
palletising.

Ad. (v) cattle identification;
cooling conditions;
obtained product quantity;
obtained product quality.

Ad. (vi) ear tag number;
cooling temperature values.

[19] Section 4.2 elaborates on any specific design choices made.

2. For the slaughter facility we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes such as animal classification, country specification, and quality certificate.

Ad. (ii) attributes such as batch integrity (violation) and meat quality (animal stress).

4.1.2 Case 2: a food processor

The second enterprise investigated on tracking-and-tracing requirements produces canned food products[20].

Production steps

In figure 4.2 we provide an overview of the production steps and the control system. The products generated by the enterprise are distinguished into canned sausage products and canned sauce products. (1) In the enterprise under discussion purchased materials such as potatoes, vegetables, meat, dry herbs and spices, and packaging materials are unloaded and received, (2) in the vicinity of a central stock point. The stock point is abstract and should be decomposed into multiple separate storage points for the incoming materials: one stock point for herbs, spices, packing materials and left over food cans, and one stock point for herbs and flower (silo), two cold storage rooms for frozen raw materials and one cooling for products that require conditioning (e.g., potatoes, vegetables and meat are fresh raw materials and enter the enterprise in cooled or frozen state). Two intermediate storage points exist prior to production, so-called shop floor warehouse points, these are used to temper frozen products (defrosting). (3 and 4) Production of sausages and other products takes place in the two production units. Unit 3 is dedicated to producing the sausages. An almost continuous production of sausages takes place in production unit 3. Unit 3 is responsible for filling the cans and sterilising the product, too. Unit 4 is used to manufacture all other products besides the sausages (i.e., sauce produces with food substances). (5) The packaging unit successively labels all food cans deriving from the production units. The cans are placed on trays, which are stacked on pallets. (6) Finally, all products resulting are stored in the Distribution Centre (DC) of the enterprise. From thereon, logistic service providers rout products to customers. The (predominant) production control situation is

[20] Object system representation and modelling analysis by the author; interviews by Van Twillert (1999).

described with Make and Ship To Stock (M&STS) as the Customer Order De-coupling Point (CODP) is placed on DC level.

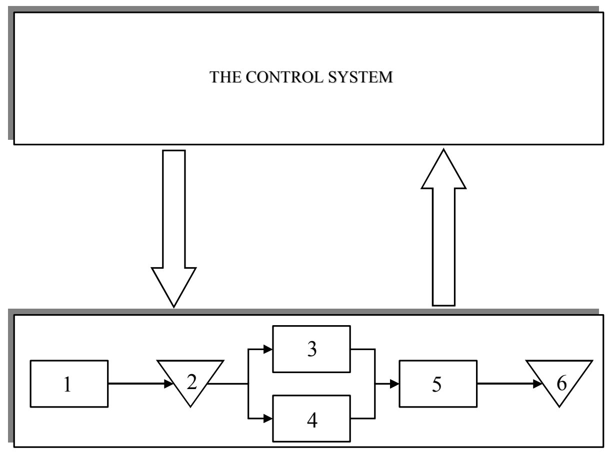

Figure 4.2: Production chain of canned food products.

Traceability considerations

Material batches that enter the organisation are assigned a unique number. The number is pre-generated on ordering. Due to the fact that only one batch number is assigned to the (purchase) order line, traceability problems can occur. After all, a supplied batch of raw materials can be composed of multiple batches from supplier production runs. Assigning one unique number and removing the supplier numbers, implies generalisation over supplier production runs. When the information is lost, it becomes difficult for the supplier to localise a particular problem on calamity. Moreover, no stock allocation system is present, making it hard to localise (track) certain batches or lots within the enterprise. Considering shelf life restrictions, products are to be released using FIFO (First In First Out). Indeed materials are booked FIFO. However in practice, stock is released in a less stringent manner, ending up in a mismatch between registered or planned material usage and actual material usage.

Some materials will be returned to the warehouse. But as some batches lose their label in production, certain goods can no longer be identified as they return. The root of the problem lies in the physical identification of lots in production. The production environment and the labelling technique are a cause for problems. The registration of lots is done manually, by writing down the applicable identification numbers. The papers and stickers used as identification labels get wet in the shop floor warehouses and/or are blown away by ventilators present. Moreover, the manual procedure takes a long time (i.e., is inefficient) and is not very reliable. Consequently, the enterprise is helped with the introduction of identification technology and bar code scanners.

Problems are noted with the potencies or active materials within batches (like % fat or protein). In many cases, the raw material used by production, is meat. Supplied meat batches can vary in composition with respect to their fat percentage. Because of such variations, often a mix of meat batches is used for production, instead of applying the FIFO method. To be able to perform more systematic selection of batches for production, data on these batches should be registered. Using different quality classes of batches enables optimised allocation to production. It then is required that all raw material lots are identified and their properties be recorded. The optimisation should be extended so as to include batches actually in production, too. This implies the registration of process variables on every batch level in production. In the current situation only the sterilisation step registers variables on batch level. Finally, the lack of contractual agreements with suppliers concerning the requirements on tracking and tracing, compromises tracking and tracing in the supply chain.

Explication of requirements

We have presented the traceability considerations for the food processor. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 4.2 gives this set.

Table 4.2: Main requirements case 2.

Food processor	- Identification of material batches - Registration of generating properties on the material batches (of special interest: active components, such as fat percentages) - Subdivision of materials in different quality classes (sub-lots) - Registration of lots/batches consumed in production - Registration of subsequent processing steps - Registration of process/operation variables on every batch level in production - Optimisation of materials allocation - Contractual agreements on traceability with suppliers

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. Similar to the previous case, the appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. Again, the attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the active components (fat percentages). We confirm the generality of our modelling, as we are able to model the requirements of the food processor in a similar way as the modelling of the requirements of the slaughter facility.

1. For the food processor we identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);
(ii) a production relation (or association) (activated between lots or batches);
(iii) a capacity unit (responsible for a particular production step);
(iv) an actual production operation (executed by a specific capacity unit);
(v) an actual production operation variable (registered for a specific operation);
(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a canned sausage product batch;
a canned sauce product batch;
a purchased material batch.

Ad. (ii) mixing relations between meat batches;
composition relations.

Ad. (iii) production units;
packing units;
cold storage rooms;
material stock points.

Ad. (iv) sausage production;
can filling;
sterilisation;
cooling;
defrosting;
conditioning;
materials receiving.

Ad. (v) batch identification;
material usage;
cooling conditions.

Ad. (vi) batch numbers;
material usage quantities;
cooling temperature;
quantity in stock.

2. For the food processor we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes detailing the material potencies (e.g., fat percentage and protein percentage) and the different material quality classes.

Ad. (ii) attributes for registering material potency anomalies.

4.1.3 Case 3: a leather producer

The third enterprise investigated on tracking-and-tracing requirements, produces leather for the furniture industry[21].

Production steps

In figure 4.3 we provide an overview of the production steps and the control system. The enterprise processes the skins of bulls in batches. The skins are delivered according to contracts with a limited number of suppliers. The whole batch for one day is supplied by one of these suppliers. Besides skins, raw materials (several chemicals and paints) are processed. (1) The raw materials and skin are received. The raw materials are stored in two separate stock points: (2) a warehouse for chemical products and (3) a warehouse for paints. The materials are delivered and contained in tanks or barrels (besides the unique lot number, no information on lots is obtained from the suppliers of paints and chemicals). The skins themselves cannot be stored due to 'shelf-life' restrictions; i.e. they need to be processed immediately (information on skins is not obtained from contracted suppliers). (4) In (wet) production, skins come in one lot a day and are successively split and mixed on such operations of skin cleaning (dirt), waste elimination (animal flesh pieces) and the allocation of skins to product variants (quality classes). (5) The outputs, i.e., the semi-finished variants, are stored in a (wet) warehouse. (6) An intermediate department is responsible for painting the products for the first time (a base colour). (7) The output of this production step is again stored in a stock point. (8) A final production step finishes the products and ensures that the leather receives its final colour. (9) The end products are stored in a stock point, called the finished goods warehouse. (10) From thereon products can be shipped to customers. The production control situation is described with Assemble To Order (ATO), as the Customer Order De-coupling Point (CODP) is placed on the wet warehouse (5), containing semi-finished variants to be completed on customer order. Prior to this point, the incoming skins determine the production.

[21] Object system representation and modelling analysis by the author; interviews by Van Twillert (1999).

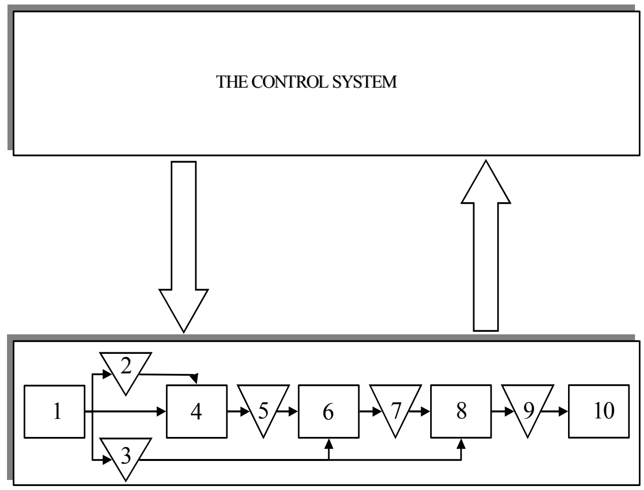

Figure 4.3: Production chain of industrial leather products.

Traceability considerations

The enterprise system discussed here stems from a less critical business as compared to the businesses from previous and upcoming case description(s). We explain this below. Producers in the food industry are concerned with guaranteeing product quality and safety. Their products are meant for human consumption. Products of producers in the non-food industry, however, have a lesser concern with respect to human consumption. So, in this case study one must assess whether the costs for extended functionality of tracking and tracing will outweigh the benefits. Nevertheless, the enterprise from the industry under discussion here, can make improvements on tracking and tracing. The main requirement noted with respect to tracking and tracing in this case, is the ability to create batches underneath a production order. It should become possible to register the semi-finished goods (batches) and the raw material lots that went into a specific batch. The registration of data on the batches in production should also be possible on batch level. As the case describes a less critical tracking-and-tracing situation, the question is open as to whether the benefits of an advanced system solution will outweigh the system solution's investment and operational costs. Nevertheless, in the industry one may even capitalise on tracking and tracing.

One can optimise the quality of semi-finished products and the quality of end products by better determining the quality of skin supply. It generally is very difficult to determine on receipt, the quality (e.g., the gaps, holes and scars). This is due to the presence of dirt on the skins. Quality is generally established on allocation of skins to the product variants (after cleaning and flesh removal). Quality of supply can alternatively be established through supplier rating. Performance rating of suppliers however requires the establishment of relationships between skin lots allocated to product variants and initial raw skin lots. To realise this, tracking and tracing is imperative. The enterprise assesses the performance of the supplier by linking the allocated lots, to the raw skin lots obtained from the supplier. In case of low performance, the supplier should make arrangements with its suppliers to ensure better quality. If performance rates eventually do not rise, the relationship can be terminated.

As skin properties are not known in advance to the enterprise, they can potentially influence the duration of processing. This is unwanted, as the skins supplied on one day should be processed that same day. For example, in winter the temperature of skins is relatively low and without altering some process variables, wet production will take longer then normal. The dirt of the skins also influences the wet production. To enable systematic process optimisation, it is desirable to store data on skin properties. Skins can then be divided into different sub-lot categories of incoming temperature and dirtiness (i.e., lots having some set of properties in common). In circumstances one cannot discern, registered data on skin lots is important. Skins need to be processed in a normative time (below maximum processing time), as capacity units should be freed within 24 hours in order to process the next batch of raw skins.

Explication of requirements

We have presented the traceability considerations for the leather producer. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 4.3 gives this set.

Table 4.3: Main requirements case 3.

Leather producer	- Identification of material batches - Registration of generating properties on the material batches (in particular: material dirt, holes, and scars). - Subdivision of materials in different quality classes (defining sub-lots) - Consumption of lots and batches by production - Consume-relations between production batches - Registration of batches underneath every production order - Registration of applied production means and associated processing time - Registration of process/operation data on batches - Systematic process optimisation - Performance rating of suppliers

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. Similar to the previous case, the appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. Again, the attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the presence of material dirt, holes, and scars. We state that the type of requirements identified for the leather producer actually coincide with the type of requirements that were listed in the previous cases. We can apply a same way of requirements modelling.

1. For the leather producer we identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);

(ii) a production relation (or association) (activated between lots or batches);

(iii) a capacity unit (responsible for a particular production step);

(iv) an actual production operation (executed by a specific capacity unit);

(v) an actual production operation variable (registered for a specific operation);

(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a skin batch;
a raw material batch (chemicals or paints);
semi-finished product-variants;
final leather product batch.

Ad. (ii) mixing and splitting relations between lots;
relationships between initial skin lots and final products;
composition relations.

Ad. (iii) tanks, barrels;
warehouse units (chemical products and paints);
painting machines;
cleaning equipment.

Ad. (iv) materials receiving;
materials storage;
skin cleaning (flesh removal);
allocation of skins to product variants;
product painting.

Ad. (v) painting colour;
skin allocation assignment (to product variants).

Ad. (vi) base colour;
other colours applied on painting;
actual skin allocations.

2. For the leather producer we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes for registering the skin category (skin classification by incoming temperature and dirtiness).

Ad. (ii) attributes such as gaps, holes, and scares.

4.1.4 Case 4: a pharmaceutical manufacturer

The fourth enterprise investigated on tracking-and-tracing requirements, produces pharmaceutical products for tests in laboratory environments[22].

Production steps

In figure 4.4 we provide an overview of the production steps and the control system. The enterprise under discussion has high quality and safety standards. (1) The first step of the goods flow is the receipt of the raw materials. Pharmaceutical enterprises have very stringent quality requirements on receipt, demanding detailed registration of data on supplier lots. A certificate accompanies purchased goods with data on lot properties. Such data is checked and elaborated with tests. In pharmacy, the number of different materials required by production usually is very high while the consumed quantities are usually low. (2) Because of the high costs associated with the materials, stock control is tightly arranged and the location is determined by the enterprise. (3) The first production phase consists of manufacturing generic pharmaceutical products and complementary products for testing. (4) The separate items are stored in different warehouses (decomposing abstract stock point no. 4). (5) In the production unit that follows, the separate items that belong together, are packed into a kit/test-box. (6) The final products, derived from compiling these test kits or boxes, are then stored in a warehouse. (7) Shipping of end products to customers is the last step.

The kits of the last production unit (5) are compiled on the bases of customer orders. Sales orders don't penetrate the enterprise any further so the Customer Order De-Coupling Point (CODP) is placed here. The associated control situation is Assemble To Order (ATO).

[22] Object system representation and modelling analysis by the author; interviews by Van Twillert (1999).

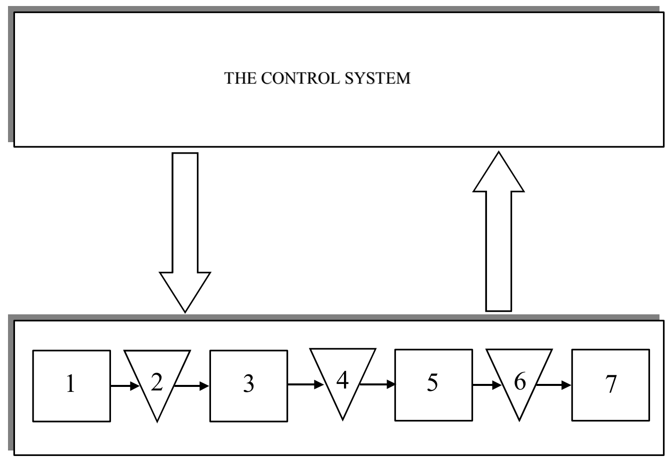

Figure 4.4: Production chain of pharmaceutical test products.

Traceability considerations

Despite the already stringent quality regime on the enterprise and its suppliers, analysis of the enterprise system revealed some improvements are possible. Given the stringent quality requirements of the industry, a sophisticated registration on quality and composition of raw materials, is needed. In warehousing and production for example, registration of data on batches is required. The required functionality often transcends that of traditional Enterprise Resource Planning or ERP (Wortmann, 1998). Most often, dedicated systems for management of data on quality and engineering are required. The enterprise under discussion uses a Laboratory Information Management System (LIMS). The LIMS is used for tracking and tracing. The LIMS is a local system. The evaluation of the enterprise system on tracking and tracing then is troublesome as much functionality for registration of data on lots or batches is handled by the local LIMS.

However, when the data on lot properties as stored in the LIMS, are not fed into the enterprise system, production planning cannot be optimised automatically. Systems integration has not been established and lot-based production is impossible, though very much desirable. It is desirable, as lot-based production optimises the allocation of lots to production. Similar, mixing and splitting of material in warehouses and the batches in production, is not registered by the enterprise system, though desirable on the enterprise level. Also, registration of data on batches in production is not accounted for by the enterprise system. This however is desirable, as the data can be used to optimise recipes of subsequent production steps. With the data, recipes can control the short-comings of certain production materials, so as to safeguard a proper production out-come.

In the pharmaceutical industry, quality control is very tight. This does not only include the end product but moreover the raw materials that are applied on processing. Suppliers must be certified before they are allowed to supply the enterprise. A certificate depicting manufacturing and testing according to required standards accompanies each delivery of lots to the enterprise. Supplied lots, extracted from different production batches however, are likely to show some variation with respect to quality properties. Batches individually therefore, carry unique identification to which test results are linked. Any possible variation of quality between the batches can then be inspected.

Explication of requirements

We have presented the traceability considerations for the pharmaceutical manufacturer. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We once again condense the traceability considerations into one single set of natural-language requirements. Table 4.4 gives this set.

Table 4.4: Main requirements case 4.

Pharmaceutical manufacturer	- Registration of batch/lot numbers - Registration of the mixing and splitting of lots and batches - Registration of generating properties on the batches (in particular: manufacture and test results) - Registration of process/operation data on batch level - Registration of the capacities of processing - Lot-based production: enabling the subsequent optimisation of production steps through improved allocation of materials and batches - Supplier certification (contractual agreements on the generating properties of supplied materials)

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. Similar to the previous cases, the appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. Again, the attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the manufacture and test results. We state that the requirements identified for the pharmaceutical manufacturer producer can be modelled similarly to those requirements, which were identified in previous cases.

1. For the pharmaceutical manufacturer we identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);

(ii) a production relation (or association) (activated between lots or batches);

(iii) a capacity unit (responsible for a particular production step);

(iv) an actual production operation (executed by a specific capacity unit);

(v) an actual production operation variable (registered for a specific operation);

(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a batch of purchased goods;
a pharmaceutical product batch;
batches of complementary products.

Ad. (ii) product compiling relations;
mixing and splitting relations between materials;
material composition relations.

Ad. (iii) packing production units;
product compilation units;
production warehouses;
manufacturing equipment.

Ad. (iv) materials receipt;
manufacture of generic products;
manufacture of complementary products;
product compilation;
product packing;
warehouse storage.

Ad. (v) production materials consumption;
stock assignments;
storage conditions.

Ad. (vi) consumed materials quantity;
stock vicinity number;
temperature, humidity.

2. For the pharmaceutical manufacturer we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes describing the certificate or the specific lot properties of a supplier.

Ad. (ii) attributes registering abnormal material test-outcomes and composition deviations.

4.1.5 Induced requirements

In the previous subsections, we described four distinct production cases: (1) a slaughter facility, (2) a food processor, (3) a leather producer, and (4) a pharmaceutical manufacturer. For each case, we described: (1) the process flow and (2) the (tracking-and-tracing) information requirements. Moreover, we performed, per case, an analysis on the natural-language requirements, so as to identify main entity (relationship) types and attribute (class) types for information-system support.

Below, we present a generalised overview of the inferred *entity (relationship) types* and *attribute (class) types*, for all cases involved. The generalised overview is the key to the design of a general modelling solution: a reference-data model.

We generally identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);
(ii) a production relation (or association) (activated between lots or batches);
(iii) a capacity unit (responsible for a particular production step);
(iv) an actual production operation (executed by a specific capacity unit);
(v) an actual production operation variable (registered for a specific operation);
(vi) an actual production operation value (registered for a specific variable).

General case examples:

(i) animal batches, canned sausage batches, product batches, skin batches;
(ii) mixing and splitting relations, composition relations;
(iii) manufacture equipment, production units, packing units, cleaning equipment;
(iv) slaughter, sausage production, waste elimination, product compilation;
(v) stock and storage variables, climate conditions, material consumption;
(vi) temperature and humidity values, stock quantities, product amount.

We generally identify two *attribute (class) types*:

(i) material quality attributes (that can be assigned to a material);
(ii) material quality anomalies (identified during quality inspection).

General case examples:

(i) attributes describing material potencies, classifications, certificates;

(ii) attributes such as test-outcome, potency deviation, composition error.

Then, from these results on the cases, we formulate general requirements for the construction of our reference-data model. The inclusion of general requirements in the reference-data model is important, so as to create the characteristic of abstraction for the reference-data model. From the case requirements, four general requirements are defined. We distinguish:

(i) the support for the registration of historic relations between lots and batches (where-from and where-used relations);

(ii) the support for the registration of operations on lots and batches in production;

(iii) the support for the registration of associated variables and values, on operation control;

(iv) the support for the registration of capacity units on which operations are executed.

The satisfaction of these requirements will give us insight into the generating properties of manufactured products i.e., the complete set of visible and invisible properties that a product (group) has in common and in which we are interested[23]. It means that the reference-data model must include the ability to support forward and backward traceability of product-related properties. The requirement for the traceability of these properties is closely related to the set of general requirements, induced from the cases.

The obtained requirements are taken to be general design principles for the construction of the reference-data model. The incorporation of these design principles provides the model with the characteristic of abstraction and subsequently allows deduction to specific cases. The question then is: how are these design principles translated into an adequate reference-data model? The upcoming sections will provide a more in-depth explanation of the transformation of the design principles into a reference-data model. Moreover, the structure of the reference-data model is discussed extensively, so as to grasp a thorough understanding of its working.

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[23] These properties of the product (group) are related to the product itself, to the processes that produced the product, and to the production means used in the production processes.

4.2 Modelling the reference-data model

In this section the construction of the reference-data model is described. First, modelling the bill of lots and batches is discussed (subsection 4.2.1). Then, the modelling of actual operations and variables is elaborated on (subsection 4.2.2). Following, modelling the integration of the bill of lots and batches and the operations, is described (subsection 4.2.3). Finally, a model overview is presented (subsection 4.2.4).

4.2.1 Modelling the bill of lots and batches

A data model is a coherent representation of objects and relations from a part of reality (Hofstede, 1998). Data models consist of entity types and relationship types. The entity types lot/batch and bill of lots/batches, and their relationship types, are elaborated on next. The mentioned types play an important role in tracing the composition of the end product through the production process.

A production process is a sequence of activities transforming a listing of raw materials, parts, intermediates and subassemblies into one particular end product. The materials, used to produce a certain end product, are contained in lots or batches. Lots and batches are on the one hand identified, and are on the other hand defined by their set of generating properties: the complete set of visible and invisible properties, the product (group) has in common. The properties are related to the product itself, to the processes that produced the product and, to the production means that are used in the production processes in which it was made.
Lots and batches contain purchase materials, production materials or end products. The different words are often used to differentiate between respectively process input and process output.

It is important to register which lots made a contribution to the composition of a certain end product batch. Lots consumed in production must be tracked through the production process in order to be able to determine the composition of the end product down to its constituent parts. It is therefore necessary that each parent assembly maintains traceability relations with its sub-assemblies. By registering the relations between sub-ordinate and super-ordinate material lots, a method of tracking the composition of the end item is obtained. When the entire sequence of activities required for manufacturing a certain end item adheres to the registering of relations, a multilevel bill of lots can be compiled. That bill of lots then contains the necessary data to determine:

(1) the composition of an end product out of component lots, and
(2) all end products having consumed a component lot of specific interest.

The composition of a product can be determined in different respect. For example, we might be interested in knowing if a product consists of biological components or chemical components, and (additionally) determine if only natural ingredients are used rather than artefacts. We have the possibility to investigate component lots on specific properties that they have in common (e.g., chemical or biological properties). Such specific application of the bill of lots is referred to as the bill of composition. A chemical bill of composition and a biological bill of composition are examples hereof. We elaborate hereon, on the next pages.

To understand the design of the bill of lots, knowledge of the bill of materials is required. The bill of materials registers each relation between a sub-ordinate entity and super-ordinate entity. It comprises of a list of components required for the production of a parent item. A representation of a bill of materials is depicted in figure 4.5. The graphical representation of the production structure is given by the associated Gozinto Graph (Loos, 2001). From a designers view, the bill of materials represents a set of parent-component relationships whereby each relationship is an entity in itself (Scheer, 1998; Bertrand et al., 1990). The relationship is characterised by the attributes: parent item identification, component item identification, effective start date/time (the date/time the relation is activated), effective end date/time (the date/time the relation is de-activated), quantity of component, and yield/scrap factor (the ratio of usable output from a process to its input). The latter, of course, is a good indicator for the materials' returns.

Bill of material for M1

pos.	material	quantity
1	M2	2
2	M3	3
3	M5	1

Bill of material for M3

pos.	material	quantity
1	M4	6
2	M5	4

pos. = position
material = subordinate material (input)
quantity = required material quantity

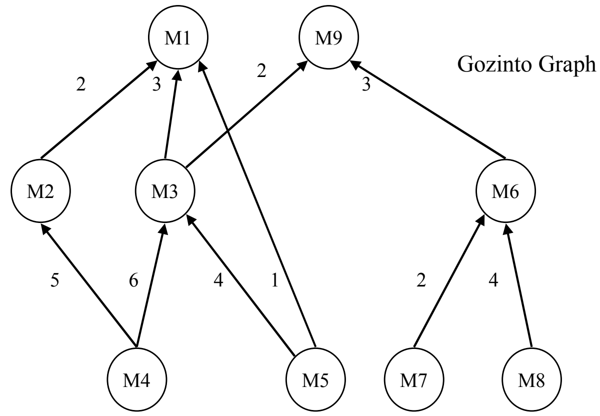

Figure 4.5: Bill of materials (Loos, 2001).

The bill of lots can be designed analogously to the bill of materials. The bill of lots is the design analogy of the bill of materials. In figure 4.6 we present the general bill of lots. Figure 4.7 represents an example of a bill of composition, too (i.e., a chemical bill of composition). Below, we explain the workings of both bills.

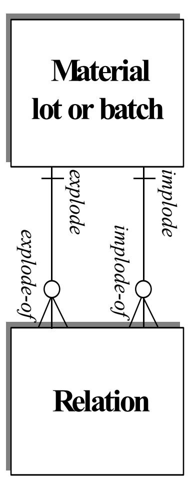

Figure 4.6: General bill of lots.

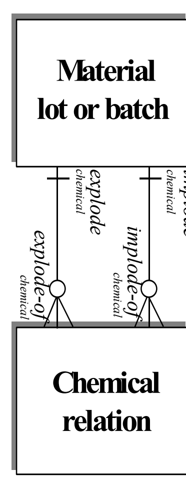

Figure 4.7: Example bill of composition.

A general bill of lots consists of several entity types and relationship types. The material lot entity type is used to store information on a material. The relation entity type is used to store the material's relations with other materials. A bill of composition is obtained when (higher-order and lower-order) material lot entities of the bill of lots are investigated on the specific properties that these entities have in common (e.g., chemical or biological properties).

We distinguish two labels, responsible for two types of searching in the (mentioned) bills:

(1) The *explode* label is used in backward traceability: backward traceability refers to the exploration of the where-from relations between objects. These relations depict the raw material lots consumed by manufacturing operations for the production of the one particular product, and further backward. The *explode-of* label makes transparent from which material is exploded (and what specific properties these materials have in common).
(2) The *implode* label is used in forward traceability: forward traceability describes the exploration of where-used relations between objects. These relations depict all end products having consumed a particular raw material of interest via certain manufacturing operations. The *implode-of* label makes transparent from which material is imploded (and what specific properties these materials have in common).

Thus far, the bill of lots (and/or the bill of composition) was discussed on the level of the entity types (i.e., the lot entity type and the relation entity type). Below, we discuss the bill of lots (and/or bill of composition) on the level of the *attribute* types. We discuss: (1) the attribute types of the lot entity type and (2) the attribute types of the relation entity type.

(1) Attributes of the lot entity type

A lot entity type is composed of a unique (lot) identification attribute type, and other lot-associated attribute types (item identification, description, unit of measure, original quantity, remaining quantity and order type, are examples of such lot entity attribute types).

(2) Attributes of the relation entity type

A relation entity type is composed of a unique (relation) identification, and other relation-associated attribute types (effective start date/time i.e., the date/time the relation is activated, effective end date/time i.e., the date/time the relation is de-activated, *actual* quantity of consumed material and *actual* yield/scrap factor, are examples of such relation entity attribute types). For every relation entity holds: the combination of sub-ordinate and super-ordinate lot identification is unique.

The relation entity type can be added a specific attribute type with which to determine whether a deficient material can be extracted from a composite product, without any problem. The relation entity type is then equipped with an attribute type, called type of relation, which discriminates the (activated) relations. This specific attribute type (then) allows the relation to be discriminated to: a vapour-relation, a blend-relation, a stir-relation, or an attach-relation). The attribute has clear advantages in traceability:

- the attribute enables one to determine whether a deficient material can be extracted from a composite product, without any problem, and
- whether the other materials of the product remain applicable for any possible re-use.

We conclude that all mixing and splitting activities with batches, inside an organisation, can be tracked when using the bill of lots (or more specific: the bill of composition). The actual circumstances, in which batches are required to be mixed or split however, may be very diverse.

For example, when larger operation quantities are desired on operation, and lots are considered of similar quality, warehousing may pool them. Material lots are then joined to form one bigger lot. In production, capacity units mix material lots and batches on sequencing operations in a routing. Regardless however of the reason of mixing, traceability of material lots must be maintained. Therefore, newly created lots should be assigned unique identification and the relations created on mixing the material lots, should be recorded. Besides mixing of material lots however, organisations may split material lots for certain reasons. Warehousing may split a material lot for example, in the case that some part of the material has become damaged and the composition of the lot is no longer uniform. Splitting of the material then takes place and the lots split are

assigned unique identification. Such lot is then split-up into two lots: a lot with damaged material and a lot with undamaged material.
Considering the above, the application of the multilevel bill of lots is extremely important to the handling of materials. The structure of the multilevel bill of lots is capable of recording all the relations to keep mixing and splitting of material lots traceable.

4.2.2 Modelling actual operations and variables

In this section, the second part of the reference model is highlighted: the traceability of operations and operation variables in production. A manufacturing process is a network of manufacturing steps, which have been aggregated into operations for the purpose of manufacturing control (Bertrand et al., 1990). In manufacturing planning, items are prescribed by so-called normative operations on capacity units. In production execution however, tracking-and-tracing requirements demand specific data on actual operations performed and not on normative operations. Hence, actual operations must be linked to the production order execution of a certain item. In figure 4.8 we present the desired linkage.

Information on items[24], orders, and actual operations are respectively stored by: the item entity type, the production order entity type and the actual operation entity type. The labels *produced by, generates, puts into effect*, and *executed by,* describe the different interrelations between the entity types. A certain amount of item, is *produced by* zero (anonymous production) or more production orders. Every production order only *generates* one item. A production order *puts into effect* zero or more actual operations[25]. Every actual operation is *executed by* only one particular production order.

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[24] Item describes a product that can be purchased by a customer. Manufacturing produces the instances.
[25] Zero, in the sense that entry of a production order not requires an immediate entry of the operations, as the production order may e.g., be scheduled a week thereafter.

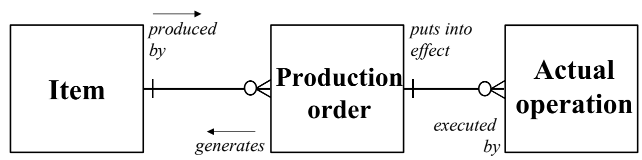

Figure 4.8: Linking actual operations.

It is assumed that the transformation of input material caused by an operation and resulting in an output material takes place within particular constraints, or stated differently: (I+ΔI) (OP+ΔOP) - (O+ΔO) is within particular boundaries. Figure 4.9 describes:

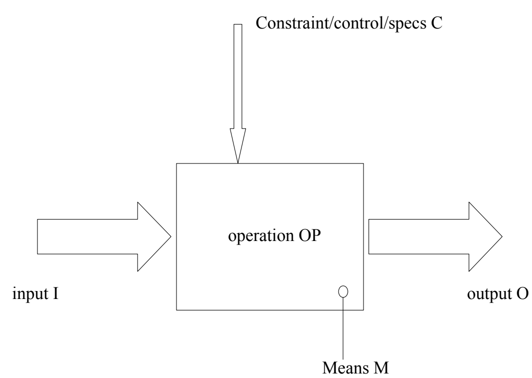

Figure 4.9: Operation control (Jansen, 1998; adapted by Beulens).

I	:	the specification of the material input;
O	:	the specification of the material output;
OP	:	the specification of the operation's behaviour;
ΔI	:	the deviation (tolerance) of the input material specification;
ΔO	:	the deviation (tolerance) of the output material specification;
ΔOP	:	the deviation (tolerance) of the operation's behaviour;
C	:	the constraints, controls and specifications;
M	:	the means of operation.

Controlling the operation's outcome requires data on the input material and its processing conditions. Material specifications can be retrieved from the material lot entity type depicted in figure 4.6. Data on processing conditions however requires the operation entity type depicted in figure 4.8, to be extended with the possibility to register operation properties. Figure 4.10 depicts the extended model.

It includes the entity types: operation variable and operation value. The labels *registers, listed by, logs, recorded by, monitors*, and *monitored by,* describe the different interrelations between the entity types. An actual operation *registers* zero or more operation variables. Each operation variable is *listed by* its actual operation (i.e., belongs to a specific operation). An operation variable *logs* zero or more operation values. Each operation value is *recorded by* its associated operation variable. Every actual operation *monitors* certain operation values (to variables) of concern. Each value is *monitored by* one particular actual operation (in relation to an operation variable).

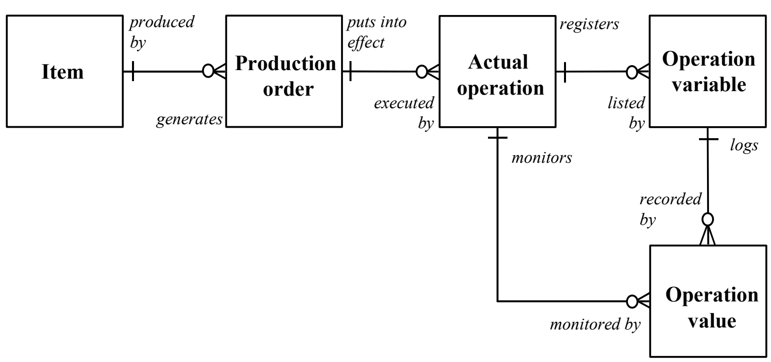

Figure 4.10: Operation properties (extended model).

The actual operation will be linked to the capacity unit(s) on which the operation is executed. The registration of capacity units is represented in figure 4.11. The new entity capacity unit, stores the information on the capacity unit(s) of processing. The labels *executed on* and *performs* describe newly added interrelations between entity types of the reference model. An actual operation is *executed on* one or more capacity units. A capacity unit can be used to *perform* zero or more actual operations.

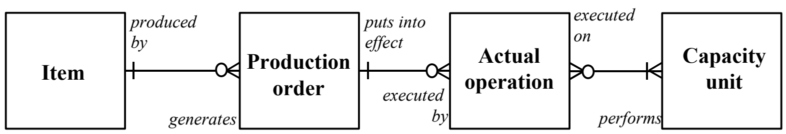

Figure 4.11: Registration of capacity units.

4.2.3 Modelling the integration of the bill and the operations

Section 4.2.1 discussed the reference-data model of the bill of lots. Section 4.2.2 discussed the reference-data model of actual operations and variables. In this section the integration of both models is discussed: the integration of the bill of lots and the actual operations.

A two-step approach is taken: first we discuss the registration of all actual operations that can be associated with a certain material lot, second we discuss the registration of all material relations activated by each of these operations, along with their conditions of processing.

We start with the first step, a description of the registration of all historic operations that can be associated with a certain material lot. Material lots are created by manufacture. They are generated through sequencing operations on a routing (sequencing in a broad sense: serial, parallel and cyclic). To trace the history of operations for a certain material lot, the list of operations should be kept alongside it. This functionality however, was not included in the data models presented previously. The functionality can be included, by relating the material lot entity type to the actual operation entity type. The history of operations is depicted by figure 4.12.

No new entity types have been added to the model: all have been explained previously in the chapter. New interrelations between entity types however, have been created, as do the labels *obtained through* and *contributed to* reveal. In this respect, every material lot is *obtained through* the processing of zero or more actual operations and each operation that is executed has actually *contributed to* bringing about the material lot.

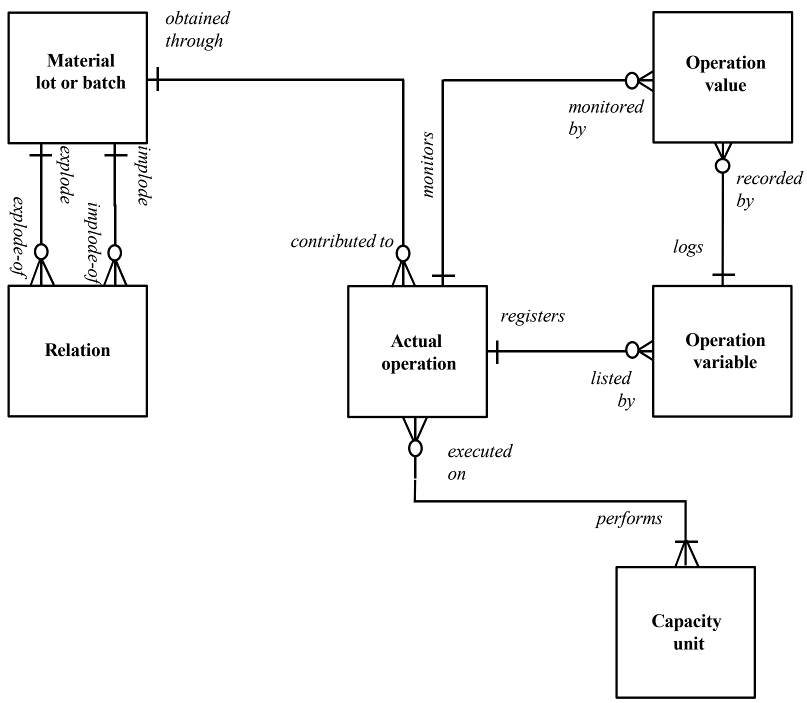

Figure 4.12: History of operations.

The section first described the registration of all actual operations that can be associated with a certain material lot. Next is discussed, the registration of all material relations activated by each of these operations, along with their conditions of processing. In the discussion thus far, the recording of material relations and the recording of processing conditions, have been treated as two separate things. Such de-coupling however is not desirable as it prevents us from mapping the actual operating data on the relations recorded in the bill of lots. Operating data and relations in the multilevel bill of lots must be related on the right level. Operating data should not be registered on the level of the production order (the final production lot), as then data on operations are aggregated over all the (multilevel) relations and it will be impossible to narrow down a particular problem. Therefore, traceability relations must be stored in conjunction with the operation that invoked them. This can be included in the data model by adding a material requirement relationship between the actual operation entity type and the relation entity type, see figure 4.13.

No new entity types have been added to the model of figure 4.13: all have been explained previously in the chapter. However, new interrelations between entity types, have been created, as do the labels *invoked by* and *material requirement,* reveal. With regard to this pair of labels (*invoked by* and *material requirement*):

- The label *invoked by* depicts which operation is responsible for creating a traceability relation between a lot of input and a lot of output.
- The label *material requirement* describes for the operation and the material output lot under discussion, what material lots were required/consumed.

The interrelations described can be characterised as: input-(process)operation-output.

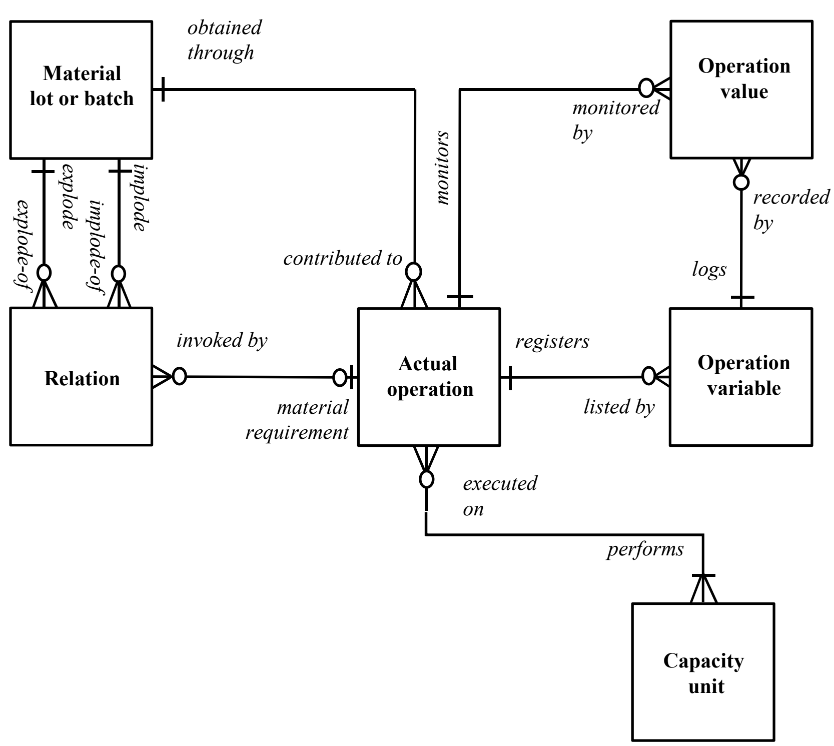

Figure 4.13: Material relations and responsible operations.

4.2.4 Model overview

In this section the overview of the reference-data model is presented. The reference-data model supports: (1) tracking, (2) forward, and (3) backward traceability of items. It enables the retrieval of (desired) generating properties of products: i.e., the complete set of visible and invisible properties that a product (group) has in common and in which we are interested. These properties of the product (group) may be related to the product itself, to the processes that produced the product and, to the production means used in the production processes. Below, we explain in more detail the functional support, offered by the reference-data model.

We distinguish: (1) the support for the registration of historic relations between lots and batches (where-from and where-used relations), (2) the support for the registration of operations on lots and batches in production, (3) the support for the registration of associated variables and values, on operation control, and (4) the support for the registration of capacity units on which operations are executed.
These requirements are general requirements. They are identified as design principles for the reference-data model. With these requirements, a more comprehensive model is successfully developed, which includes relevant data entity types and relationship types, concerning the item produced, the production order responsible, the material lot obtained, the history on constituent material parts, the data of processing and the capacity units processed on.
The requirement of the generating properties (i.e., the set of properties of interest that products have in common) is identified as an overlaying requirement. The inclusion of the four (general) requirements is a prerequisite for (satisfying) the latter requirement.

Next, follows an elaboration on 'reading' the reference-data model (depicted again in figure 4.14). The model includes the entity types and relationship types discussed in the chapter. A requested item is produced with a production order that issues a material lot[26]. Under the production order, operations are put into effect and executed on capacity units. The operation's material consumption is maintained by relating the actual

[26] Material lots need not solely stem from production orders: purchase orders may for example be the origin of material demand too (i.e., demand tracking for a material lot may include other order types as well).

operation to the registered relations (within the bill of lots/batches). Operational performance is registered by the operation variables and values. Operation values are registered in relation to the operation variables, which in turn are related to the actual operation executed. Every operation executed is also related to the final production lot generated. An obtained material lot can be exploded into constituent parts of which it is made up, via the so-called explode relationship. Any obtained material lot can also be imploded via the so-called implode relationship to discover its consumption by other lots or production orders. In determining product compositions, material lots can be investigated on the (set of) properties that they have in common (e.g., chemical or biological properties).

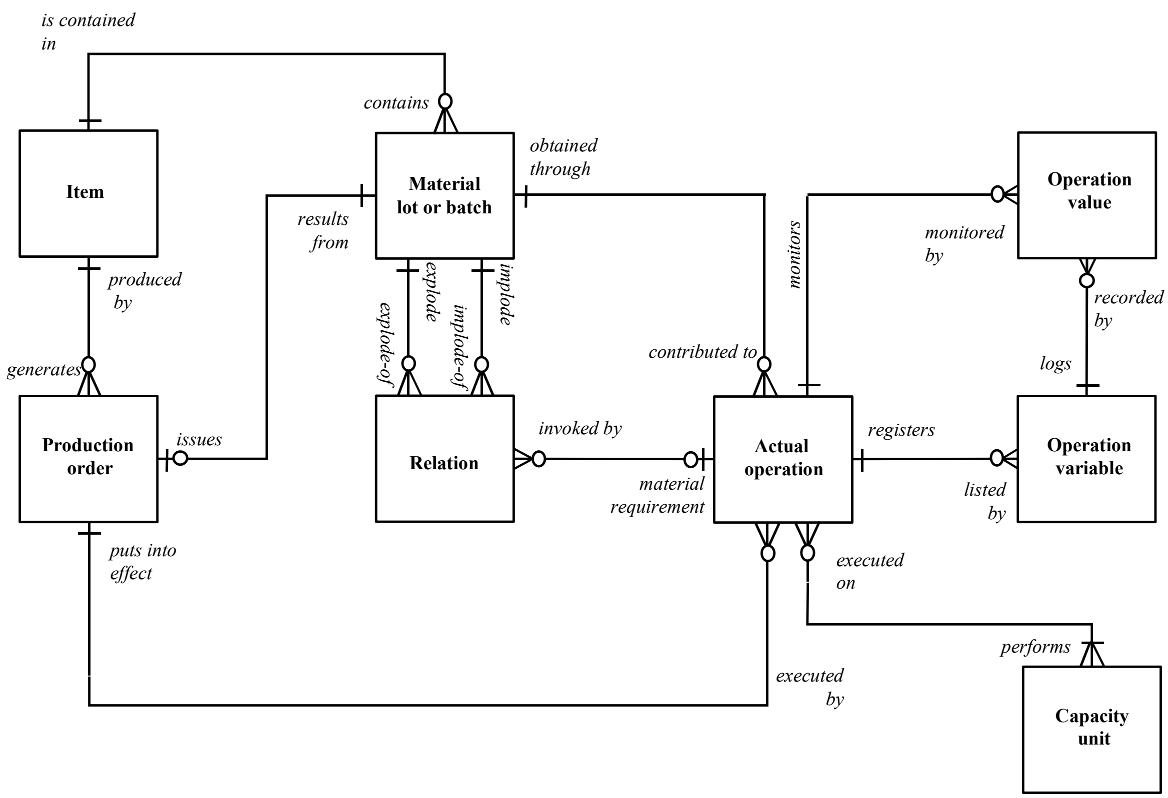

Figure 4.14: Comprehensive model overview.

Two interrelations between entity types have not been discussed: the interrelation between the item entity type and the material lot entity type, and the interrelation between the order entity type and the material lot entity type. Regarding the first interrelation, the interrelation between the item entity type and the material lot entity type, it is depicted with the following two labels: *is contained in* and *contains.* In the reference-data model, a certain kind of item *is contained in* (i.e., kept in) zero or more material lots, and every material lot only *contains* one kind of item[27]. Regarding the second interrelation, the interrelation between the order entity type and the material lot entity type, it is depicted with the following two labels: *issues* and *results from.* In the reference-data model, every production order *issues* a material lot or batch that holds a specific and desired item. Every material lot or batch *results* either *from* a production demand (a production order) or any other kind of demand (e.g., a purchase order).

The entity types of figure 4.14 are all uniquely identified with a unique (composed) identifier, called a key. The keys to the entity types are shown in table 4.15.

Table 4.15: Keys to the entity types.

Entity type	**Unique identifier**	**Comments**
Production order	OrderIdentification	Every production order is identified uniquely
Item	ItemIdentification	Every item is identified uniquely
Material lot	LotIdentification	Every lot is identified uniquely
Relation	MaterialHigh, MaterialLow	The combination of two material lots is identified uniquely
Capacity unit	CapacityUnitIdentification	Every capacity unit is identified uniquely
Actual operation	ActualOperationIdentification	Every actual operation is identified uniquely
Operation variable	ActualOperationIdentification, ActualVariableIdentification	The combination of an actual operation and a variable is identified uniquely
Operation value	ActualValueIdentification	Every value is identified uniquely

[27] When the material lot entity would not be related to the item entity, redundancy would arise in the model, as different lots can hold the same kind of items.

4.3 Chapter summary

In the chapter, we described the analysis of four distinct production cases:

Case 1: a slaughter facility;

Case 2: a food processor;

Case 3: a leather producer;

Case 4: a pharmaceutical manufacturer.

For each case, we investigated three aspects: (1) the process flow, (2) the tracking-and-tracing information requirements, and (3) the inference of *entity (relationship) types* and *attribute (class) types*. With respect to the results of the latter aspect, we present a generalised overview:

Identification of six *entity (relationship) types*:

- (i) a material lot and batch (identified in production);
- (ii) a production relation (or association) (activated between lots or batches);
- (iii) a capacity unit (responsible for a particular production step);
- (iv) an actual production operation (executed by a specific capacity unit);
- (v) an actual production operation variable (registered for a specific operation);
- (vi) an actual production operation value (registered for a specific variable).

Case examples:

- (i) animal batches, canned sausage batches, product batches, skin batches;
- (ii) mixing and splitting relations, composition relations;
- (iii) manufacture equipment, production units, packing units, cleaning equipment;
- (iv) slaughter, sausage production, waste elimination, product compilation;
- (v) stock and storage variables, climate conditions, material consumption;
- (vi) temperature and humidity values, stock quantities, product amount.

Identification of two *attribute (class) types*:

- (i) material quality attributes (that can be assigned to a material);
- (ii) material quality anomalies (identified during quality inspection).

Case examples:

- (i) attributes describing material potencies, classifications, certificates;
- (ii) attributes such as test-outcome, potency deviation, composition error.

Subsequently, we were able to induce some general requirements from these case-study results. We distinguish four general requirements:

- (i) support for the registration of historic relations between lots and batches;
- (ii) support for the registration of operations on lots and batches;
- (iii) support for the registration of associated operation variables and values;
- (iv) support for the registration of capacity units on which operations are executed.

The satisfaction of these requirements will give us insight into the generating properties of manufactured products. Generating properties are the properties that may be related to the product itself, to the processes that produced the product, and to the production means that are used in the production processes. The generating properties describe the (set of) properties (of interest) that the products have in common.

The presented general requirements were (then) successively formalised by data models so as to enable the construction of a more general model: a reference-data model.
The chapter extensively discussed the modelling of the general tracking-and-tracing requirements. The names of the entity types reoccurring in the reference-data model, are: Item, Production order, Material lot or batch, Capacity unit, Relation, Operation, Actual operation variable, and Operation value. In particular the inclusion of the multilevel bill of lots (or batches) must be considered important to tracking and tracing. The multilevel bill of lots is capable of recording all the constituent parts of a material lot obtained, and in relation to operations, keeps all necessary processing data on these (constituent) parts accessible, on the right level of operation (non-aggregated).

In summary, the induced reference-data model described in the chapter, records the knowledge and experience on the design of enterprise tracking and tracing. The model enables us to list information on raw materials, parts, intermediates, and subassemblies, and information on their transformation into an end product, through the execution of operations by capacity units. The model enables us to perform the important functions of tracking and tracing on objects within the object system: tracking, forward traceabilty and backward traceability.

With the developed reference-data model, a tracking-and-tracing information system can be constructed. The model can be customised so as to satisfy specific domain requirements of (information system) customers. Some limitations however must be mentioned. The first limitation concerns the traceability of rework and cyclic production. This has not been investigated. The second limitation concerns the application domain of the reference model. The cases investigated on tracking and tracing, did not exceed the manufacturing domain. As such, model-requirements for traceability within, e.g., the distribution domain, were not investigated. Hence, the validity of the developed reference-data model is not supported for cases located outside the manufacturing domain. On generalisation then to a chain or network, only manufacturing functions within the chain or network, and their interrelations, may be considered.

A final remark is on the difference between the theory on the object system (chapter 3), and the empirical data on the cases (chapter 4). Quality system requirements were not dominant in the chapter, though they were considered important in theory. The empirical cases within the chapter mainly focused on 'logistic' requirements for tracking and tracing. The explanation lies in the fact that most of the investigated companies already had a developed quality function installed and saw no need for duplicating this function onto a tracking-and-tracing system. With this standpoint, they tend to overlook the advantages of a system that combines the best of both worlds. However, in chapter 5, we discuss cases in which the advantages of a combined view on quality and logistic indeed are acknowledged. We then make a special reference to the quality system of HACCP (Hazard Analysis of Critical Control Points).

Chapter 5

Evaluation of the reference-data model

Chapter contents

5. Evaluation of the reference-data model

In this chapter the reference-data model and the application with respect to tracking and tracing are evaluated[28]. The reference-data model is evaluated by a thorough analysis of the requirements specified for three test cases (companies involved in egg production). With respect to each case, the instantiation of the reference-data model is addressed, thus establishing the applicability of the model. The actual application of the reference-data model is evaluated by the presentation of the prototype and the analysis of the (relevant) feedback.
The chapter starts with a description of the test cases and their requirements (section 5.1). Then, a description of the application is given (section 5.2). Next, the reference-data model is evaluated (section 5.3). Subsequently, the application is evaluated (section 5.4). The chapter is completed by a conclusion (section 5.5).

5.1 Description of the test cases

In this section we discuss the requirements with respect to tracking and tracing for three test cases. The test case are: the consumer-egg producer, the grower, and the breeder. The requirements are used to evaluate how the reference-data model functions under different circumstances. The test cases are instrumental to the evaluation of the reference-data model. They are situated within a production network that is depicted in figure 5.1. The production network consists of a breeder, a grower, a consumer-egg producer, a packing station (the main production line) accompanied by two supporting agents, a feed producer, and a veterinarian. We briefly explain their interrelationships. We start at the packing station that maintains a relationship with the consumer-egg producer (consumer eggs). The consumer-egg producer maintains three other relationships: with the grower (layers), the veterinarian (medication) and the feeder (feed). The grower also maintains three other relationships: with the breeder (chickens), the feeder (feed) and the veterinarian (medication). Finally, the breeder maintains two

[28] Parts of this chapter have been published in Van Dorp et al. (2002a) and in Van Dorp (2003).

more relationships: with its supplier (not illustrated) and with the veterinarian (medication).

The (tracking-and-tracing) requirements of the consumer-egg producer, the grower, and the breeder are selected for the evaluation of the reference-data model. The enterprises belong to the main production chain of the network. The primary production and the traceability considerations of the three test cases are discussed in the next subsection (similar to the method discussed in chapter 4).

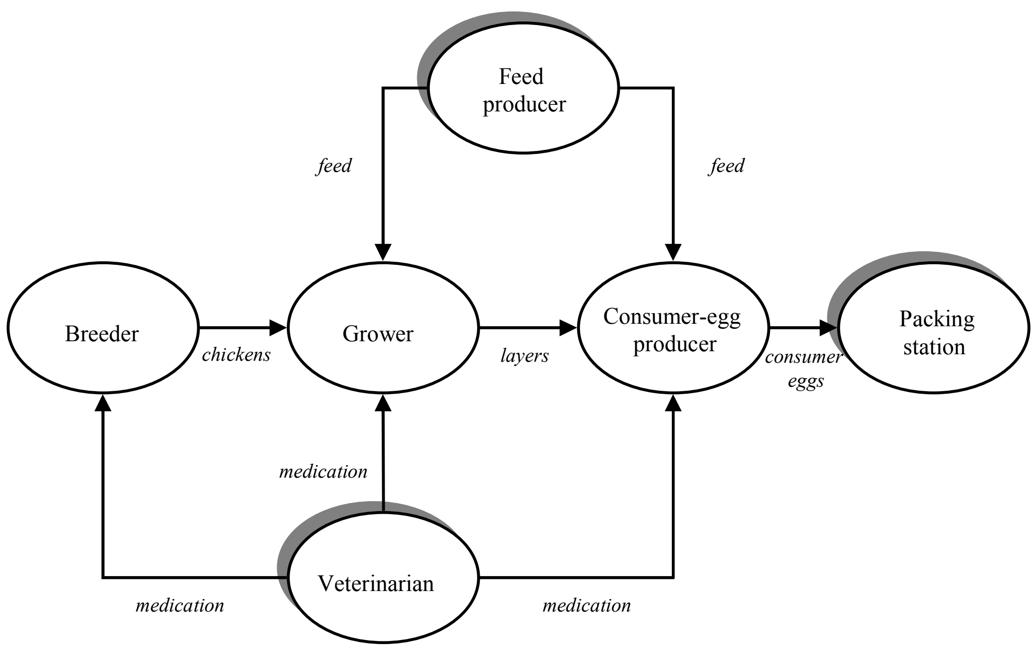

Figure 5.1: Production network.

5.1.1 Case 5: the consumer-egg producer

The first enterprise investigated for its tracking-and-tracing requirements produces consumer eggs. We call the enterprise a consumer-egg producer.

Production steps

In figure 5.2 we provide a schematic overview of the production steps of the consumer-egg producer; a control system governs its functioning. It is without saying that the consumer-egg producer produces eggs for consumption purposes (see figure 5.1). The enterprise obtains a flock of layers from the grower. The layers remain active for about some 50 weeks after which the production of eggs decreases. The consumer-egg producer delivers to packing stations, cooking and peeling companies (for further use in salads), painting companies (painted eggs), processing companies (bulk processing, quality processing [egg-liqueur]) and auction cash and carry. The primary process of the consumer-egg producer is described next.

Receipt of the layers, obtained from the grower, takes place in (1). Receipt of feed from feeding companies takes place in (2). Three to four shipments of feed in a week is not unusual. The feed is delivered by trucks and on average it happens weekly; the total shipment may amount to 30 tons. The feed is stored in silos, designated to stables, see (3). The layers are then fed and used to produce the eggs; this happens in (4). The eggs produced by the layers are successively collected, palletised, and labelled, see (5). Eggs are collected on a daily basis. Per stable, the eggs of different layer units are transported and brought together to enter the palletising machine. It results in an inbound supply of a final product, see (6). In the end, the consumer eggs are delivered to the customer, see (7). Usually, the customers of the eggs are known in advance; if not, the production is anonymous. The production is characterised as the combination of a Make To Order (MTO) and Make To Stock (MTS) control.

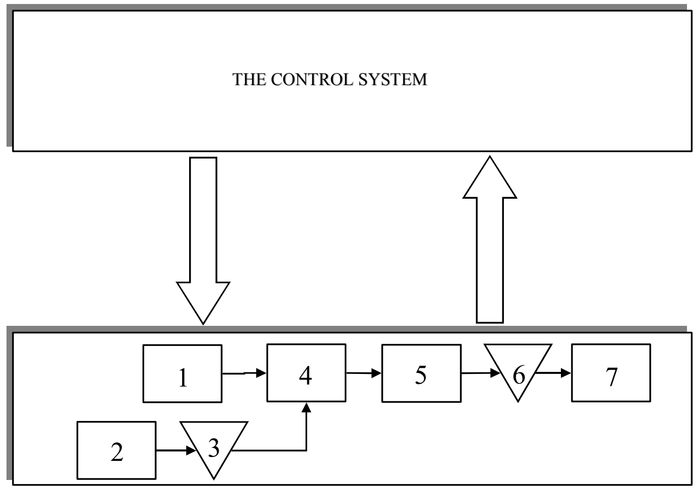

Figure 5.2: Production chain of the consumer-egg producer.

Traceability considerations

For the production of consumer eggs, the consumer-egg producer obtains layers from the grower. For tracking and tracing it is clear that the purchased layer batches must be identified uniquely, and the information on the supplier must be recorded adequately. For any non-desirable batch-generating properties as Salmonella and Campylobacter, an appropriate traceability system is required. Batches must remain traceable from receipt throughout production. The identification of both layer batches and consumer-egg batches must be addressed in accordance with the requirements. To enable the traceability of consumer-egg batches back to the initial layer batches, a relationship between the two identifiers will have to be established. The distribution of a layer batch over different stables and the concurrency of different layer batches into one stable, must be addressed too. Moreover, registration must take place of the mixing and splitting of layer batches on the premises of the consumer-egg producer. Next to addressing the origin and the allocation of layer batches, the actual operations performed on the layer batches must be kept traceable over the different stables (i.e., non-aggregated), too. Examples of operations executed on the stable level are: the supply of water and feed, the control of the climate, the collection of the eggs, and the medicating. In registering feed and medication operations, vital traceability information such as batch numbers of feed and medication are included. Very important are the results of lab tests. With respect to feed traceability, a special interest exists in the traceability of non-desirable batch-generating properties such as dioxin. In addition, the consumer-egg producer requires (historic) production information from the grower (the growing conditions of the layers in the previous chain link: information on feeding, watering, medication, lab tests, climate, etc). The farm conditions of the consumer-egg producer should then be matched with these preceding grower conditions and should prevent layer (health) irregularities from occurring. However, the exchange of information on medication or vaccination may be controversial.

Explication of requirements

We have presented the traceability considerations for the consumer-egg producer. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 5.1 gives this set.

Table 5.1: Main requirements case 5.

Consumer-egg producer	- Identification of layer and egg batches - Registration of batch-generating properties (with a specific interest in Salmonella and Campylobacter properties) - Relationships between layer batches and egg batches - Distribution of layer batches over different stables - Bringing together layer batches into a stable - Operations performed in the stables on batches during certain periods - Registration of generating properties of feed batches (with a specific interest in dioxin properties) - Information on detailed operations - Production data of the preceding chain link

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. We distinguish in this respect: (1) entity (relationship) types and (2) attribute (class) types. The appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. The attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the quality of egg batches, the presence of Campylobacter, etc.

1. For the consumer-egg producer we identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);
(ii) a production relation (or association) (activated between lots or batches);
(iii) a capacity unit (responsible for a particular production step);
(iv) an actual production operation (executed by a specific capacity unit);
(v) an actual production operation variable (registered for a specific operation);
(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) consumer-egg batch;
a layer batch.

Ad. (ii) the relation between layer batches brought together in one stable;
the relation between layer batches distributed over different stables;
the relation between layer batches and final consumer-egg batches.

Ad. (iii) a water unit;
a feed process unit;
a climate control unit;
a stable.

Ad. (iv) the supply of water
the supply of feed;
the control of climate;
the collection of eggs;
medicating and taking lab samples.

Ad. (v) climate temperature;
medication type;
medication batch number;
amount of water;
water unit;
type of feed;
amount of feed;
feed silo number.

Ad. (vi) actual stable temperature;
actual admitted vaccination;
actual batch numbers of feed;
actual medication batch numbers.

2. For the consumer-egg producer we propose that two *attribute (class) types* are incorporated:

(ii) material quality attributes (that can be assigned to a material);

(iii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes describing the consumer-egg class (e.g., consumption class A and consumption egg second quality, i.e., class B/C).

Ad. (ii) attributes such as Salmonella and Campylobacter.

5.1.2 Case 6: the grower

The second enterprise investigated on tracking-and-tracing requirements produces layers from one-day-old chickens. We call the enterprise a grower.

Production steps

In figure 5.3 we provide a schematic overview of the production steps; a control system governs its functioning. Through a growing process, a grower obtains his layers from little chickens. The little chickens are purchased from the preceding network link: the breeder. The breeder offers them to the grower when they are about one day of age. From the grower, the layers are purchased by the succeeding link of the network: the consumer-egg producer. The layers are supplied to the consumer-egg producer when the chickens are about seventeen weeks of age. The entire growing process (therefore) takes about seventeen weeks. The primary process of the grower is described below.

Initially, the receipt of the one-day-old chickens takes place, see (1). This receipt may include chickens of a different race, such as white and/or brown. The chickens that are received can be distributed over different stables. Further, the receipt of feed from the feed company takes place in (2). Similar to the consumer-egg case, this feed is stored in silos; this happens in (3). The silos are designated to particular stables. The chickens then are fed to grow into layers, see (4). The layers that are grown then await the delivery to purchasers and are expedited, see (5). During the growing, the purchasers of the layers may not have been identified all together (i.e., usually the customers are known in advance; if not, the production is anonymous). The production is characterised as a combination of a Make To Order (MTO) and Make To Stock (MTS) control.

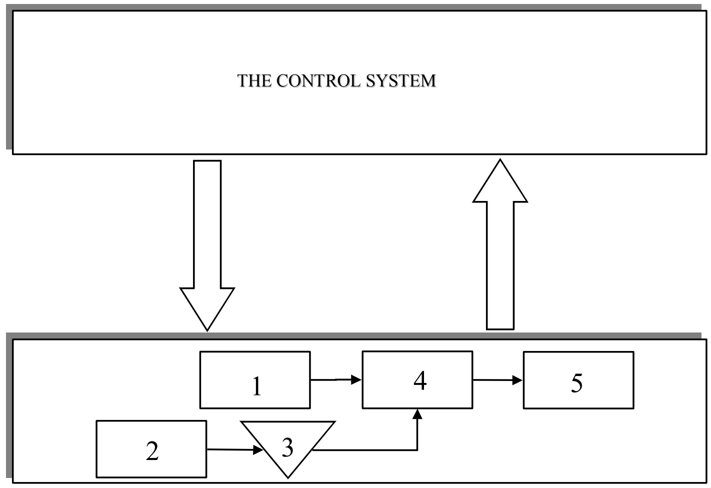

Figure 5.3: Production chain of the grower.

Traceability considerations

The traceability requirements of the grower are similar to the requirements of the consumer-egg producer. The identification of batches and the mixing and splitting of batches must be recorded appropriately in such a way that traceability of batch-generating properties (with a specific interest in Salmonella and Campylobacter properties) is assured. The capacity units, i.e., the stables to which batches are allocated, should be kept traceable along with the operations that are performed on the batches in these capacity units. Therefore, the layers that are expedited must be traceable to the stables of the grower and the operations executed. Outbound batches should be identified uniquely and maintain a relationship with the processing data of the grower. Of particular importance is the desire to keep feed batches traceable during operations. Feed is one of the important components of the growing process. First and foremost it must be possible on feeding operations to register the feed batches successively presented to the layers in the capacity units. When tracing feed batches, specific interest goes to tracing the batch-generating property: dioxin. Medication batches, used by the veterinarian on medical operations, must remain traceable, too (along with lab tests taken). Moreover, additional quality information is required from the breeder. The information concerns all data logged during different phases of breeding.

For instance, the information concerns storage and climate conditions, percentage fertilised/ non-fertilised eggs, medication, doses of medication, microbiological test results, fall-out in the first week, etc. The information can be used by the grower, in aligning the process along the production conditions of the breeding. When irregularities occur in the breeding process, the grower can pro-actively adapt its growing process and supply vitamins or medication to the chickens and compensate any quality deficiency. Sometimes, the chicken's parents might be the cause of health problems. Then, it is of interest to receive information on the parents' health conditions, too (this information is registered by the breeder's supplier and can be obtained through the breeder).

Explication of requirements

We have presented the traceability considerations for the grower. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 5.2 gives this set.

Table 5.2: Main requirements case 6.

Grower	- Identification of the animal batches - The mixing and splitting of batches - Registration of batch-generating properties (with a specific interest in Salmonella and Campylobacter properties) - Batch allocation to stables - Registration of operations on batches in capacity units (stables) - Registration of feed batches and batch-generating properties (with a specific interest in dioxin or any other toxin) - Traceability of medication batches in operations - Production data of the preceding chain link

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. Similar to the previous case, the appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. Again, the attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the presence of Campylobacter or Salmonella. We confirm the generality of our modelling, as we are able to model the requirements of the grower in a similar way as the modelling of the requirements of the consumer-egg producer.

1. For the grower we identify a similar set of six *entity (relationship) types*:
   (i) a material lot and batch (identified in production);
   (ii) a production relation (or association) (activated between lots or batches);
   (iii) a capacity unit (responsible for a particular production step);
   (iv) an actual production operation (executed by a specific capacity unit);
   (v) an actual production operation variable (registered for a specific operation);
   (vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a one-day-old chicken batch;
a layer batch.

Ad. (ii) the relation between chicken (or layer) batches set together in one stable;
the relation between chicken (or layer) batches distributed over different stables.

Ad. (iii) a feed process unit;
a climate control unit;
a stable.

Ad. (iv) a feeding operation;
a medication operation;
a watering operation;
a climate control operation.

Ad. (v) a feed type;

feed batch;
feed silo;
type of medication;
medication batch;
amount of water
unit of watering.

Ad. (vi) actual batch number of applied feed;
actual batch number of applied medication;
actual unit number of watering.

2. For the grower we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes describing the race of the purchased chickens but also chicken and layer health irregularities.

Ad. (ii) attributes signalling the detection of Salmonella and Campylobacter.

5.1.3 Case 7: the breeder

The third enterprise investigated on tracking-and-tracing requirements, produces chickens from eggs. We call the enterprise a breeder.

Production steps

In figure 5.4 we provide an overview of the production steps of the breeder; a control system governs its functioning. The breeder obtains eggs from its supplier and uses these eggs for breeding purposes. The eggs are bred into chickens and are expedited to the grower. The primary process of the breeder is described next.

Initially, the receipt of the breeding eggs happens in the breeder's place, see (1). Eggs usually are in good condition although it may occur that eggs arrive cracked. Cracked eggs are sent to the feed processing industry. After the receipt of the breeding eggs, conditioned storage of the eggs takes place in (2). Next, the eggs are put into the breeding machine and pre-breeding is initiated in (3). The pre-breeding phase takes about seventeen or eighteen days to complete. After pre-breeding, observation takes place, see (4). The eggs from pre-breeding are then assessed on their result. Non-fertilised eggs are selected and go to waste or are sold to the processing industry. After a successful observation, post-breeding follows, see (5). Post-breeding can take up to about three days to conclude. After the post-breeding phase the outcome is established in (6). The outcome records the percentage of chickens obtained successfully. Following the outcome, medication is given to the chickens in (7). Finally, the one-day chickens obtained are ready for transport, see (8). Usually, the customers are known in advance; if not, the production is anonymous. The production is characterised as the combination of a Make To Order (MTO) and Make To Stock (MTS) control.

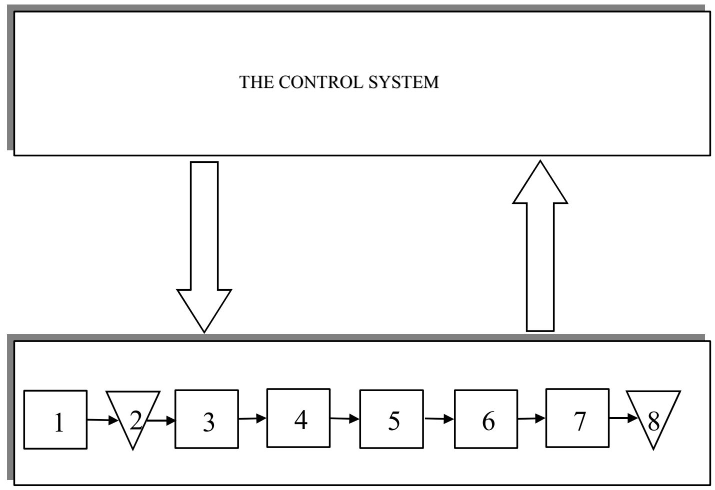

Figure 5.4: Production chain of the breeder.

Traceability considerations

The breeding organisation obtains breeding eggs from its supplier. The breeding eggs must hold a batch and supplier identification. The breeder uses the eggs to produce chickens. Chicken batches successfully bred must remain traceable, for instance to the originating egg batches. Batch-generating properties (with a specific interest in Salmonella and Campylobacter properties) must be registered. A relationship between the breeding-egg batches processed and the final outcome batch must be assured. However, in the observation phase of the primary process (discussed previously) the traceability to the stable level of the breeder's egg supplier may be lost. Nevertheless it should be considered important to establish an information relationship between the initial supplier of the egg batches and the final chicken batch obtained. Moreover, the capacity units that process the egg batches and perform the operations must be registered, along with the operation variables and values. Further, the breeder requires additional information from its supplier. The information concerns the health status and the farm conditions of the parent animals. This information is not only important for satisfying the information needs of the grower, but it can also be applied to limit the breeder's own fall-out of eggs in the breeding process, and to assess fertilisation and outcome.

Explication of requirements

We have presented the traceability considerations for the breeder. These considerations however need to be translated into requirements for the construction of a tracking-and-tracing information system. For the construction of such a system we need a more formal description of the information-system requirements. We accordingly condense the traceability considerations into one single set of natural-language requirements. Table 5.3 gives this set.

Table 5.3: Main requirements case 7.

Breeder	- Egg and chicken batch identification - Registration of batch-generating properties (with a specific interest in Salmonella and Campylobacter properties) - Batches successfully bred must remain traceable to the originating egg batches - Registration of capacity units that process egg batches - Registration of operations performed by units on batches - Logging of operation variables and values - Production data of the preceding chain link

Modelling concepts

From our main natural-language requirements we distil the modelling concepts for our information-system design. Similar to the previous case, the appropriate entity (relationship) types are identified easily: they namely depict the objects we want to store information on, such as: batches, operations, capacity units, etc. Again, the attribute (class) types are also not difficult to identify: they namely depict the detailing of the identified objects, such as: the presence of Campylobacter or Salmonella. We state that the type of requirements identified for the breeder actually coincide with the type of requirements that were listed in the previous cases. A same way of modelling can be applied.

1. For the breeder we accordingly identify six *entity (relationship) types*:

(i) a material lot and batch (identified in production);

(ii) a production relation (or association) (activated between lots or batches);

(iii) a capacity unit (responsible for a particular production step);

(iv) an actual production operation (executed by a specific capacity unit);

(v) an actual production operation variable (registered for a specific operation);

(vi) an actual production operation value (registered for a specific variable).

Below, we present six corresponding case examples (per item more examples are given):

Ad. (i) a batch of breeding eggs;
a (successfully bred) chicken batch.

Ad. (ii) mixing and splitting relations between breeding egg batches;
relationships between breeding egg batches and final outcome batches.

Ad. (iii) pre-breeding process units;
post-breeding process units;
climate control units.

Ad. (iv) egg receipt;
conditioning;
pre-breeding;
post-breeding;
observation (result assessment);
medication.

Ad. (v) quality at receipt;
conditioning temperatures;
the (breeding) outcome;
type of medication;
medication batch.

Ad. (vi) amount of cracked eggs at receipt;
the percentage of chickens obtained successfully at breeding;
medication batch numbers.

2. For the breeder we propose that two *attribute (class) types* are incorporated:

(i) material quality attributes (that can be assigned to a material);

(ii) material quality anomalies (identified during quality inspection).

Below, we present two corresponding case examples:

Ad. (i) attributes stating the fall-out of (purchased) breeding eggs, the fertilisation of (purchased) breeding eggs, and the outcome of (purchased) breeding eggs.

Ad. (ii) attributes listing the occurrence of Salmonella and Campylobacter.

We have now described the tracking-and-tracing requirements of three distinct test cases:

Case 5: the consumer-egg producer;

Case 6: the grower;

Case 7: the breeder.

The explication of the tracking-and-tracing requirements is of particular importance to the evaluation of the reference-data model (which was developed in chapter 4). The requirements of the test cases are taken as the vehicle with which to evaluate the reference-data model. We will validate the reference ability of the reference-data model by determining if the model can be instantiated with success to the test cases. For this, we will determine if the model has the proper functional coverage to satisfy the case-specific requirements.

We commence with the evaluation in the upcoming sections. The evaluation of the reference-data model takes place in section 5.3. The evaluation of the application is discussed in section 5.4. A description of the application is presented first (the next section).

5.2 Description of the application

In this section we describe the application built. The application will be explained using the test data of the consumer-egg producer[29]. Below, we describe (a) the functionality of the application and (b) the implemented queries.

(a) The functionality of the application

1. A material lot and batch (identified in production)
A production order initiates the production process. On the entry of a production order for an item, a destined production lot is identified. On this identified production lot, data is entered. A reference must be made to the production order that issued the lot, and the item that is contained in the lot. Technically speaking: within the application, lot entities record the order and item identification(s). These identifications are referred to as foreign keys. The first key can be used for the purpose of demand tracking (the origin of demand); the second key can be used to retrieve the product characteristics (the product attributes). On entry of a production order, the following data are entered in the application: the item to be produced, the date of order-entry and the order type (high/low priority). Consumption Egg Class A, Consumption Egg Class B/C (second quality) are typical production items entered.

2. A production relation (or association) (activated between lots or batches)
As a result of splitting and mixing activities in the enterprise, new batches are created. For example: (1) different layer batches are allocated to the same stable, (2) a large layer batch is split up into sub-batches, which are allocated to different stables. Newly formed relations between batches or lots require registration. This is taken care of by the Relation entity type. On pooling of batches, the new higher order batch is recorded in relation to the existing lower order batches. On segregation of batches, the new higher order batches are recorded in relation to the existing lower order batch. To make apparent (any) historic relation(s) between batches i.e., trace established relations, batch

[29] An overview of implemented database tables is given in the Appendix, Figure I; an overview of the discussed test-data for the consumer-egg producer is presented in the Appendix, Figure II.

explosion and batch implosion functionality is implemented in the application. The relationships explosion and implosion between the entity types MaterialLot and Relation depict this functionality.

3. A capacity unit (responsible for a particular production step)
It is important to have a relation to the capacity units in which the operations are executed. It is registered in what capacity units (read: stables) an operation is executed. For example, when an improper SalmonellaSampling operation is identified, one traces the stable(s) subjected to the bad operation. Or, when an improper Watering operation is executed, one traces what stables have been affected. With regard to the application of the consumer-egg producer, capacity units include: EggStorage1, PackingArea1, ReceiptArea1, Stable1, Stable2, Stable3. In as far as primary production operations are concerned, the identification of the capacity units is registered along with the operation entity as a foreign key. For HACCP (support) operations it is implemented arbitrarily.

4. An actual production operation (executed by a specific capacity unit)
Executed operations are identified and registered along with their associated operation variables and values. Reviewing the reference-data model, we see that the model enforces the registration of a production order and an associated material batch. However, so as to obtain flexibility with the entry of quality system operations, we did not enforce this in the actual implementation. Operations that are registered are those of primary production and those of quality management systems. Primary production operations of the consumer-egg producer include:

(1) Feeding;
(2) Medicating;
(3) Watering.

Quality system operations of the consumer-egg producer include:

(1) FeedSampling;
(2) MedicationSampling;
(3) SalmonellaSampling;
(4) StableCondition;
(5) WaterSampling.

5. An actual production operation variable (registered for a specific operation)

Operations require the logging of operation variables. On the operation of Feeding, the variable registration includes: FeedBatch and FeedAmount. To prevent undefined operations and variables from being entered by a user into the system, the actual operation and the actual variables are enforced referential integrity with predefined (normative) operations and variables (enabling a user to simply 'pick and choose'). New normative operations and variables can be entered into the application when needed.

6. An actual production operation value (registered for a specific variable)

For any specific variable it is possible to determine the operation value, which was registered. Either one value is stored in relation to a specific variable or multiple values are stored. It depends on the type of variable under discussion. The registration of a watering unit for example constitutes typically of one value (namely the unit number), the registration of the day temperature however, constitutes typically of multiple (temperature) values.

(b) The implemented queries

Queries are used to obtain data in a predefined a format. We present an overview of the queries implemented for the application (table 5.4). The first column provides the name of the query. The second column gives the description of the outcome.

Three queries with their outcomes are taken up in the Appendix:

(1) Overview all lots (presented in Figure III);
(2) SingleLevelTraceBackward (presented in Figure IV);
(3) SingleLevelTraceForward (also presented in Figure IV).

Table 5.4: Implemented queries.

Name of the query	**Description of the outcome**
Lot-selection on property	On entry of the variable and value, associated lots are retrieved
Lots-selection on item	On entry of the specified item, all lots containing that Item will be displayed
Operations on lot	On entry of the lot identification, all operations associated to the lot are made transparent
Operations selection	On entry of the normative operations, all actual operations of this type are listed
Overview all lots	Displays all lots in the database, a description of the contained items and the associated lot production orders
Overview all products	Displays all possible items that can be contained in batches
SingleLevelTraceBackward	Explodes one batch into multiple lower-order batches (where-from)
SingleLevelTraceForward	Implodes one batch into multiple higher-order batches (where-used)

5.3 Evaluation of the reference-data model

In this section we evaluate the reference-data model by three questions:

(1) Does the reference-data model support the requirements of the test cases?
(2) Are the semantics of the model accurate enough?
(3) What evaluation do the network parties give to the coverage of the model?

(1) Does the reference-data model support the requirements of the test cases?

We conclude that it does. The cases prescribe that the registration of layer and egg batches, operations executed on these batches, and the historic relations between the batches, must be dealt with. Moreover, it should be possible to register what egg batches are derived from a layer batch and enable the registration of the mixing and splitting of layer and egg batches. Operations such as feeding or watering (executed on batches) must be registered along with the capacity units (stables) in which the associated batches reside. The associated operation values such as feed batch or water unit and/or the amount supplied, must be registered, alongside. The case requirements were formalised by six entity (relationship) types and two attribute (class) types. We confirm that these types are included in the formalisation of the functionality of the reference-data model, as presented in chapter four. Below, we describe these entity types of the reference-data model (which support the identified requirements of the cases).

The reference-data model includes six entity (relationship) types:

(1) Material lot or batch;
(2) Relation;
(3) Capacity unit;
(4) Actual operation;
(5) Operation variable;
(6) Operation value.

The support to register layer and egg batches is covered by the Material lot or batch entity type. The support to register the historic relations between batches is covered by the Relation entity type. The support to register capacity units of operation is covered by the Capacity unit entity type. The support to register operations executed on batches is covered by the Actual operation entity type. The support to register operations executed on batches is covered by the Operation variable entity type. The support to register variables of operations is covered by the Operation variable type. The support to register values of operation variables is covered by the Operation value entity type. Because of the registration support, we conclude that the reference-data model developed in chapter four can (initially) be instantiated with success to the different cases.

(2) Are the semantics of the model accurate enough?

We conclude that a more accurate formulation of certain relationship types is needed on instantiation of the reference-data model to specific cases (figure 4.14 depicts all the relationship types of the reference-data model). Below, we explain this.
In the production situation of the consumer-egg producer and the grower, batches are not pooled on sequencing operations on a routing, as often is the case in industrial environments, but operations are executed far more project-oriented: within one certain stable, one capacity unit, and around one specific (layer) batch. The *material requirement* relationship type (figure 4.14) can then be omitted for the consumer-egg producer and the grower. Also, it may be favoured by the consumer-egg producer and the grower to change the *executed on* relationship type (figure 4.14), between the operation entity type and capacity unit entity type, into an *executed within* relationship type; as operations of the consumer-egg producer and the grower typically are executed within one designated capacity unit (read: stable) in contrast to industry, where the processing of batches is routed along multiple capacity units. Likewise, the relationship type *performs* (figure 4.14) is then altered into *hosts*. Thus, for the consumer-egg producer and the breeder, the suggested relationship adjustments can be made.

The breeder's production has characteristics of both industrial production as well as project-oriented production. It is advised in the situation of the breeder to maintain the *material requirement* relationship type (figure 4.14). In the situation of the breeder, one batch cannot be considered 'a project' around which all relevant operations are centred. In the breeder's production system, batches (also) follow an 'industrial' path with operations on a routing. Then, to prevent operations from being aggregated over (one final) production (batch), the operations need to be registered in conjunction with the specific batches of the operation, on the right level of the production.

(3) What evaluation do the network parties give to the coverage of the model?

We asked a panel of future users (the network actors) and domain-experts to respond to the question: is the functional support of the reference-data model sufficient to provide for the important functions of tracking and tracing?

The panel agreed on one thing: the registration of the batches, where-from relations between batches, where-used relations between batches, processing data of operations on batches, and information on the capacity units processed on, should foremost be a part of a tracking-and-tracing system. Discussion however focussed on how to incorporate functionality to exchange production data within the network. The exchange of production data would enable actors of the network to align better their processes. For example, a consumer-egg producer would be able to adhere better to the production conditions initiated by a grower, and avoid animal stress and loss of weight. Moreover, detailed data can be viewed as a guarantee of a product's integrity. Not all the actors of the network shared the need for a large amount of data though most parties liked the thought of being able to back up their product integrity (showing that the product conforms to specification). To support the idea, product certificates were proposed. A product certificate would include a reference to actual and detailed production data, which can be made available on customer-demand. The certificate(s) operate much like an interface, in the access of raw production data. Technical growing conditions and salmonella conditions would become accessible. Products carry certificates and assure the product's integrity in a certain respect. With the data sets, actors are (also) able to differentiate their products from competition. Producers are able to promote better their products. Considering contemporary legislation, it was noted that Salmonella-*free* certificates were favoured. With the quality infrastructure of HACCP already in place for most of the actors, guarantees on product integrity with respect to Salmonella were a priority.

5.4 Evaluation of the application

A group session with future users (the network actors) and domain-experts was held in which the prototype functionality was displayed. The breeder, grower, and consumer-egg producer provided the author of the thesis (and creator of the application) with instant feedback on the functionality. Afterwards they (also) supplied feedback in written form, by evaluation forms. With regard to the evaluation forms, the relevancy of functionality was expressed on a range from [1] - [9], whereby [1] implies that the functionality was not relevant and [9] implies that the functionality was highly relevant (figure 5.8).

Functionality:

[1] [2] [3] [4] [5] [6] [7] [8] [9]

Not relevant …………………………………………………...Highly relevant

Figure 5.8: Relevance of functionality.

The results obtained with the evaluations are discussed below. First, the functionality of the prototype is evaluated (section 5.4.1). Second, the desired extra functionality is reflected upon (section 5.4.2).

5.4.1 Functionality of the prototype

The breeder, the grower, and the consumer-egg producer gave their opinion on the functionality demonstrated. The prototype visualised the previously identified functional support for: the registration of historic relations between lots and batches, the registration of operations on lots and batches, the registration of operation variables, the registration of associated values, and the registration of the capacity units of processing.
The functional support demonstrated was vital for the breeder, the grower, and the consumer-egg producer. They especially considered the multilevel bill of lots important to tracking and tracing. The multilevel bill of lots is that part of the reference model, which is capable of recording all the constituent parts of the final product lot or batch, and in relation to operations, keeps the necessary processing data on these (constituent) parts accessible, on the right level (non-aggregated). The importance of the bill of lots was reflected in the evaluation rankings, as the functionality to trace the mixing and splitting of batches, and the functionality to trace the operations executed on batches, were given a high score.
The breeder gave the score of nine. With respect to the evaluation given by the consumer-egg producer, it can be concluded that the functionality of tracing the mixing

and splitting of batches and the operations executed hereon, was valued too. The score of eight was given. The grower however attached a lesser relevancy to the functionality. The grower found it of lesser relevance to have functionality to trace the mixing and splitting of batches (considering the score of three), although the breeder values the functionality to trace operations executed on batches (a score of six). The lesser score on the functionality of mixing and splitting most probably results from the production layout and the capacity available at the grower's site, in which little mixing and splitting is required.

We also evaluated the support of quality system operations. It was asked whether it was appreciated that the prototype could deal with these operations (the prototype included HACCP operations). Functionality to register HACCP operations within the organisation was rated high by the breeder, the grower, and the consumer-egg producer. The relevancy-score attached to it by the breeder was eight, by the grower seven, and by the consumer-egg producer nine. Support for the registration of operations from other quality systems, was answered positively though mixed: the HACCP functionality was to have priority.

We conclude that the functionality demonstrated was adequately received. However, the application functionality was not exhaustive, as possibilities for the functional extension of the application were suggested. We describe these functional extensions in the next section.

5.4.2 Desired extra functionality

The section describes the results of the need for extra prototype functionality by the stakeholders. This functionality was obtained from the group session and from the evaluation forms that were handed-out. The functionality is grouped into four categories: (1) system integration, (2) decision making, (3) product labelling, and (4) product integrity.

System Integration

The category of system integration is divided into four subcategories: (1) integration with administrative systems, (2) integration with process systems, (3) integration with quality systems, and (4) integration with automatic identification and data capture.

(1) Integration with administrative systems

The tracking-and-tracing application must be integrated with the backbone implemented for transaction processing. Such integration enables most enterprise domains to gain access to information of the goods flow and the operations executed hereon. It enables an efficient and effective retrieval of data on items of the sales order-line. Every order can then be traced as to what batches were shipped. Production data of any of the shipped items can be retrieved. The actors all favoured the integration (a score of nine by the consumer-egg producer and a score of seven by the grower and the breeder).

(2) Integration with process systems

Various process applications are currently operable in the enterprise domain. Data from these applications, such as temperature registrations or feeding registrations, can be transferred automatically into the tracking-and-tracing system on realisation of systems integration. As process data, relevant to tracking and tracing, is generated in different functions of the organisation, the horizontal integration requires specific attention: redundancy and data inconsistencies should be avoided as much as possible for integrity reasons. The actors all favoured integration with process systems (a score of nine by the consumer-egg producer, a score of eight by the grower, and a score of seven by the breeder).

(3) Integration with quality systems

The researched enterprises have quality systems in their organisation. These systems however are pencil and paper based. This forms an obstacle for efficient information retrieval. Information systems have the advantage of automated search and reporting possibilities. Moreover, it is desirable to support different quality systems in an information system, and not only the HACCP quality system (discussed previously). The actors all favoured the integration with quality systems (a score of seven by the consumer-egg producer, a score of six by the grower, and a score of eight by the breeder).

(4) Integration with automatic identification and data capture

Automatic identification and data capture (AIDC) instruments are required to communicate with the tracking-and-tracing system so as to enable internal product tracking. They provide an accurate view on the goods flow. Instruments for automatic identification and data capture can reduce the administrative loads of product identification. They are economically more attractive than manual data entry. AIDC instruments are versatile with respect to their programming (code recognition). In the production chain, which was researched, the use of AIDC was not encountered. Actors however would like to have it implemented (a score of seven by the consumer-egg producer, the grower, and the breeder).

Decision making

The category of decision making is divided into four subcategories: (1) technical data, (2) production performance, (3) active optimisation, and (4) supplier assessment.

(1) Technical data

It would be desirable to have information on how to interpret certain technical data from production links. Take the link of the grower and the consumer-egg producer and the exchange of technical data between them. Preferably, the consumer-egg producer should be supported with information on how to interpret data and irregularities in the data from the grower. It is possible that without such support, the consumer-egg producer overreacts on certain irregularities, while in fact there is no reason for concern at all (from the viewpoint of the grower); the consumer-egg producer may have simply interpreted the data in the wrong way. Currently, providing data on acceptable production and food norms at different links is not supported by the prototype application. For such actions, the lack of standardised norms for food safety and production throughout the chain or network is the main obstacle. The consumer-egg producer values technical data (a score of eight), followed by the grower and the breeder (both a score of seven).

(2) Production performance

The prototype can be extended with a functionality in which benchmarking of the production performance takes place. Benchmarks can give the enterprise management the information on the best way to produce their materials. Utilising resources in production, efficiently and effectively, increases performance and business profit. For a grower different feed types may be compared on growing results and associated costs. By monitoring the resources supplied to the production and the final production result obtained, a best practice can be established. The prototype should thereto support registration and analyses of historic production figures. The consumer-egg producer values the production performance with a score of seven, the grower with a score of six, and the breeder with a score of seven.

(3) Active optimisation

Performance support described above is a passive instrument, in the sense that the system then only displays the performance as occurred over time. It would however be more convenient to include in the system, some functionality for adequate prediction. Currently, the consumer-egg producer looks at the growing data from the grower's and then decides on the basis of these data, to feed in the best way. It would however be more convenient when such advice could be automated. Based on the supplier data, the system could recommend the consumer-egg producer alternative scenarios so as to obtain the best production results. When alternative production models are added, the nature of the tracking-and-tracing application changes from passive to active. The consumer-egg producer values active optimisation with a score of seven, the grower with a score of six, and the breeder with a score of seven.

(4) Supplier assessment

Next to optimising the internal production performance, the performance of suppliers must be looked-into. In the consumer-egg chain, downstream entities must largely follow the production conditions of suppliers, as drastic changes in downstream production conditions cause a lower end product quality (due to animal stress, etc.). Consequently, downstream entities favour those suppliers that have an aligned production system, because then no extra costs need to be made. Functional support to assess suppliers in this respect is valuable. The consumer-egg producer is in favour of supplier assessment and gives this functionality a score of eight. The grower is neutral in his evaluation of supplier assessment and gives a score of five. The breeder is in favour with a score of seven.

Product labelling

The category of product labelling is divided into two subcategories: (1) label printing and (2) legal information.

(1) Label printing

Customers are increasingly interested in information on the origin and the composition of products. Required data on the origin and the composition of products must therefore be available for automatic printing on product labels. Information-system functionality should be added to the prototype, so that it is able to transform data (on batch origin and composition) into a customer-readable and label-printable format. This functionality is not included in the prototype as yet. The consumer-egg producer and the grower favour it and rate the functionality with a score of six, the breeder too, who rates it with a score of seven.

(2) Legal information

When printing data on customer products one should know what legally is allowed and what is not. Not just any information can be depicted on a consumer product. On the one hand, the information must not mislead the consumer and should adhere to specific requirements. On the other hand, certain information is obliged and must be printed on the customer product. Some advice on what is allowed on consumer labels from the system can be advantageous. For this to be implemented into the system, legal information on the labelling of domestic and foreign products must be included. The consumer-egg producer adds little relevancy to this functionality with a score of four; the grower is neutral on this issue with a score of five. The breeder however rates it high with a score of seven. The explanation there-of lies in the fact that the breeder is (also) active on foreign markets (different legal regimes).

Product integrity

The category of product integrity is divided into three subcategories: (1) reference data, (2) third party audits, and (3) government control.

(1) Reference data

A tracking-and-tracing system should host reference data on operations (normative data on operations). The reference data is used to enforce product integrity. Operations that are not executed properly (i.e., operations that do not match the reference data) are a cause for alarm. By matching the operations' data with the reference data, anomalies in production can be detected and products can be excluded from further processing. By inclusion of this functionality, deficient products or materials may be detected early on in production. The consumer-egg producer appreciates this type of functionality most, followed by the breeder and the grower (respectively scores of eight, seven, and six).

(2) Third party audits

Enterprises that generate products with a certain claim, for example Salmonella-free, should be audited by third parties, so as to have independent confirmation of the product's integrity (signalling that the product itself conforms to specification and that the rules and regulations have been adhered to). The integrity of the product must be established in a way that is transparent to all stakeholders of the supply chain. Product integrity should be audited by researching the method of production and registration, as well as the actual data itself. Though all actors agree on the importance, the consumer-egg producer and grower find this even more important than the breeder (respectively scores of eight, eight, and seven).

(3) Government control

Many organisations in the food sector report specific activities to controlling agencies of our government. In the consumer-egg chain, enterprises are required to report successive mutations of product batches to the product board. The registration of these mutations enables the product board to keep track of batch pooling and segregation. The product board issues the identification numbers for the mutations. Actors of the chain are required to report to the board on a specific document template. It would be very convenient if our prototype would support an automated reporting facility for this purpose. Both the consumer-egg producer and the breeder would like this functionality included and rated the relevancy with a score of seven. The grower however, is less convinced of the use of this functionality and rated the relevancy of this functionality with a score of four.

5.5 Chapter conclusion

In this chapter (1) the reference-data model and (2) the application were evaluated. Three test cases were involved in the evaluation: the consumer-egg producer, the grower, and the breeder.

(1) Three questions guided the evaluation of the reference-data model.

- (i) Does the reference-data model support the requirements of the test cases?
- (ii) Are the semantics of the model accurate enough?
- (iii) What evaluation do the network parties give to the coverage of the model?

Ad. (i) We conclude that the reference-data model can be instantiated with success to the three cases as of its inclusion of required entity (relationship) and attribute (class) types:

a. a material lot and batch (identified in production);
b. a production relation (or association) (activated between lots or batches);
c. a capacity unit (responsible for a particular production step);
d. an actual production operation (executed by a specific capacity unit);
e. an actual production operation variable (registered for a specific operation);
f. an actual production operation value (registered for a specific variable).

And,

a. material quality attributes (that can be assigned to a material);
b. material quality anomalies (identified during quality inspection).

Ad. (ii) We note with respect to the semantics of the reference-data model that the *material requirement* relationship type, the *executed on* relationship, and the *performs* relationship type require our attention. We conclude that when the model is instantiated to a specific case, these semantics are not accurate enough. They require more a precise specification.

Ad. (iii) We conclude that the network parties were satisfied with the functionality, which was already incorporated in the reference-data model. However, an omission in the model was the functional support to exchange aggregated production data in the network (via certificates).

(2) The application of the reference-data model was guided in two ways:

(i) by a presentation of the prototype's functionality;

(ii) by a questionnaire.

We conclude that:

a. the stakeholders found it necessary that the prototype included the possibility to record all the constituent parts of a final product lot or batch, and in relation to operations, keeps all necessary processing data on these (constituent) parts accessible, on the right level (non-aggregated);

b. the stakeholders agreed that the functionality to perform quality system operations was of added value;

c. the stakeholders favoured the extension of the application with extra functionality:

   (i) system integration;

   (ii) decision making;

   (iii) product labelling;

   (iv) product integrity.

Chapter 6

Conclusions

Chapter contents

6. Conclusions

This chapter provides the conclusions of our research. We reiterate the problem statement from chapter one.

> *How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?*

To answer the problem statement we formulated five research questions. An overview thereof is presented in chapter one. The way in which we investigated the questions is described in chapter two. The research questions themselves are addressed in the chapters three, four, and five. For the answer to the first research question, chapter three examines the scientific literature on tracking and tracing. For the answer to the second, third and fourth research question, practical research on the development of a reference-data model is described in chapter four. For the answer to the fifth research question, an evaluation of the reference-data model is described in chapter five.
Below, we summarise the answers to the research questions by section (section 6.1 to 6.5); the final conclusion is given in section 6.6 and the future research in section 6.7.

6.1 Research question 1: the characterising elements

To determine the elements that characterise tracking and tracing, in relation to (i) an enterprise in the chain, (ii) its objective, and (iii) its administration, we examined the scientific literature. We investigated: (1) appropriate theories and models that describe (the properties of) the object system, and (2) the tracking-and-tracing functionality within the object system. The elements that characterise tracking and tracing are: (1) tracking, (2) backward traceability, (3) forward traceability, (4) generating properties, (5) active use, and (6) passive use. The first four elements are essential to tracking and tracing for any enterprise in the chain. The last two elements, active use and passive use, are closely related to an enterprise's objective and administration. Enterprises in the chain that use tracking and tracing actively (i.e., process optimisation) have more complex administration, as compared to enterprises that use tracking and tracing passively (i.e., recall).

6.2 Research question 2: functionality and performance

To determine which functionality and performance with regard to tracking and tracing can be derived from the enterprise in the chain, we performed case studies. The *functionality* derived for tracking and tracing consists of: (1) the support for the registration of historic relations between lots and batches (where-from and where-used relations), (2) the support for the registration of operations on lots and batches in production, (3) the support for the registration of associated variables and values on operation control, and (4) the support for the registration of capacity units on which operations are executed. The *performance* for tracking and tracing is strongly related to: (1) the integrity of the representation of the object system and (2) the integrity of the object system itself. High performance is obtained (i) when the representation of the object system is in accordance with the reality of the object system it represents, and (ii) when the object system itself is in a state of being complete.

6.3 Research question 3: relevant data models

To determine which data models are fit for an adequate representation of the functionality, we started with the practical development of adequate modelling solutions. We present our findings on the data models suitable for an adequate representation of the identified functionality:

(1) The data model of figure 4.6 is suitable for the adequate representation of the functionality for the registration of historic relations between lots and batches (where-from and where-used relations).
(2) The data model of figure 4.12 is suitable for the representation of the functionality to register operations on lots and batches in production. A suitable representation, in which lot and batch relations are also stored in conjunction with the operation that invoked them is depicted by the data model of figure 4.13.
(3) The data model of figure 4.10 is fit for the adequate representation of the functionality to register variables and values during operation control.
(4) The data model of figure 4.11 satisfies the need to represent the capacity units on which operations are executed.

6.4 Research question 4: adequate reference-data model

By combining the data models identified above, a reference-data model was constructed with success. The reference-data model is given in figure 4.14. The reference-data model supports the registration of the formulated requirements. The inclusion of these requirements makes also possible the tracing of generating properties, which has been identified as an overlaying requirement.

6.5 Research question 5: evaluation of the application

Three test cases were selected to determine the evaluation of the application of the reference-data model. The application of the reference-data model received a satisfying evaluation for two important reasons.

(1) The solution of the reference-data model included the functionality identified by the requirements of the test cases. Especially, the functionality to trace lots and batches and the operations executed thereon, test case respondents could not do without.

(2) Next to the tracing of logistic operations, the tracing of quality operations proved to be of added value. The model enabled the registration of such operations.

6.6 Final conclusion

We conclude from the research in this thesis that we have successfully captured and formalised case-specific tracking-and-tracing requirements, and accordingly developed a *general* modelling solution i.e., a reference-data model. An instantiation of the model to three cases of a consumer-egg chain (i.e., a consumer-egg producer, a grower, and a breeder) was conducted. The reference-data model was generally able to satisfy the identified requirements of this chain. In that the consumer-egg chain is not an enormous complex chain, we conclude that the reference-data model is initially applicable to supply chains with a fairly low degree of complexity.

6.7 Future research

The development of tracking-and-tracing information systems is not over. In this respect we would like to point out two areas of interest and present the examples of future work to be done herein:

(1) the development of the reference-data model;

(2) the application of the referential strategy.

(1) The development of the reference-data model

(i) A recommendation for future research is to determine what modelling solution is able to satisfy the registration of actual multiple input-output material relations, *in conjunction* with the associated actual multiple input-output operations. The reference model developed in this thesis is not able to support complex multiple-input multiple-output process traceability.

(ii) Future research should further determine what modelling solution is able to satisfy the registration of material relations, on *actual* cyclic operations (as opposed to normative ones). In cyclic production, part of the processed material is fed back into the production system. The reference-data model developed in this thesis is not able to support the registration of actual cyclic operations.

(2) The application of the referential strategy

The reference-data model and its prototype were evaluated with the stakeholders of the involved production network. As a chain-implementation was not realised during the research, we have not drawn conclusions on:

(i) the actual performance of the reference-data model in daily operations;

(ii) the practical trade-off between the customisation of the reference-data model on location, and the model's reference capability, throughout the chain.

Hence, we conclude with the suggestion that future research be done on these practical aspects.

Appendix

Implementation

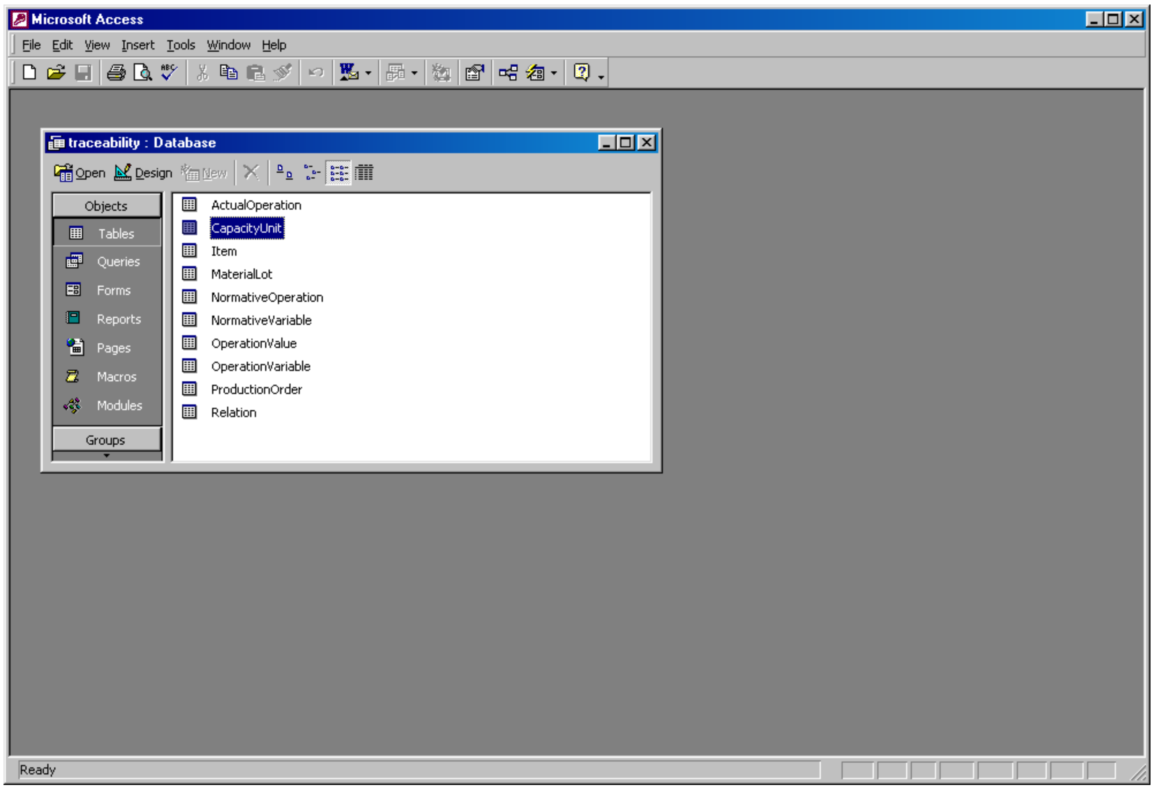

Figure I: Implemented tables.

Figure I depicts ten tables in an alphabetic order. Eight tables, i.e., ActualOperation, Capacity-Unit, Item, MaterialLot, OperationValue, OperationVariable, ProductionOrder, and Relation, reflect the eight entity (relationship) types of the developed reference-data model. The two other tables, i.e., NormativeOperation and NormativeVariable, are included for usability purposes so as to enable a user to 'pick and choose' existing examples of operations and variables for entry.

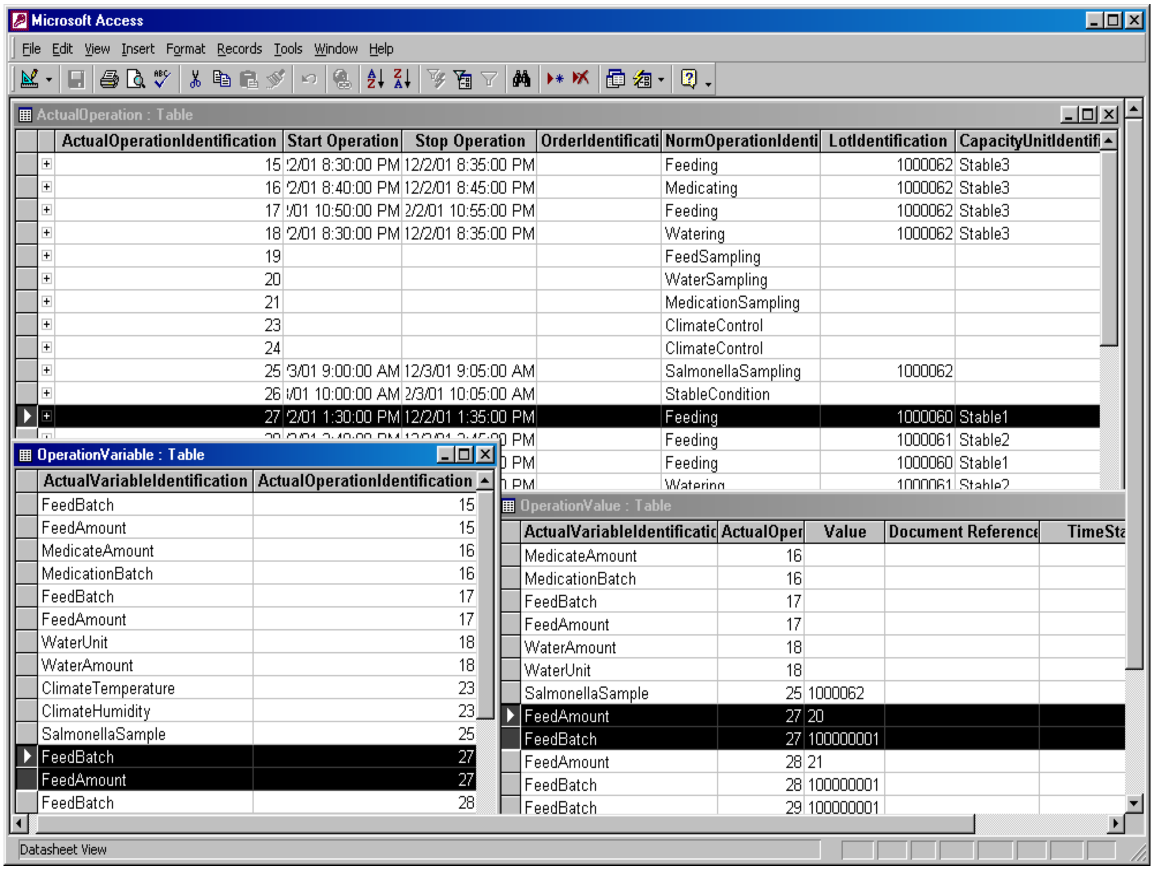

Figure II: Data entered for the consumer-egg producer.

Figure II depicts three screenshots on the relation between the *test* data of ActualOperations, OperationVariables, and OperationValues. We discuss the highlighted ActualOperation, OperationVariable, and OperationValue. The ActualOperation is a Feeding operation No. 27. The operation is executed on a group layers, which is identified by a LotIdentification No. 1000060, and which resides in Stable 1. For the Feeding operation two variables are registered: (1) the FeedBatch and (2) the FeedAmount. The Value 100000001 is registered for the FeedBatch and indicates the batch number. The Value 20 is registered for the FeedAmount and indicates the feed quantity.

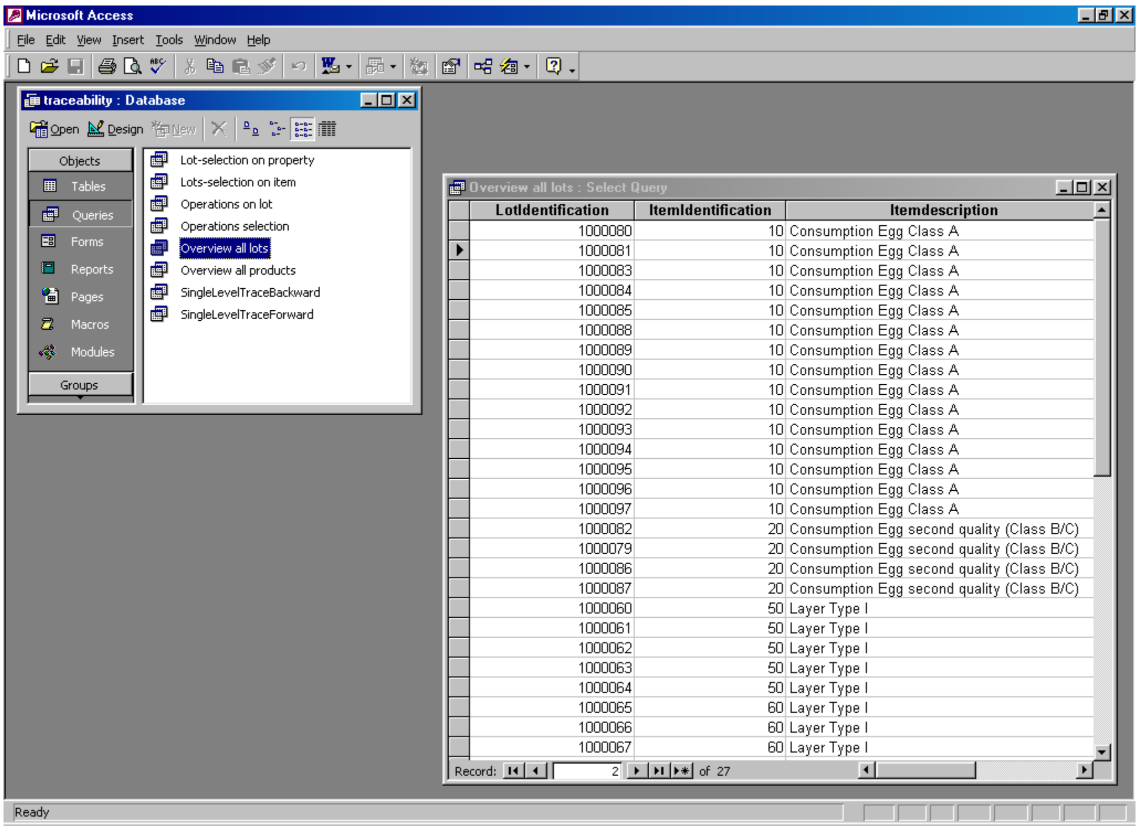

Figure III: Overview all lots.

Figure III depicts a screenshots of a specific query. The query is named: Overview all lots. On executing this query an overview is shown of all the lots that are entered in the database. The overview provides information on the identification of lots (i.e., LotIdentification), on the identification of the items contained in the lots (i.e., ItemIdentification), and on the name of the items (i.e., Itemdescription).

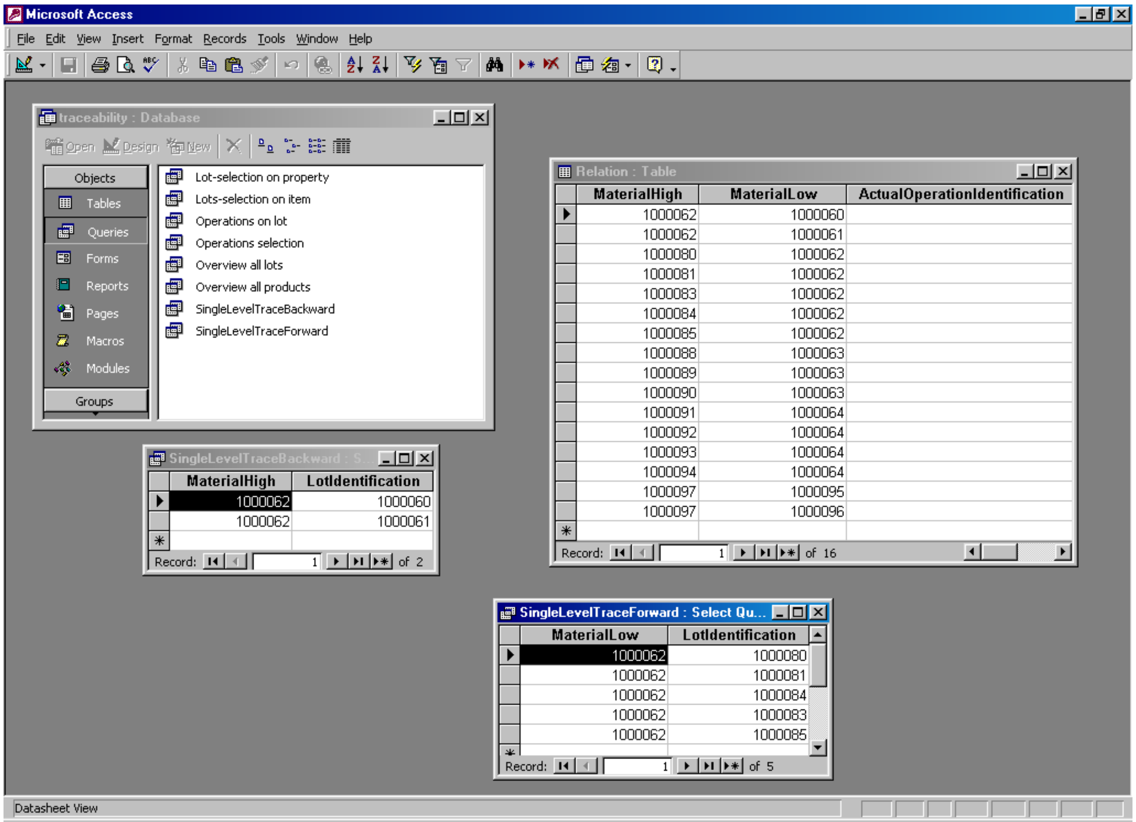

Figure IV: Single-level trace backward and single-level trace forward.

Figure IV depicts a screenshot of two queries: SingleLevelTraceBackward and SingleLevelTrace-Forward. The queries are executed by entry of a LotIdentification, in our case: 1000062. The result of the SingleLevelTraceBackward query is the overview of all constituent lots of 1000062 (MaterialHigh): 1000060 and 1000061 (the LotIdentifications in the screenshot). The result of the SingleLevelTraceForward query is the overview of all lots that consumed 1000062 (MaterialLow): 1000080, 1000081, 1000084, 1000083, and 1000085 (the LotIdentifications in the screenshot).

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Summary

Research description

Food consumption is not without risk. Every year people become ill from food contamination. Regular causes are Salmonella, Campylobacter and E-Coli O 157. Over the years, different food incidents have occurred. In chapter one eleven incidents illustrate this observation. We mostly refer to the cases by a company name: Planta, Iglo, Perrier, raw eggs, Heineken, Frisolac, Olvarit, Raak Cassis, Brinta, dioxin, and Coca-Cola. Food incidents have encouraged the development of technical means supporting the tracking and tracing of products. In our investigation we study the means and the development of these means. For the purpose of tracking and tracing, we describe the development and the application of a general information-system blueprint, i.e., a reference-data model. The thesis aims at contributing to the improvement of the way tracking and tracing of products takes place, so that food safety is guaranteed. The main issue is formulated more precisely in our problem statement:

> *How can we improve tracking and tracing (with the help of modern ICT means) in such a way that food safety is guaranteed to a larger extent than happens at this moment (2003)?*

The research objective is twofold:

(1) establishing the tracking-and-tracing functionality within an object system, i.e., establishing the supply chain, and
(2) representing the functionality by data models so as to facilitate the development of information systems suitable for tracking and tracing.

To obtain the objective, the following five research questions are addressed:

(1) which elements characterise tracking and tracing, in relation to (i) an enterprise in the chain, (ii) its objective, and (iii) its administration?
(2) which functionality and performance with regard to tracking and tracing can be derived from the enterprise in the chain?
(3) which data models are fit for an adequate representation of the functionality?
(4) which reference-data model can be successfully constructed?, and
(5) what is the evaluation of the application of the reference model?

Research approach

In chapter two we present a view on the empirical reality. We describe which relevant factors are investigated, i.e., variables, constructs, and concepts; and how they are investigated. Moreover, the interrelationships between a variety of factors are explained, and a discussion on the representation and the validation of the research findings is given. We aim to answer our problem statement by establishing a sufficient set of requirements for adequate ICT support for tracking and tracing. For this task we use the extended Process-Control-Information (PCI) framework. In the framework's setting, production can be organised in such a manner that several independent enterprises are involved (i.e., establishing a supply chain).

Tracking and tracing

In chapter three we examine the scientific literature. Two main points of the investigation are: (1) finding appropriate theories and models that describe (the properties of) the object system, and (2) describing the tracking-and-tracing functionality within the object system. Both points are briefly elaborated below:

(1) We describe *logistic* models, which conceptualise the object system for logistic control, and detail their associated information needs. Likewise, we describe *quality* models, which conceptualise the object system for quality control, and detail their associated information needs. Essential representation requirements for tracking and tracing are distilled.

(2) We then establish from the literature the functionality of tracking and tracing for an object system. We identify: (i) tracking, (ii) forward traceability, (iii) backward traceability, and (iv) generating properties (all briefly explained below).

  (i) Tracking is the method of following an object through the supply chain and registering any data considered of any historic or monitoring relevance.

  (ii) Forward traceability is the exploration of where-used relations between objects (we search the end products that include the [erroneous] material).

  (iii) Backward traceability is the exploration of where-from relations between objects (we search the materials of which the [erroneous] end product is composed).

(iv) Generating properties: the complete set of (visible and invisible) properties that a product (group) possesses, and in which we are interested.

Reference-data model

Our practical research commences in chapter four with the design of a reference-data model. Four case studies help us (1) to obtain a preliminary idea of the entity (relationship) types and attribute (class) types that should be included in a modelling solution, and (2) to distinguish four (natural-language) requirements. The latter is an important issue as all our data models are constructed with the help of domain knowledge. The models allow for: (i) the registration of historic relations between lots and batches, (ii) the registration of operations on lots and batches, (iii) the registration of associated operation variables and values, and (iv) the registration of capacity units on which operations are executed. From the individual models, a reference-data model is constructed.

Evaluation of the reference-data model

In chapter five we discuss the evaluation of the reference-data model. The evaluation is based on three test cases. It enables us to identify (1) the main entity (relationship) types and (2) the attribute (class) types for the instantiation of the model. From our evaluative research we may conclude that these types cover the entire reference-data model. Moreover, it is obvious that the reference-data model holds a broad coverage of requirements.

(1) The identified entity (relationship) types are:

(i) a material lot and batch (identified in production);
(ii) a production relation (or association) (activated between lots or batches);
(iii) a capacity unit (responsible for a particular production step);
(iv) an actual production operation (executed by a specific capacity unit);
(v) an actual production operation variable (registered for a specific operation);
(vi) an actual production operation value (registered for a specific variable).

(2) The identified attribute (class) types are:

(i) material quality attributes (that can be assigned to a material);
(ii) material quality anomalies (identified during quality inspection).

Answers to the research questions

Chapter six discusses the answers to the five research questions. Below, we recapitulate them.

Answer to research question 1

The elements that characterise tracking and tracing are: (1) tracking, (2) backward traceability, (3) forward traceability, (4) generating properties, (5) active use, and (6) passive use. The first four elements are essential to tracking and tracing for any enterprise in the chain. The last two elements, active use and passive use, are closely related to an enterprise's objective and administration. Enterprises in the chain that use tracking and tracing actively (i.e., process optimisation) have a more complex administration, as compared to enterprises that use tracking and tracing passively (i.e., recall).

Answer to research question 2

The *functionality* derived for tracking and tracing consists of: (1) the support for the registration of historic relations between lots and batches (where-from and where-used relations), (2) the support for the registration of operations on lots and batches in production, (3) the support for the registration of associated variables and values on operation control, and (4) the support for the registration of capacity units on which operations are executed. The *performance* for tracking and tracing is strongly related to: (1) the integrity of the representation of the object system and (2) the integrity of the object system itself. High performance is obtained (i) when the representation of the object system is in accordance with the reality of the object system it represents, and (ii) when the object system itself is in a state of being complete.

Answer to research question 3

Below, we present the data models suitable for an adequate representation of the identified functionality.

(1) The data model of figure 4.6 is suitable for the adequate representation of the functionality for the registration of historic relations between lots and batches (where-from and where-used relations).
(2) The data model of figure 4.12 is suitable for the representation of the functionality to register operations on lots and batches in production. An appropriate representation,

in which lot and batch relations are also stored in conjunction with the operation that invoked them is depicted by the data model of figure 4.13.

(3) The data model of figure 4.10 is fit for the adequate representation of the functionality to register variables and values on operation control.

(4) The data model of figure 4.11 satisfies the need to represent the capacity units on which operations are executed.

Answer to research question 4

A comprehensive model (a reference-data model) is constructed by combining the data models identified above. The reference-data model is depicted in figure 4.14. This model supports the registration of the formulated requirements. The inclusion of these requirements makes also possible the tracing of generating properties, which has been identified as an overlaying requirement.

Answer to research question 5

The application of the reference-data model received a satisfying evaluation for two important reasons.

(1) The solution of the reference-data model included the functionality identified by the requirements of the three test cases. Especially, the functionality to trace lots and batches and the operations executed thereon, test case respondents could not do without.

(2) Next to the tracing of logistic operations, the tracing of quality operations proved to be of added value. The model enabled the registration of such operations.

Contributions

We contributed to tracking-and-tracing information systems by four achievements:

(1) the identification of object-system models to represent the object system from both quality and logistic perspectives;

(2) the formulation of concept validity and main functionality for tracking and tracing;

(3) the derivation of general requirements for tracking-and-tracing information systems;

(4) the design of a reference-data model that facilitates the development process of the information systems.

Moreover, we contributed to our two-folded research objective by:

(1) determining a particular tracking-and-tracing functionality within the object system;

(2) developing an information system for tracking and tracing with data models.

Samenvatting

Onderzoeksbeschrijving

Voedselconsumptie is niet zonder risico. Ieder jaar worden er mensen ziek door voedselvergiftiging. Reguliere oorzaken zijn Salmonella, Campylobacter en E-Coli O 157. In de loop der jaren hebben zich verschillende voedselincidenten voorgedaan. Hoofdstuk een illustreert deze observatie met elf gevalbeschrijvingen. We verwijzen naar de gevalbeschrijvingen voornamelijk middels een bedrijfsnaam: Planta, Iglo, Perrier, rauwe eieren, Heineken, Frisolac, Olvarit, Raak Cassis, Brinta, dioxine, en Coca-Cola. Voedselincidenten hebben de ontwikkeling van technische hulpmiddelen voor de ondersteuning van tracking en tracing van producten, aangemoedigd. In ons onderzoek bestuderen we de hulpmiddelen en de ontwikkeling van deze hulpmiddelen. Voor tracking en tracing beschrijven we de ontwikkeling en toepassing van een generiek informatiesysteem ontwerp, i.e., een referentie datamodel. Het proefschrift hoopt een bijdrage te leveren aan de verbetering van de tracking en tracing van producten zodat de voedselveiligheid kan worden gegarandeerd. De hoofdzaak is preciezer geformuleerd in onze probleemstelling:

> *Hoe kunnen we tracking en tracing verbeteren (met de hulp van moderne ICT middelen) zodanig dat de voedselveiligheid in een hogere mate wordt gegarandeerd dan gebeurt op dit moment (2003)?*

De onderzoeksdoelstelling is tweeledig:

(1) vaststellen van de tracking en tracing functionaliteit binnen een objectsysteem, dat wil zeggen, vaststellen van de voortbrengingsketen, en

(2) representeren van de functionaliteit middels datamodellen, teneinde de ontwikkeling te faciliteren van informatiesystemen die geschikt zijn voor tracking en tracing.

Voor het halen van de onderzoeksdoelstelling, worden de volgende vijf onderzoeksvragen geadresseerd:

(1) welke elementen karakteriseren tracking en tracing, in relatie tot (i) een onderneming in de keten, (ii) haar doelstelling, en (iii) haar administratie?
(2) welke functionaliteit en prestatie voor tracking en tracing is af te leiden van de onderneming in de keten?
(3) welke datamodellen zijn geschikt voor een adequate representatie van de functionaliteit?
(4) welk referentie datamodel kan succesvol worden geconstrueerd?, en
(5) wat is de evaluatie van de toepassing van het referentiemodel?

Onderzoeksmethode

In hoofdstuk twee presenteren we een gezichtswijze op de empirische realiteit. We beschrijven welke relevante factoren worden onderzocht, i.e., variabelen, constructen, en concepten; en hoe die worden onderzocht. Bovendien worden de interrelaties tussen een verscheidenheid aan factoren uitgelegd en vindt een discussie over de representatie en de validatie van de onderzoeksresultaten plaats. We beogen onze probleemstelling te kunnen beantwoorden door het benoemen van een voldoende set van eisen voor de adequate ICT ondersteuning voor tracking en tracing. Voor deze taak gebruiken we het uitgebreide Proces-Controle-Informatie (PCI) raamwerk. Binnen dit raamwerk kan de productie dusdanig worden georganiseerd dat er verschillende onafhankelijke ondernemingen bij betrokken zijn (i.e., het vaststellen van de voortbrengingsketen).

Tracking en tracing

In hoofdstuk drie onderzoeken we de wetenschappelijke literatuur. Twee hoofdpunten van het onderzoek zijn: (1) het vinden van beschikbare theorieën en modellen die (de eigenschappen van) het objectsysteem beschrijven, en (2) het beschrijven van de tracking en tracing functionaliteit binnen het objectsysteem. Beide punten worden onderstaand kort uitgelegd:

(1) We beschrijven *logistieke* modellen die het objectsysteem conceptualiseren vanuit logistiek management, en detailleren de geassocieerde informatiebehoeften. Op gelijke wijze beschrijven we *kwaliteits*modellen die het objectsysteem voor kwaliteitsmanagement conceptualiseren, en detailleren de daarbij horende informatiebehoeften. Essentiële representatie-eisen voor tracking en tracing worden hieruit gedestilleerd.

(2) Vervolgens stellen we aan de hand van de literatuur de functionaliteit van tracking en tracing vast voor een objectsysteem. We onderscheiden: (i) tracking, (ii) voorwaarts traceren, (iii) achterwaarts traceren, en (iv) genererende eigenschappen (allen onderstaand kort toegelicht).

   (i) Tracking is de methode voor het volgen van een object door de voortbrengingsketen en het registreren van enige data van historische of monitoring relevantie.

   (ii) Voorwaarts traceren is de exploratie van waar-gebruikt relaties tussen objecten (we zoeken de eindproducten die de deficiënte materialen bevatten).

   (iii) Achterwaarts traceren is de exploratie van waar-vandaan relaties tussen objecten (we zoeken de materialen van waaruit het deficiënte eindproduct is samengesteld).

   (iv) Genererende eigenschappen: de complete verzameling van (zichtbare en onzichtbare) eigenschappen die een product(groep) bezit, en welke interessant is voor ons.

Referentie datamodel

Ons praktisch onderzoek begint in hoofdstuk vier met het ontwerp van een referentie datamodel. Vier gevalstudies helpen ons om (1) een voorlopig idee te krijgen van de entiteit (relatie) typen en attribuut (klasse) typen die opgenomen moeten worden in een modelleeroplossing, en (2) vier eisen (in natuurlijke taal) te onderscheiden. De laatste is een belangrijke zaak, omdat al onze datamodellen geconstrueerd zijn met de hulp van domeinkennis. De modellen voorzien ons van: (i) de registratie van historische relaties tussen lots en batches, (ii) de registratie van operaties op lots en batches, (iii) de registratie van geassocieerde operatievariabelen en –waarden, en (iv) de registratie van capaciteitseenheden verantwoordelijk voor de uitvoer van operaties. Uit deze individuele modellen is een referentie datamodel geconstrueerd.

Evaluatie van het referentie datamodel

In hoofdstuk vijf bespreken we de evaluatie van het referentie datamodel. De evaluatie is gebaseerd op drie gevalstudies. Het stelt ons in staat om te identificeren (1) de belangrijkste entiteit (relatie) typen en (2) de attribuut (klasse) typen voor de instantiatie van het model. Uit ons evaluerend onderzoek mogen we concluderen dat deze typen het gehele referentie datamodel beslaan. Het is bovenal duidelijk dat het referentie datamodel een brede dekking geeft van de eisen.

(1) De geïdentificeerde entiteit (relatie) typen zijn:
- (i) een materiaal lot en batch (geïdentificeerd in productie);
- (ii) een productierelatie (of associatie) (geactiveerd tussen lots of batches);
- (iii) een capaciteitseenheid (verantwoordelijk voor een bepaalde productiestap);
- (iv) een daadwerkelijke productieoperatie (uitgevoerd door een specifieke capaciteitseenheid);
- (v) een daadwerkelijke productieoperatie variabele (geregistreerd voor een specifieke operatie);
- (vi) een daadwerkelijke productieoperatie waarde (geregistreerd voor een specifieke variabele).

(2) De geïdentificeerde attribuut (klasse) typen zijn:
- (i) materiaal kwaliteitsattributen (die toegewezen kunnen worden aan een materiaal);
- (ii) materiaal kwaliteitsanomalieën (geïdentificeerd tijdens kwaliteitsinspectie).

Antwoorden op de onderzoeksvragen

Hoofdstuk zes bespreekt de antwoorden op de vijf onderzoeksvragen. Onderstaand, recapituleren we deze.

Antwoord op onderzoeksvraag 1

De elementen die tracking en tracing kenmerken zijn: (1) tracking, (2) achterwaarts traceren, (3) voorwaarts traceren, (4) genererende eigenschappen, (5) actief gebruik, en (6) passief gebruik. De eerste vier elementen zijn essentieel in tracking en tracing voor iedere onderneming in de keten. De laatste twee elementen, actief gebruik en passief gebruik, zijn nauw verwant aan de doelstelling van de onderneming en diens administratie. Ondernemingen in de keten die tracking en tracing actief gebruiken (i.e., procesoptimalisatie) hebben een complexere administratie vergeleken met ondernemingen die tracking en tracing passief inzetten (i.e., recall).

Antwoord op onderzoeksvraag 2

The *functionaliteit* afgeleid voor tracking en tracing bestaat uit: (1) de ondersteuning voor de registratie van historische relaties tussen lots en batches (waar-vandaan en waar-gebruikt relaties), (2) de ondersteuning voor de registratie van operaties op lots en batches in productie, (3) de ondersteuning voor de registratie van geassocieerde variabelen en waarden voor operatiemanagement, en (4) de ondersteuning voor de registratie van capaciteitseenheden, verantwoordelijk voor de uitvoer van de operaties.

De *prestatie* voor tracking en tracing is sterk gerelateerd aan: (1) de integriteit van de representatie van het objectsysteem en (2) de integriteit van het objectsysteem zelf. Een hoge prestatie wordt verkregen (i) wanneer de representatie van het objectsysteem in overeenstemming is met de werkelijkheid van het objectsysteem die het representeert, en (ii) wanneer het objectsysteem zelf, compleet is.

Antwoord op onderzoeksvraag 3

Onderstaand, presenteren we de datamodellen die geschikt zijn voor een adequate representatie van de geïdentificeerde functionaliteit.

(1) Het datamodel van figuur 4.6 is geschikt voor de adequate representatie van de functionaliteit voor het registreren van historische relaties tussen lots en batches (waar-vandaan en waar-gebruikt relaties).

(2) Het datamodel van figuur 4.12 is geschikt voor de representatie van de functionaliteit voor de registratie van operaties op lots en batches in productie. Een geschikte representatie waarbij lot en batch relaties ook opgeslagen worden in samenhang met de operatie die hen activeerde, wordt afgebeeld in het datamodel van figuur 4.13.

(3) Het datamodel van figuur 4.10 is geschikt voor de adequate representatie van de functionaliteit om variabelen en waarden te registreren gedurende operatiemanagement.
(4) Het datamodel van figuur 4.11 voldoet aan de behoefte om capaciteitseenheden waarop operaties zijn uitgevoerd, te representeren.

Antwoord op onderzoeksvraag 4

Een omvattend model (een referentie datamodel) is vervaardigd aan de hand van de combinatie van bovenstaande geïdentificeerde datamodellen. Het referentie datamodel is afgebeeld in figuur 4.14. Dit model ondersteunt de registratie van de geformuleerde eisen. Het meenemen van deze eisen, maakt het ook mogelijk de genererende eigenschappen te traceren, hetgeen geïdentificeerd was als een algemene eis.

Antwoord op onderzoeksvraag 5

De toepassing van het referentie datamodel kreeg een bevredigende evaluatie (en wel) om twee belangrijke redenen.

(1) De oplossing van het referentie datamodel omvatte de functionaliteit zoals geïdentificeerd in de eisen van de drie test gevalstudies. In het bijzonder konden de respondenten van de test gevalstudies niet buiten de functionaliteit van het traceren van lots en batches en de operaties hierop uitgevoerd.
(2) Naast het traceren van logistieke operaties, bleek de tracering van kwaliteitsoperaties van toegevoegde waarde. Het model maakte de registratie van dergelijke operaties mogelijk.

Bijdragen

We hebben bijgedragen aan tracking en tracing informatiesystemen door vier resultaten:

(1) de identificatie van objectsysteem modellen om objectsystemen te representeren vanuit kwaliteits- en logistieke perspectieven;
(2) de formulering van conceptvaliditeit en hoofdfunctionaliteit voor tracking en tracing;
(3) de afleiding van algemene eisen voor tracking en tracing informatiesystemen;
(4) het ontwerp van een referentie datamodel dat het informatiesysteem ontwikkelingsproces faciliteert.

Bovendien hebben we een bijdrage geleverd aan onze tweeledige onderzoeksdoelstelling door:

(1) bepaling van een bepaalde tracking en tracing functionaliteit binnen het objectsysteem;

(2) ontwikkeling van een tracking en tracing informatiesysteem middels datamodellen.

Curriculum Vitae

Kees-Jan van Dorp was born on 20 April 1970 in Leiden, the Netherlands. He studied Electrical Engineering/Computer Science at the Haagse Hogeschool and received his B. Eng. degree in 1993. He studied Technology and Society at the Faculty of Technology Management of the Eindhoven University of Technology (TUE) and majored in the combination of Information Technology (IT) and Technology and Policy. He received his M. Eng. degree in 1996. His thesis addressed the information exchange in supply chains by Product Data Interchange (PDI).

Kees-Jan started working on supply chain projects in 1996 at the Agricultural Economics Research Institute (LEI) in The Hague. In 1997 he was appointed by the Wageningen University and Research centre (WUR) at the Information Technology Group. In that year he started his Ph.D. thesis on data structures for tracking and tracing. During his work on his Ph.D. thesis he further contributed to (such) courses in education: Systeemkunde en Strategisch Informatie Management (SSIM), Bestuurlijke InformatieKunde (BIK) and the course on Information Management (IM) of the Master of Business Administration programme (MBA).

In the period April 2000 to February 2004, while working simultaneously on his Ph.D. thesis at the WUR, Kees-Jan was part-time appointed by the University of Maastricht (UM) at the Department of Computer Science of the faculty of General Sciences. His work included the co-ordination of the Knowledge Management Group (KMG) at the Institute for Knowledge and Agent Technology (IKAT), assisting and/or supervising Ph.D. and Master's thesis research, and lecturing courses on Knowledge Management (KM) and Man-Computer Interaction and Multimedia (MCIM). He also lectured Knowledge Management & IT (KM & IT) at the University College of Maastricht (UCM). Kees-Jan additionally held a position of elected member of the representative advisory council of the tUL (transnationale Universiteit Limburg).

Kees-Jan has written more than thirty national and international publications and has participated in many different projects.

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