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REALISING THE POTENTIAL OF TRACEABILITY

- A case study research on usage and impacts of product traceability

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ABSTRACT

This thesis studies the use and impacts of product traceability in business enterprises. Prior research in the field of traceability is scarce and fragmented. This study first draws together and explores the existing body of knowledge to identify the state of current understanding and the gaps that remain in it. Moreover, this study identifies the position of traceability as a discipline with respect to related subjects including product data management. Furthermore, it analyses the ability of these subjects to help to understand the problems in the field of traceability.

Based on the gaps identified in the existing body of knowledge, the following research questions are raised:

1. How is traceability data used in business enterprises?
2. What are the impacts and benefits of using traceability data?
3. What factors enable a business enterprise to fully realise the positive impacts of traceability data?

The research questions are answered using the case-study methodology. The use of traceability is studied in nine different companies from automobile, food, electronics, pharmaceuticals and transportation industries. The case-study research begins with a description of the case-study companies as stand-alone entities, after which the cross-case analysis is conducted.

The empirical study establishes a theoretical and a pragmatic framework for categorising the applications of traceability. Moreover, it identifies a multitude of ways of using traceability data in business enterprises. The results of analysing the impacts and benefits of traceability data point out the importance of traceability for business enterprises. A framework for categorising the impacts of using traceability data as well as a number of practical benefits resulting from the use of this data emerge. Finally, several factors in the organisational and technical setting contributing to the realisation of these benefits are identified.

Altogether, this study establishes the foundations of comprehensively understanding the phenomenon of traceability.

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FOREWORD

The subject for this study emerged when I was working in an industrial company on a product traceability project. Traceability, a problem area which at the first glance seemed to be limited in scope and importance, started to expand the more I examined it. The need to improve my understanding on the subject led me to study the existing body of knowledge. Soon I realised that not much was available. Although traceability was frequently referred to in various articles, the discussion was largely superficial. At the same time, I was looking for a subject for my dissertation with both theoretical and pragmatic relevance. After considering several other subject areas, I finally determined to start studying traceability. So the research project began.

During this process, I received invaluable help and support from numerous people and organisations without whom this research could not have successfully been completed. Without Prof. Ari Vepsäläinen (Helsinki School of Economics), who raised my interest on post-graduate studies, I never would have started this research. Most importantly, I want to thank my supervisor, Prof. Eero Eloranta (Helsinki University of Technology, HUT) for keeping me on the right track towards successful completion of the research. Timo Hannukainen's and Jussi Pyykkö's support during the process of carrying out this study was of central importance. The opportunity to participate in the work of ICT-BP project at the Laboratory of Industrial Management at the Helsinki University of Technology was highly valuable. I want to thank Prof. Paul Lillrank and the other members of the project.

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1. INTRODUCTION

Traceability is defined (Juran et al., 1988) as the ability to preserve the identity of the product and its origins or more vividly (Jönson, 1988, p. 16) as a 'possibility to trace the history and the usage of a product and to locate it by using documented identification'¹. Lot traceability again, refers to traceability at the lot-level. Traceability is not limited to the identification of the physical characteristics of the product alone, but it also covers the history of the product and the circumstances that prevailed in various phases of the production and the distribution process (see e.g. Jönson, 1985, p. 16).

A number of reasons underlying the need for traceability have been identified in the literature. Minimisation of the magnitude and costs of the quality problems, management of product liability risks, and fulfilment of regulatory and customer requirements (see e.g. Staffieri, 1975, p. 20; Juran et al., 1988; Caplan, 1989, p. 45; Williams, 1990; Feigenbaum, 1991, p. 55; Petroff et al., 1991, p. 55; Wall, 1994b, p.9; Steele, 1995, p. 53) are frequently emphasised as justifications for traceability. One prominent example of the customer requirements for traceability is the demand for proof-of-origin information on raw materials used in different products (see e.g. Hobbs, 1996; Maitland, 1996; Rutanen, 1996). For example, concerns about food safety increased by the BSE² crisis and environmental concerns on the origin of lumber used in the wood products are well-known examples of these requirements (see e.g. Rutanen, 1996). Companies unable to provide provenance information may meet difficulties in marketing their products (see e.g. Hobbs, 1996; Maitland, 1996; Rutanen, 1996) and be forced to sell their products for a lower price than would be necessary if adequate information was available. Increasing requirements for quality and logistics management - e.g., the need for improved quality assurance (Juran et al., 1988) and logistics transparency (Florence et al., 1993, pp. 3 - 8) - have also set requirements for traceability.

The emergence of strict product liability and the rise of consumerism have played a significant role in the history of traceability since the 1960s and 1970s (see e.g. Feigenbaum, 1991, pp. 34 - 38; Petroff, 1991, p. 55; Ballou, 1992, pp. 103; Steele, 1995, p. 53). Although other early applications can be identified, product-liability- and product-recall-related applications have dominated the use of traceability until recently. However, both reductions in the costs of data

¹ There are also other definitions for traceability, that are not within the scope of this research. For example 'traceability' is commonly used to refer to the ability to trace the decisions made in software development (see e.g. Choi, 1997, Bohner, 1996) and ability to trace the designated standards in measurements (see e.g. Garner et al., 1993).

² BSE refers to Bovine Spongiform Encephalopathy or 'mad cow disease'. According to World Health Organisation (WHO, 1996a), it is a newly-recognised (in 1986) form of neurological cattle disease. It has been recommended (WHO, 1996b) that no part of any animal which has shown signs of BSE should enter any food chain, human or animal due to possible link between BSE and Variant Creutzfeld-Jakob Disease (V-CJD). V-CJD is a variant of diseases in humans with sponge-like findings in brain under the microscope, and with severe and fatal neurological signs and symptoms.

collection through advancement of automatic identification technologies, and the development and convergence of telecommunications and information technology have contributed to the feasibility of using traceability in new application areas (see e.g. Schantz, 1982; Adams, 1990, p. 1; Florence et al., 1993, pp. 3 - 8; Wall, 1994b, pp. 9 - 10). A well known example of a traceability application enabled by the advancement of technology is the package tracking application at FedEx (see e.g. Davenport, 1993, p. 52). Particularly recently, the literature has identified an increasing number of ways to use traceability data. However, much of the existing literature is written by practitioners and is anecdotal in nature. It largely discusses traceability from a perspective of a single company (Petroff et al., 1991, p. 55) or a single application. Moreover, it gives little guidance for understanding what elements are required to realise the benefits of traceability (cf. Steele, 1995, p. 53).

Hence, the purpose of this dissertation is *to increase understanding of the use and impacts of traceability data by examining the issue from a comprehensive perspective, i.e. as a subject in its own right.*

More precise research questions will be defined after the current state of knowledge on traceability and related subjects is explored in the literature review.

1.1 Study outline

The remainder of the dissertation progresses as follows:

- Chapter 2 introduces the existing body of knowledge on use, impacts and enablers of product traceability and discusses how traceability is related to other disciplines.
- Chapter 3 introduces research questions and discusses research design and methodological issues.
- Chapter 4 describes the status of traceability in the case study companies. This description includes a short summary of the usage of traceability data in these companies. A detailed description of the usage of traceability data is presented in Appendix 1.
- Chapter 5 contains a cross-case analysis and answers to the research questions.
- Chapter 6 compares the findings of the dissertation with the existing body of knowledge provided by prior research and outlines directions for future research.

2. LITERATURE REVIEW

The literature review is divided into four parts. In the first part, the usage and impacts of traceability data and the factors underlying the need for traceability are analysed. The second section continues by examining the alternative approaches available for responding to the traceability needs. In the third section, the requirements for traceability and enablers of full realisation of the positive impacts of traceability data are studied.

Finally, in the fourth section, disciplines associated with traceability are introduced and the role of traceability within these areas is analysed in order to understand how this literature can increase understanding of the problems in the field of traceability.

2.1 Importance of traceability

2.1.1 Use and benefits of traceability data

The literature identifies a wide range of applications for utilisation of traceability data. However, a limitation of the existing writings is that they lack comprehensiveness. In other words, their scope is limited to a single function, application or application area instead of discussing the uses of traceability comprehensively, e.g. from a company-wide, cross-organisational or industry-independent perspective. In the following, the existing literature on traceability is drawn together to identify how traceability data can be used in general and what benefits it provides.

2.1.1.1 Recall applications

According to Siomkos et al., a product recall may be involuntary, as when a company recalls the defective product only after an agency orders such action, or voluntary, where the company chooses to recall the product prior to governmental intervention (1994, p. 32). Several examples demonstrate that the scope, and correspondingly the cost, of a product recall can be significant. For example, Japanese car manufacturers needed to recall over eight million vehicles containing seat belts made by the Takata Corporation that had a safety defect (Armstrong, 1995, p. 37). The cost of Intel's recall of flawed Pentium chips was estimated to be as much as USD 675 million if all of the units in circulation would have been replaced (Barker, 1995, p.1). According to an article published in *Purchasing*, General Motors needed to recall 470 000 Cadillacs due to their emitting unlawful amounts of carbon monoxide (1996, p. 117). The costs of a recall can include (see e.g. Jacobs et al., 1975; Williams, 1990; Siomkos, 1994):

1. The total internal and external costs of recall in labour and materials.
2. Loss of the use of key personnel and resources during the recall.
3. Damage to the company's reputation, which may affect sales due to lower confidence in the marketplace.
4. Increases in insurance premiums.

The use of traceability data during a product recall is perhaps the most prominent application of traceability. The role of traceability is to facilitate minimisation of costs and other adverse effects resulting from a recall. In the event of product recall, traceability data is supposed to enable precise identification of the affected products from among the total product population and locating the products in distribution and use (see e.g. Jönson, 1985, p. 16; Caplan, 1989, p. 41).

According to Caplan (1989, p. 45), the benefits obtained through the ability to identify affected items can be enormous. Williams (1990) demonstrates the benefits provided by an effective traceability system with an example comparing two Australian manufacturers who experienced similar recalls of their products in the 1980s due to an identified potential hazard caused by the inadequate machining tolerances of a similar component in a fabrication. Manufacturer 1 needed to recall 25 per cent of the manufactured units. On the other hand, Manufacturer 2 was able to individually identify affected units and needed to recall only eight per cent of them, which significantly reduced the cost of the recall. Moreover, Manufacturer 1 needed to rely on an advertising campaign to encourage purchasers of products over a large range of ID numbers to contact the manufacturer, while Manufacturer 2 was able to identify the individually affected items and thereby trace the purchaser of those products.

2.1.1.2 Product-liability-prevention applications

In addition to reducing the risk of product liability claims by recalling the defective items (cf. Feigenbaum, 1991, pp. 37 - 38), a company can use traceability data to provide evidence in the event of product liability claim.

In the European Union³, the producer shall not be liable if he proves that:

- he did not put the product to circulation, or
- with regard to the circumstances, it is probable that the defect which caused the damage did not exist at the time when the product was put into circulation by him or that this defect came into being afterwards, or
- that the product was neither manufactured by him for sale or any form of distribution for economic purpose nor manufactured or distributed by him in the course of his business.

Moreover, according to this directive, 'the rights conferred upon the injured person pursuant to this Directive shall be extinguished upon the expiry of a period of ten years from the date on which the producer put into circulation the actual product which caused the damage, unless the injured person has in the meantime instituted proceedings against the producer.'

The affirmative defences in the Product Liability Law of Japan (Law No. 85 of 1994) are similar to the ones in the EU Council Directive. According to the law, manufacturers are not liable for damages if they can prove that it was impossible

³ Relevant parts of the European Union Council Directive 85/374/EC are introduced in Appendix 4.

to recognise the defect in the product with the level of scientific or technical knowledge at the time when the product was delivered by the manufacturer. Parties liable include the persons in the business of manufacturing, processing and importing the product and parties representing or misrepresenting themselves as the manufacturer by putting their name or any other similar indications on the product. In Japan as well, damage claims are valid only within the lapse of ten years after the manufacturer delivered the product.

In the United States, the legislation varies from state to state. However, valid defences on the defectiveness of a product seem to be similar to those used in the EU or Japan. According to Hodges (1993, pp. 94 - 95), the strict liability in most states is based on section 402A of the Restatement (Second) of Torts 1965. It imposes liability on 'one who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property'.

2.1.1.3 Quality- and process-improvement applications

Jacobs et al. (1975, p. 19) suggest that traceability provides an opportunity for correlating returns and field experience with changes in product design, its source, production and quality procedures. They claim that use of traceability data is the only way that many product changes can be checked for customer satisfaction and lack of quality problems. Similarly, Kendrick (1994, pp. 25 - 28) proposes that product history can be used to improve product quality, e.g. through root-cause defect identification. For example, Swiss Colony, a speciality mail-order food company used traceability data, as demonstrated by Alonzo (1993, p.8), in root problem identification when it had a problem with suspected contamination of its products by the bacteria *listeria monocytogenes*. This bacteria can cause miscarriages and stillbirth and is suggested to be especially dangerous to small children and elderly and those with weakened immune systems. Swiss Colony was able to trace the problem to a single piece of cutting equipment, which could then be removed.

In addition to quality improvement, Wall (1993a, p. 19) points out that traceability can likewise be used to identify the factors affecting the efficiency of the manufacturing process and to facilitate process improvement. Kendrick (1994, pp. 25 - 28) and Wall (1993a, p. 19) emphasise that traceability provides tools for identifying problems that might otherwise go unnoticed, e.g. through averaging. According to Kendrick (1994, p. 27), traceability can e.g. be used in calculating accurate machine capability. He gives an example of a moulding machine with multiple cavities and winding machines with multiples spindles. When each cavity or spindle is set up as a traceable subgroup and when samples are recorded for each cavity and spindle, a reliable machine capability can be calculated. Dutton (1993, p. 42) observed that ability to track manufacturing jobs on the shop floor enables better co-ordination of set-ups and minimisation of scrap.

2.1.1.4 Proof-of-quality and proof-of-origin applications

Requirement for traceability to provide proof of quality and proof-of-origin information originates from market demand for the information (see e.g. Hobbs,

1996, pp. 509 - 523). For example, meat consumers have started to require information on food safety and animal welfare standards (Hobbs, 1996, pp. 509 - 523). Viane et al. (1998, p, 139) state that in Belgium, between 75 per cent and 80 per cent of daily meat consumers have serious concerns about hormones, antibiotics, BSE and salmonella in fresh meat. In comparison, concerns about fat and cholesterol are currently less important, with between 45 per cent and 50 per cent of daily meat consumers expressing concern about these issues. Leat et al. (1998, p. 115) emphasise the use of traceability to demonstrate that every reasonable step has been taken to ensure that the products have been produced in a safe manner that also takes animal welfare into consideration. To respond to consumer requirements, for example, many supermarkets in the United Kingdom insist on traceability to the origins of the meat (Maitland, 1996). Consequently, in addition to meat traceability, pilot traceability projects have been running for potatoes, carrots, onions, salads and peas (Wilson et al., 1998, pp. 127 - 133), and will be run for poultry, dairy, eggs and other food in the UK.

It appears that lack of provenance information may cause difficulties in marketing the products (cf. Hobbs, 1996; Maitland, 1996) and may require the products to be sold for a lower price than would be necessary if adequate information was available (cf. Fausti et al., 1995). Under certain circumstances, the sales of the products lacking provenance information may also be banned. For example, during the BSE crisis, the European Union proposed (Paljakka, 1998) that meat can only be exported if the origin and movements of the slaughtered animal can be traced and if it is possible to show that there has been no suspicion of BSE in the cattle for eight years. Thus, in Great Britain, which was affected by the disease, only Northern Ireland, which fulfilled the requirements, was proposed to be allowed to export meat.

Jack et al. (1998, pp. 134 - 137) present a case where Scottish maltsters have started to pay a premium on cereals with accredited traceability and where Scottish grain distillers have started to make financial contributions to support establishment of cereal traceability. According to Jack et al., this is due to the fact that the variety and specific qualities of particular grains can have a profound effect on the success of large-scale food and drink processing activities such as malting. They state that the situation is similar in baking and brewing. Due to this reason, the absolute integrity of batches of grain can be of vital importance to large scale industrial customers in the food processing industry. Additional pressure for traceability has come from the need to respond proactively to consumer concerns about cereal production by improving food safety and addressing the environmental issues in cereal production. Jack et al. continue that the failure of a farmer to declare the field of origin and variety of the cereals will result in the load being put into the "feed" grade, thus attracting no premium. Moreover, some major Scottish maltsters will not be issuing barley contracts to non-accredited farms.

It is also suggested that the collected history of an item may be needed as a proof of quality to show that the contractual requirements have been met and to provide item-level quality control data for the customer (see e.g. Kendrick, 1994,

p. 27; Wall, 1994a, p. 28). In contractual disputes, traceability documentation can provide documentation to be used as legal evidence (Williams, 1990).

2.1.1.5 Logistics applications

Traceability provides visibility across the supply chain (Florence et al., 1993, p. 6; Dürr, 1997, pp. 1524 - 1531). Florence et al. (1993, p. 7) suggest that visibility provided by traceability affords an opportunity for creating logistics partnerships through creation of seamless supply chains and improved operational flexibility to react to changes in demand. They propose that the ability of the purchaser to track the order will, for example, allow the buyer to plan the distribution of the order with more certainty, allowing the buyer to react to replenishment needs more quickly when changes occur in the sales situation. Moreover, with prior notification of delivery of the order to the warehouse, the buyer can modify the distribution pattern. Bowersox et al. (1996, pp. 383 - 385), Dobler et al. (1996, p. 587) and Dürr (1997, pp. 1524 - 1531) underline the use of traceability in locating and managing shipments that have been delayed or gone astray. According to Dürr, monitoring shipments may be of special importance under conditions of exacting product movement control, such as just-in-time procurement to ensure prompt delivery and continuity of manufacturing operations. In a similar vein, Ballou (1992, p. 155) regards shipment traceability as a way to provide improved customer service, as traceability supports the goal of guaranteed delivery service.⁴ Dürr (1997, pp. 1524 - 1531) and Armstrong-Smith (1997b, pp. 22 - 25) emphasise the potential of traceability-based shipment monitoring to improve utilisation of resources in the transportation chain. Based on the interviews of combined traffic operators, Dürr suggests that a detailed overview of the current allocation of the resources in the intermodal shipments could yield up to 20 per cent cost reduction while at the same time improving offered quality of service. In Dürr's example, the overview categories used by the operators included wagons/loads underway to/from a terminal, assignments of load units to wagons, listings of free wagons, load units at the terminal, load units due to arrive and load units picked up. The cost savings would be achieved through information supporting the operators' tasks of accepting a booking, reserving a place on a transport medium, managing the transport resources (wagons) and controlling delivery and pickup.

Greene (1992, p. 79) suggests that lot traceability can be used for monitoring product shelf life. A traceability system can be used to automatically transfer expired lots into another reserved or non-issuable status (Moulding, 1993, p. 339). Florence et al. (1993, p. 6) state that many retail chains are insisting that for short-shelf-life products with deliveries on consecutive days, 'the best-before dates' on the products are similarly consecutive. They add that this requires tracing the deliveries at the best-before-date level, not just at the quantity level.

⁴ Customers can also be given the opportunity to monitor the status of a shipment themselves, e.g. using the Internet. A prominent example of this kind of service is the shipment traceability system provided by FedEx (see e.g. Ballou, 1992, p. 155, Davenport, 1993, pp. 52 - 130)

In addition to status identification and monitoring, examples of applying traceability data to detect and prevent errors and to provide alerts about error situations in manufacturing and distribution processes appear in the literature.

Dürr emphasises the problem in freight transport (e.g. rail transport), where the load is not accompanied by a driver, which causes a “black hole” of information during that part of the journey. One can only wait for the arrival of the delivery, as it is not possible to get early warnings on possible delays. He suggests that the lack of information makes the use of combined traffic alternatives unattractive for just-in-time logistic applications. Dürr illustrates how tracing and tracking-based alarms can be used to alleviate the problem in intermodal transportations. By setting up a network of readers along the transportation corridors, the load units can be identified during their journey. This information can then be compared against a load unit’s planned timetable and alarms on deviations can be generated. Dürr identifies four distinct transportation alarm situations:

1. Too-late alarm
2. Unexpected alarm (too early or wrong route)
3. No-show alarm (expired time window) and
4. Unknown (there is no planning for the item).

He offers this system as a way of improving transparency and considerably reducing waiting “in vain” at terminals, thus increasing efficiency at pick-up and delivery. (Dürr, 1997, pp. 1524 - 1531).

Juran et al. (1988) note that traceability can be used in the manufacturing processes to assure that ‘only materials and components of adequate quality enter the final product’. Further, they stress the importance of using the obvious identification provided by traceability to avoid mix-up of products which otherwise look alike. Parker (1992, pp. 36-37) gives an example from Tellabs of using traceability data to verify that a given module has gone through all necessary manufacturing steps. Before the module is shipped, a complete history can be printed as a final check to ensure that all process steps have been completed.

Additionally, accumulated traceability data can be used for analysis purposes. Moulding (1993, pp. 337 - 340) highlights the potential of performance-related data offered by traceability. He suggests that lot traceability can be used to measure and analyse e.g. change-over times, lead-times in various process phases and cumulative lead-times. He suggests that traceability-based measurement gives ‘a clear view of true lead-times’. He criticises the conventional back-scheduling process, where cumulative lead-times are built using level-by-level lead-times. He claims that this approach assumes no delays and represents an ‘unachievable minimum lead-time’. Sohal (1997, pp. 583 - 591) argues that traceability system is more than a system to trace the sources of problems. In his example at Nippondenso Australia, a traceability system has become a factory management system where daily production can be planned, machine/line utilisation analysed and internal or external parts shortages notified.

2.1.1.6 Security applications

Swerdlow et al. (1997, pp. 31 - 32) state that traceability can provide an audit trail between each point in the supply chain if items are logged in and out when they move through the strategic nodal points in the supply chain. This can highlight where breaches of security in the chain are occurring. Moreover, Amrstrong-Smith (1997b, pp. 22 - 25) proposes traceability to enable identification of losses and responsibilities at the level of individual items. Hook (1997, p. 28) states that item identification can be used to prevent return fraud. When a product is returned by a customer, it is possible to validate when and where the item was sold to detect fraudulent returns.

Furthermore, literature identifies applications in which traceability is used to identify counterfeit and illegal items. Sharp (1990, p. 151) suggests that counterfeiters are likely to copy only a limited number of serial numbers. If a manufacturer receives a shipment of counterfeits, the identification system is likely to start detecting duplicate serial numbers.

Traceability data can also be used to identify illegal channels of distribution. For example, according to Violino (1995, pp. 15 - 16), from Silicon Valley companies, components worth of USD one million are stolen every week. Freeman (1995, pp. 15 - 16) suggests that the difficulty of tracing makes the components attractive to thieves. Schoening (1995, pp. 15 - 16) states that major problems are caused by chips rejected by the manufacturer, which end up in the market and cause system failures. For example, Intel and American Micro Devices Inc. have started to serialise micro processors and trace shipments, supporting traceability of system failures due to stolen parts (Violino, 1995, pp. 15 - 16). According to Knill (1994, p. 3), Lotus Development Corporation used shipment traceability data to prevent illegal copying and unauthorised channels of distribution, usually created by regular distributors who 'moonlight products at cut-rate prices'.

2.1.1.7 After-sales applications

Several after-sales applications of traceability are discussed in the literature. A product's warranty can be tied to product serial number, which can then be used in warranty status verification (Jacobs, 1975, p. 18; Juran et al., 1988; Ukens, 1996, p. 106). Caplan emphasises the possibility of the manufacturer learning about the product and its quality in use through record-keeping in installation, service, engineering changes applied in the field and associated inspections and tests. Further, he emphasises the ability to provide customised service for customers. Addition of options and modifications to the products leased by the customer can be offered when the exact configuration of the particular equipment is known (Caplan, 1989, pp. 45 - 46). According to an article published in *Gas World* (1994, p. 143), for example, in a pipe system, coupler-specific data on the manufacturer, type and electrofusion parameters, the time and date of installation, the name of installer and the geographical location of the fitting can be recorded. The resulting traceability through the entire life cycle of the pipe system then facilitates the renewal of the installed base.

2.1.1.8 Accounting applications

Traceability data can also be used for to support cost accounting. Florence et al. (1993, p. 7) emphasise the opportunity for throughput accounting techniques that assist in accurately measuring where costs are incurred. Swerdlow suggests that the audit trail will help measure the value added between each point in the supply chain and will highlight where particular inefficiencies occur (Swerdlow, 1997, pp. 31 - 32).

Sohal (1997, pp. 584 - 585) demonstrates the importance of traceability for accurate determination of work-in-progress inventory values. He refers to a case study of an automobile parts supplier (Nippondenso Australia) that carries out thousands of transactions each week. Before the traceability system was set up, the manufacturing stock records were unreliable due to the large number of transactions and manual recording of materials usage. Work-in-progress inventory values needed to be estimated until an accurate physical stock count was undertaken. Implementation of full traceability with bar-code scanning was observed to have filled the 'traditional manufacturing black hole', giving precise inventory statistics. Furthermore, this was suggested to have led to continuous reduction in the work in progress.

2.1.2 Factors underlying the need for traceability

The need for traceability appears to emerge as a result of differences in the characteristics of otherwise identical items. Six factors underlying differences and thus, the need for traceability, can be identified by analysing the applications of traceability discussed in the previous section and by studying the literature. The identified factors are the following:

1. Age: Differences in age appear to cause differences in otherwise similar products in two ways. First, design changes, application differences, product cost reductions, production-process changes, and several other changes take place in relation to a particular product during the passage of time (cf. Feigenbaum, 1991, p. 273). Secondly, product units may have a shelf life, after which they must be recertified, downgraded, or scrapped, as a result of which a difference needs to be made between products manufactured at different points of time (cf. Petroff, 1991). Similarly, the validity of the warranty of a product unit is normally tied to the date of purchase or date of manufacturing (Jacobs et al., 1975, p. 18).
2. Origin: Differences in product characteristics are caused by different sources of the raw materials used in otherwise similar products (cf. Feigenbaum, 1991, p. 273). The importance of origin is apparent for example in cattle procurement, where different sources of the raw materials may or may not be affected by BSE (see e.g. Hobbs, 1996; Maitland, 1996).
3. Destination: Although products are otherwise similar, they may be in different physical locations in the supply chain and delivered to different destinations in the market. For example, in the event of recall, information on countries or areas to which the products have been delivered or information on the end-users of the products supports the recall activity (see e.g. Williams, 1990).

4. Customisation: Diversity in the characteristics of products may be intentionally created by configuring the products according to customer requirements (cf. Petroff et al., 1991, p. 57).
5. Errors and variations: Unintentional diversity is caused by errors and variations in the manufacturing and distribution processes. Errors in the distribution processes for example are reflected in lost and late deliveries, resulting in the need for shipment traceability (see e.g. Bowersox et al., 1996).
6. Illegal activities: The need for traceability is caused by illegal activities as a result of which there is for example a need analyse where the products are being stolen (see e.g. Swerdlow et al., 1997, pp. 31 - 32; Armstrong-Smith, 1997b, pp. 22 - 25) and whether a product is counterfeit product or not (see e.g. Sharp, 1990, p. 151).

2.1.3 Factors determining the relative importance of traceability

Although the existence of differences in item characteristics seem to underlie the need for traceability, this alone does not automatically determine the relevance of traceability. According to Petroff et al. (1991, p. 55), the nature of the items determine the importance of traceability. Juran (1988) for example recommends different levels of traceability for low- and- high value items. In addition to item characteristics, environmental factors affect the appropriate level of traceability. Altogether, the following five variables that determine the relative importance of managing the differences in item characteristics can be identified in the literature:

1. Item value
2. Item criticality
3. Length of item's life
4. Complexity of the system
5. External environment

Item value

Item value is a main affecting the desirable level of traceability. Juran et al. (1988) differentiate levels of traceability-based on unit value. They advocate the use of serial numbers for high-value items and date codes for low-value items in continuous production. Serial numbering is needed in high-unit-value items for instance to enable keying the system of guarantees to the serial numbers.

Sharp (1990, p. 179) emphasises the importance of tracing small sized, high-value items, which are tempting targets for theft. Not only wholesale value, but also black market value⁵ may affect the need for loss control. Howell (1997, pp. 24 - 25) connects item value to the feasibility of using certain techniques in identification.

⁵ E.g. syringes and narcotics may have a low value in legitimate markets but high value in the black markets.

Item criticality

An increase in the item's criticality in relation to the safety of the environment, item's criticality in relation to the quality or functionality of the system the item is a part of, or an increase in the sensitivity of the item appear to increase the need for traceability.

Williams (1990) identifies three categories of item criticality that affect the level of traceability. Items in the highest category of criticality, also requiring highest level of traceability are characterised by substantial warranty work or replacement costs. Moreover, the failure of these items will affect the performance of the system or personnel safety, or cause loss of life or injury.

Petroff et al. (1991, p. 55) refer to items that due to their nature, require more detailed traceability than other items. These include items that require special storage in order to manage temperature, humidity, cleanliness, or cross-contamination and items, such as flammables and explosives, which may be dangerous.

Jönson (1985, pp. 1 - 16) suggests that the level of traceability should reflect the potential costs of recall or damage. The costs are connected to product safety risk, which Jönson defines as the probability of undesired consequences and the criticality of these consequences. According to her, the consequences may include injury caused by the product to its users or other persons in contact with it and damage caused to the product, other property and/or the environment. These consequences can take place during the product's entire life cycle: during manufacturing, distribution, use and destruction. In a similar vein, Feigenbaum (1991, p. 38) connects product safety and the possibility of product recalls, for which he proposes tracking mechanisms to be vitally important. Saussele (1995, pp. 91 - 95) suggests that an increase in the sensitivity of the product should result in a reduced lot size in order to improve traceability.

An extreme example of the need for traceability is illustrated by Vasilash. In the manufacturing of automobile airbags practically everything is tracked due to the high safety criticality of the airbags (Vasilash, 1992, pp. 36 - 39). As suggested by Jönson (1985, pp. 1 - 16), not only user safety but also environmental consequences may increase the need for traceability. For instance, as suggested by an article published in the *Purchasing* (1996, p. 117), automobiles, whose emissions do not conform to legal requirements may need to be recalled.

Quality criticality as a determinant of the level of traceability is emphasised in several articles (see e.g. Juran et al., 1988; Sharp, 1990, pp. 179 - 189). Juran et al. underline the traceability of components which are decisive in achieving overall fitness for use or chiefly responsible for final product quality.

Length of item's life

Jönson (1985, p. 17) suggests that the longer the life of the products, the higher the number of the products in distribution and use. She argues that the shorter

the life of a product, the smaller the product safety risks and consequently, the smaller the requirement for detailed traceability.

Complexity of the system

Williams (1990) emphasises the importance of product complexity in determining the level of traceability. He identifies three categories of product complexity, where the increase in complexity should increase the level of traceability. In the category of the highest complexity, the traced item has a high replacement cost in time, money or prestige, the failed unit is a non-propriety item or no spares are available, system loss affects related systems or it is not possible to replace or service the unit in situ or during plant operation.

For instance some of the items or products in the aerospace, nuclear (Juran et al., 1988) and defence industries (Williams, 1990) require increased traceability due to item or product complexity.

Petroff et al. (1991, p. 57) suggest that detailed and extensive traceability is an appropriate method for tracing large and complex products with a manufacturing quantity of one.

External environment

Factors in the external environment like customer values and the legal environment can affect the appropriate level of traceability. For example Hobbs (1996, p. 509) suggests that increased customer concerns about farm animal welfare may have increased the need for traceability as there is a need to trace cattle to the farm of origin. Similar consumer pressures have been caused by genetically engineered food (Bentley, 1996).

Similarly, the level of demand for standard mass-market products versus fragmentation of demand for different 'flavours' of similar products determines the need for customisation (Pine, 1992, pp. 44 - 48).

The legal environment is another example of a factor affecting the need for traceability. Even when the legal setting does not directly require traceability, it may implicitly increase the need for it. Feigenbaum, for example, suggests that introduction of strict product liability places increasingly heavy pressures on the development and assurance of a very high degree of factually based evidence. This is due to the need of the manufacturer and the merchandiser to provide an immediate response to unsatisfactory quality and the ability of the manufacturer to support advertised statements by valid company quality-identification data (Feigenbaum, 1991, pp. 36 - 37).

2.1.4 Justification for traceability

Factors underlying the differences in item characteristics together with factors determining the relative importance of managing the differences were observed to determine the necessity of traceability. The former set of factors determine

whether there are differences to be managed, and the latter set of factors determines whether these differences are relevant. Finally, the decision to implement traceability can be justified by:

1. Cost and benefit analysis
2. Compliance with direct external requirements from authorities, customers, etc.

2.1.4.1 Cost and benefit analysis

Traceability can be justified economically using the same techniques that are used to justify any other capital investment (cf. Sharp, 1990, p. 57). The 'economics of the situation' (Feigenbaum, 1991, p. 802), i.e. the costs of traceability in comparison to the estimated benefits, determine the desirable level of traceability. It may also be a competitive necessity to trace items (Sharp, 1990, p. 3)⁶.

Cheng et al. (1993, pp. 4-5) consider traceability as a cost-adding rather than value-adding activity. According to them, a good traceability design sets out to provide the right amount and form of information at an appropriate level and an acceptable cost.

2.1.4.2 Direct external requirements

External requirements, e.g. government regulations, customer requirements and various standards, set requirements for the level of traceability. These requirements, of which the most commonly appearing are discussed in the following, seem also to be largely derived from item characteristics.

Industry-specific government regulations set direct traceability requirements in certain industries. Perhaps the most detailed requirements are specified in the Good Manufacturing Practice (GMP) for pharmaceutical products. GMPs setting detailed traceability requirements for pharmaceutical products are in effect e.g. in the European Union and in the United States (cf. Moulding, 1982; The Magazine of Manufacturing Performance, 'Pharmaceutical firm employs micro system for lot traceability', 1989; European Community, 1992).

Several standards like ISO 9000 and QS 9000 set requirements for companies looking for certification. ISO 9001⁷ (International Standard ISO 9001:1994) for example requires the supplier, where appropriate, to establish and maintain documented procedures for identifying the product by suitable means from receipts and during all stages of production, delivery and installation.

⁶ Sharp (1990, p. 3) suggests that because of Fedex's market presence and their automatic identification advertising, it would be very difficult to enter the overnight package business without an automatic identification system, no matter what the rate of return was on that particular investment.

⁷ Appendix 4 introduces Section 4.8, Product Identification and Traceability of European standard EN ISO 9001:1994, Quality systems - Model for quality assurance in design, development, production, installation and servicing (ISO 9001:1994).

Moreover, customers set varying requirements for the level of traceability (cf. Williams, 1990; Florence et al., 1993, p. 6; Wall, 1994a, p. 24; Sohal, 1997, pp. 583 - 591). For example, car manufacturers set requirements for the parts suppliers to have the capability to trace the source of any faulty automotive part (Sohal, 1997, p. 587).

2.1.5 Discussion

Traceability has traditionally been connected to management of crisis situations like product recalls and product liability cases. However, the review of the literature shows that the potential for using traceability data is much wider than the traditional view would suggest. A number of important applications in day-to-day operations as well as in various analysis can be found in the logistics, quality, legal, security and cost accounting activities.

Based on the literature, it can be suggested that differences in the characteristics of individual items underlie the need for traceability. These differences are caused by time-related differences, differences in the origin or destination of the items or their parts, differences intentionally created to meet customer requirements, undesired variation and errors in the material flow processes, and differences caused by illegal activities. Traceability is needed to identify these individual item- or lot-specific characteristics and to manage the items accordingly.

However, it appears that the need for traceability is determined by the relative importance of the differences, which again is determined by the characteristics of the item in question, the setting in which it is used and a set of environmental factors. These include the item's value, criticality and length of life, the complexity of the setting the item is used in or the item itself, and factors in the external environment like customer values and the legal environment.

Finally, the decision to trace or not to trace an item is based either on comparison of the cost and benefits of traceability or on direct external requirements.

2.2 Managing the need for traceability

2.2.1 Alternative approaches

Three alternative approaches for managing the need for traceability emerge in the literature. The identified approaches are the following:

1. Documentation-based traceability
2. Inherent traceability
3. Elimination of the factors underlying the need

These approaches are discussed in the following sections.

2.2.1.1 Documentation-based traceability

In its traditional meaning, traceability is based on documentation. This can be seen in the definitions of traceability. As discussed earlier, Jönson (1988, p. 16), for example, defines traceability as the ‘possibility to trace the history and the usage of a product and to locate it by using documented identification’.

The literature (see e.g. Steele, 1995, pp. 53 - 59) identifies a number of elements which together enable documentation-based traceability. These elements include the collection of traceability data, linking the physical items to the collected data, and carrying out reporting in order to provide the required information. The elements of traceability are discussed in detail in Section 2.3.

2.2.1.2 Inherent traceability

Instead of using documentation to provide the information required, the material flow processes can be structured to inherently provide traceability so that the information related to the traced object in question is immediately obvious to everyone without (or with a reduced amount of) documentation. Inherent traceability can be improved by simplifying material flow structures. Hobbs (1996, pp. 509 - 523) has found that complexity in the supply channels increases the need for traceability. She demonstrates that different supply channels impose different amounts of traceability costs. By selecting direct supply channels, traceability efforts can be minimised while still maintaining the required level of traceability. According to Violino (1995, p. 16), computer manufacturers have faced the problem of stolen or defective chips ending up in their machines. Dell has managed the problem by not using chip distributors or other third parties, but by instead dealing directly with chip manufacturers.

Dürr (1997, p. 1524) demonstrates that the selection of the mode of transportation affects the need for traceability. He suggests that in intermodal deliveries characterised by the involvement of a large number of transport parties, particularly when rail transportation is involved, shipment status is not known as the load is not accompanied by a driver throughout the delivery. On the contrary, with road transport, where one driver delivers the cargo from end to end, the driver can be contacted to provide information on delivery status and delays.

The first-in-first-out (cf. Steele, 1995, pp. 53 - 54) and just-in-time (cf. Violino, 1995) methods can be used to reduce or eliminate the need for traceability.

Inherent identification mechanisms have also been discussed by Kyllönen (1994, p. 12) in product data management context. Kyllönen proposes that company size affects the need for product data management. Kyllönen underlines that in small companies, where all activities are rather similar and where communication between the small number of employees is inherently spontaneous and easy, the need for product data management is small.

2.2.1.3 Reduction of the need

In addition to using documentation or inherent traceability to communicate the required information, it is clear that the need for product identification or traceability can also be approached by reducing or eliminating the impact of the factor underlying the need.

The risk of recalls can, for example, be managed through quality programs, which enhance the likelihood of turning out products of high initial quality, as well as through the records and logs and product-tracking mechanisms that can be used if a product recall is needed (cf. Feigenbaum, 1991, p. 38). Similarly, security problems can be managed by increasing security as well as through improved traceability (cf. Violino, 1995, pp. 14 - 16).

2.2.1.4 Discussion

Traditional, documentation-based traceability is not the only alternative for meeting the need for identification. In addition to documentation-based traceability, two alternative methods for managing the product identification need were described: inherent traceability and elimination of the reason underlying the identification need. Although the need for documentation-based traceability can to some extent be reduced with these approaches, it is clear that documentation-based traceability is still needed to manage uncertain and complex products and environments. During the transportation process, for example, inherent traceability can be achieved, and the need for traceability in its traditional meaning be decreased by using road transportation and by reducing the number of transportation parties to one (cf. Dürr, 1997, pp. 1524 - 1531). However, as a result, the opportunity to use more attractive transportation alternatives would be lost. The same applies to elimination of the factors - like quality problems - underlying the need for traceability. For example, Feigenbaum (1991, p. 37) suggests that even well-managed companies today find themselves obligated to prepare for the possibility of having to call back quantities of product from the field to correct problems which they have been unable, for a variety of reasons, to anticipate.

Thus, it can be concluded that the requirements for traceability cannot be met with inherent traceability and elimination of the underlying factors alone and that a genuine need for documentation-based traceability exists in business enterprises. In the following, the discussion is focused on documentation-based traceability.

2.2.2 Elements of documentation-based traceability

Although traceability is often referred to in the literature, the existing body of knowledge on the elements needed to enable traceability seems to be limited (cf. Steele, 1995, p. 53). The following two models with general relevance are introduced in the following sections:

- Steele's elements of traceability, which discusses the elements needed to create a traceability system.

- Caplan's techniques of material tracking, which focus on the different types of data needed to implement a traceability system.

2.2.2.1 Steele's elements of traceability

Steele (1995, pp. 53 - 59) identified four elements which 'together define the full scope of lot traceability' in a study of two companies in repetitive, discrete item manufacturing. The four elements are as follows:

1. Physical lot integrity: How large a lot is and how well lot integrity or separateness is maintained determines the resolution or precision of the traceability system. When exploding from a defective item, a wider resolution means more component material and processes are exposed as possible sources. Further, when a defective component material or process is identified, a wider resolution means more items are exposed as possibly defective. Steele identifies three situations that can lead to loss of lot integrity: a) lot mismatching, where a lot is transformed into a new lot, but the new lot does not exactly match the source lot, b) lot-end mixing, the failure to maintain clear separation between adjacent lots can result in mixing at the end of one lot and at the beginning of the other lot, and c) lot-sequence mixing, where the failure to honour the first-in-first-out principle leads to a loss in lot integrity when record keeping is based on first-in-first-out.
2. Data collection: Two types of data are identified - lot-tracing data and process data. Lot-tracing data records the occurrence of movement into processing or storage and the merging or transformation of one lot into another lot. Process data records important process information, such as statistical process control or quality assurance information.
3. Lot-process linking: Lot-process linking is the cross-referencing of process or component material data to physical lots. The link can be created by recording both physical lot tracing and process data by the same physical lot identification number or by using the date and time in lot and process records. Raw material usage can be recorded by lot number or, in some cases, be marked directly on the part or item. Steele suggests that when linkage is based on lot numbers, the link is 'tight and accurate'. When a date- and time-based method is used, lot and process data can be collected independently and linked later only when needed. Steele argues that a major advantage of this method is that existing systems are not required to be linked together. However, one weakness of date-time identification is that retrieval of data can be cumbersome and time-consuming and may lead to loss of lot integrity.
4. Reporting: Reporting is the retrieval of data from the system. The design of the reporting function is proposed to be determined by how data is stored, the frequency of access required, the retrieval time permitted and storage space limitations. Manual filing or computerised systems may be used in the reporting.

Steele's model aims at describing the elements needed in a manufacturing context to precisely identify defective products in the event of product recall. The model is limited to lot-level traceability.

2.2.2.2 Caplan's techniques of material tracking

Caplan (1989, pp. 45 - 46) identifies five techniques used in material tracking:

1. Lot integrity control: Identification of lots and prevention of pieces straying from the parent lots by accident.
2. Processing control: Unique identification of each item or group of items (e.g. with serial or lot numbers) and permanent records of the routine and special processing steps applied to it (e.g. furnace temperature).
3. Build control: Identification of assembly and further processing information needed to show which items or lots of parts, components and subassemblies were combined to make the product and what process conditions existed at the time of each step through product completion.
4. Inspection and test: Recording of specific results of appraisal efforts including rework, repair and other non-standard treatment of items.
5. Field activity and modification control: Records kept of installation or erection processes, service, engineering changes applied in the field and associated tests.

Furthermore, Caplan suggests that control programs must be extended, as necessary, back to the supplier's operations or even beyond. However, he stresses that the adequate level of traceability varies from producer to producer and depends on regulation, product liability and customer reaction.

Like Steele, Caplan considers the ability to minimise the magnitude of the problem and the associated cost savings (in recall) as a primary reason for traceability. However, Caplan identifies also other uses of traceability. He suggests that traceability can expand the manufacturer's knowledge on the products in use and enable the manufacturer to provide tailored services for customers.

Departing from Steele's model, Caplan's 'techniques of material tracking' focus on describing the different types of data needed to provide traceability throughout the lifecycle of a product. At the same time, the discussion on other elements of traceability is limited in comparison with Steele's model.

2.2.2.3 Discussion

The elements of traceability observed in Steele's and Caplan's model can be summarised as:

- Physical lot integrity
- Data collection
- Product identification and lot process linking
- Reporting

A limitation of these models is that they discuss traceability at the lot-level and thus do not identify the differences in unit-level traceability. It is feasible to suggest that lot integrity for example is not a relevant issue when traceability is based on individual units i.e. products are traced at the serial number level.

Moreover, unit level traceability affects the way products are identified and documentation is linked to the physical items. In this kind of setting, the documentation can be keyed to individual serial numbers or blocks of serial numbers. This method is proposed to be suitable when products are manufactured in continuous production and the unit value is high (Juran et al., 1985).

2.3 Enablers in the management of traceability data

It appears that establishing a traceability system with the elements described in the previous section alone does not guarantee success in applying traceability. This section discusses the requirements for the quality of the information provided by a traceability system as well as the enablers in the technical and organisational setting that enable success of the system.

2.3.1 Usefulness of traceability information

Several criteria for the usefulness of the traceability information can be identified in the traceability literature, including:

1. Comprehensiveness,
2. Accuracy,
3. Timeliness,
4. Easy availability and
5. Security⁸

⁸ An in-depth discussion on information usefulness can be found in information management literature. In this context, Alter (1996, p. 178) defines information usefulness as the extent to which information can be used for a particular purpose. According to him, information usefulness is determined by three factors: information quality, information accessibility and information presentation. In addition to information itself, Alter suggests that information systems affect information usefulness in all of these categories.

According to Alter, information quality can be divided into the following elements:

1. Information accuracy: the extent to which information represents what it is supposed to represent.
2. Information precision: the fineness of detail in portrayal.
3. Completeness: the extent to which the available information is adequate for the user.
4. Age: the time that has passed since the data was produced.
5. Timeliness: the extent to which the age of the data is appropriate for the task and user.
6. Source: the person or organisation that has produced the data.

Information accessibility again, can be divided into two parts:

1. Availability: the necessary information exists and can be accessed effectively by the people who need it.
2. Access restrictions: the conditions under which specific items may be used.

Finally, Alter suggests that information presentation can be divided into two elements:

1. Level of summarisation: the comparison between the number of items in the original data and number of items displayed.
2. Format: the arrangement and appearance of information displayed to the user. (Alter, 1996, pp. 109 - 110)

In addition to the determinants named by Alter, Kleijnen identifies the role of system flexibility in the use of data. This refers to the ability of the system to adjust to changing information needs.

From the quality management perspective, Wall (1993b, p. 37) stresses the importance of collecting data that has potential to influence the efficiency of the process and the quality of the product. Wilson et al. (1998, pp. 127 - 133) identify two basic sorts of data used: 1) information relating to a specific consignment or collection of material i.e. traceability data, and 2) data on the general environment in which the material is processed. Caplan (1989, p. 46) extends data collection to the whole material chain, from the suppliers to the after-sales field activities. In a similar vein, Jacobs et al. stress that 'traceability does not start at the receiving dock'. Materials must be traceable through lower-tier vendors; their responsibility is similar to that of the final product manufacturer (Jacobs, 1975, p. 17). Cheng et al. also underline the importance of the completeness of the collected data. However, they state that too much tracing information can be counter-productive if it masks important control parameters (Cheng et al., 1993, pp. 5 - 14).

Accuracy of the tracing information is also implied to be an essential requirement for the traceability system in order to realise the practical benefits of traceability (see e.g. Cheng et al., 1993, p. 9; Wall, 1995, p. 10).

The importance of real-time (see e.g. Feigenbaum, 1991, p. 802; Lord, 1997, p. 33; Swerdlow et al., 1997, p. 31; Williams, 1997) and easy (see e.g. Feigenbaum, 1991, p. 802) availability of the data in the supply chain monitoring is underscored by numerous writers. Martin (1983) suggests that if information is not easily available, it will not be used. Miller (1996) stresses that accessibility and timeliness should complement each other. He claims that timely information that is inaccessible or accessible information that is obsolete cannot satisfy an information customer's needs. Dürr (1997, pp. 1524 - 1531) emphasises that the real-time availability of data in the information systems from one single point of contact, which enables real-time reaction is significant in certain logistics applications of traceability. Wall (1994a, pp. 26 - 28) and Kendrick (1994, p. 25) stress the importance of the ease and quickness of data availability in manufacturing quality control and data analysis. Similarly, Cheng et al. (1993, pp. 12 - 13) underline the importance of the frequency, quickness and accuracy of the information collection, processing and acting on the data in the success of a short-term control mechanism. However, at the planning-, design- and strategy-level applications, quickness is not seen being as critical as it is in short-term control.

Long-term availability of data is emphasised by Steele (1995, p. 55), who states that storage space for several years of data, electronic or physical, must be planned.

Security through access restrictions in inter-organisational systems are also emphasised. Restrictions offer security and protection and provide confidence to

Moreover, Kleijnen suggests that user-machine modes determine how information is further processed after it has been displayed to its user. (Kleijnen, 1980, pp. 89 - 110).

all users of the system (cf. Armstrong-Smith et al., 1997, p. 32; Dürr, 1997, pp. 1528 - 1529; North, 1997, p. 34).

2.3.2 Technical enablers

The literature identifies a set of technical enablers that can be used to improve the usefulness of traceability information.

The accuracy of the entered data can be improved by using automatic identification instead of manual data entry (cf. Sharp, 1990, pp. 1 - 5). Howorth (1997, p. 17) suggests that when a system is automatic, human error is eliminated. According to Sharp (1990, p. 2), skilled data entry people make approximately one mistake out of every 300 characters they enter when they work from legible forms. He continues that on the other hand, some automatic identification techniques offer error rates of less than one character in a million.

A number of methods of supporting easy and timely⁹ availability of data are suggested in the literature. The use of automatic identification is one way to reduce effort in data collection and provide increased speed of data availability (see e.g. Sharp, 1990, pp. 1 - 5; Keighley, 1993, p. 10). When data is retrieved, non-computerised records (North, 1997, pp. 32 - 34) lead to limited and complex traceability. Retrieval of data can be time-consuming in terms of clerical labour (Steele, 1995, p. 59). However, it is argued (Steele, 1995, p. 58 - 59) that paper records can be sufficient when time is allowed for retrieval and when requests for data are expected infrequently. Data can be made readily available with the format of the product identification number (cf. DeSain, 1993, p. 28). Capron (1986, pp. 222 - 223) advocates the use of identifier codes that are not only unique keys but also have a built-in meaning related to the data itself. Garrett et al. (1993, pp. 25 - 26) propose that traceability documentation can be stored on CD-ROM disks. Copies of the disks may then be delivered to various units requiring the data. They suggest that this solution will provide quick access to data.

Plant-wide information systems can (cf. Kendrick, 1994, p. 25, Steele, 1995, p. 56) enable quick and easy entry and analysis of data. Garrett et al. (1993, pp. 25 - 26) suggest that the ideal (manufacturing) bar-code tracking system has

⁹ In the information management context, Kleijnen has identified four elements affecting the recency of information:

1. Update processing delay (P): When data is submitted to the computer, it requires P time units to process it. This includes the input time needed by human operators. In batch systems P can be notably larger than in on-line systems.
2. Update interval (L): Data, which is collected over L time units before submission for processing. In on-line data-capture systems this interval is virtually zero, as in batch systems, L is not negligible.
3. Retrieval delay (R): If the decision maker asks information at time t, the information becomes available at time t + R. In real-time systems, this refers to response time.
4. Decision delay (D): When the information is available, the decision maker needs time to reach a decision. In complex decision-making situations, D can be reduced by computerised decision models or by presentation or format of the data. (Kleijnen, 1980, pp. 92 - 94).

distributed data-gathering nodes and a local area network interconnection to a central file server, which then implements data requests and monitors transactions. Sharp (1990, pp. 37 - 38) advocates the use of distributed processing in data collection and utilisation. A number of personal computers communicating with each others create the foundation of the system instead of one mainframe computer. Sharp identifies several benefits of distributed processing. He claims that it allows more people access to the information, as computing tasks are not accomplished 'in a remote computer room'. Additionally, Sharp believes a distributed system increases reliability of data availability. According to Sharp this is due to the fact that distributed systems are less prone to catastrophic failures than centralised systems, as the processing is distributed between many small computers.

On the other hand, Wilson et al. (1998, pp. 127 - 133) emphasise one data store, a common means of access, and a system whereby data is defined by consensus across the industry as ways of ensuring traceability in fragmented supply chains with a large number of players. In a similar vein, Florence et al. point out that traceability is the end-to-end view of moving stock, tracking vehicles, tracing a product's status and many other activities. In order to support this view, a certain level of integration among the information systems is needed (Florence et al., 1993, pp. 3 - 6). Goodhue et al. (1992, p. 301) demonstrate that use of a single logical data model and common sharable data in the traceability systems can greatly improve the use of traceability data in shipment tracking. According to North (1997, pp. 32 - 34)¹⁰, a central database can also reduce 'the threat of fraud and rustling' and enable or enhance the functionality of a number of traceability applications. However, the majority of the application packages and even of the tailored systems are by some authors to lack required compatibility and integration (see e.g. Florence et al., 1993, pp. 3 - 6; Kendrick, 1994, p. 25).

2.3.3 Organisational enablers

As the technical setting appears to affect the usefulness of traceability data, the main impacts of the organisational setting seem to be in the overall success and acceptance of the system. The utility of data can only be realised when the opportunities for the use of data are perceived and the data is used. Unruh (1997) stresses that too often, technology takes centre stage, when it really only exists as an enabler. He continues by claiming that the real value is in the information itself and how well it is used and managed to create a business advantage. Similarly, Johnston et al. (1988, pp. 44 - 47) suggest that profitability often depends on using information that others lack to execute transactions before others recognise the opportunity.

Conflicting views of the appropriate owner of traceability are presented in the literature. Bowersox et al. (1996, p. 383) suggest that tracing (locating) is the responsibility of transportation management. On the other hand, Jacobs et al. (1975, p. 17), who discuss traceability in the manufacturing context, propose that

¹⁰ North discusses traceability in a context where an inter-organisational system is used to provide proof-of-origin data.

a traceability program can logically be one of quality control's responsibilities since it is this department that in reality is responsible for much of the record-keeping in most organisations. However, it appears that departmental ownership may hinder the utilisation of the data. Moulding claims that quality departments often 'jealously guard' data, thus preventing active utilisation of data, as the traceability system is seen more as an extension of laboratory systems than as a management tool and is characteristically only used when problems arise (Moulding, 1993, p. 337).¹¹

However, some authors stress the importance of comprehensive design and planning of traceability systems. Florence et al. (1993, p. 6) emphasise an end-to-end view of logistics processes and the need for establishing traceability across the supply process. Sohal (1997, pp. 583 - 591) sees the multidisciplinary team approach to planning and implementation of traceability systems as beneficial. However, he claims that a champion and top management understanding is crucial to the success of the overall project. Feigenbaum (1991, p. 802) exhorts establishment of a systematic program for identification, product configuration, record keeping and dissemination. Jönson (1985, p. 16) underlines the importance of comprehensive understanding of identification requirements before determining plans. She continues that the traceability requirements that are set should cover suppliers of raw materials and components, distributors and dealers.

On the other hand, the bottom-up approach to planning and design of traceability systems is also advocated. Wall (1993b, p. 37 - 39) claims that it is crucial that the enhancement of the system is driven from the bottom up, since, the system is more likely to work in practice as a result. He suggests that a comprehensive programme of traceability can be built up at the company's own pace from its various constituent parts. Williams (1990) argues in a similar manner. He sees traceability as a part of the quality system, which cannot be induced to a company from the top down. He claims that the only way to effectively implement a quality system is to build it up from the shop floor. Williams reasons that 'the system will then accurately reflect the true operation of the company and is now not regarded as an overhead to be minimised as much as possible, but can be seen as asset to the company providing direction and planning'.

¹¹ The problem of fragmented ownership has been addressed in information management literature also. Brittain claims that departments are often reluctant to make data and information available to other departments. He stresses the role of a single co-ordinating IT and information function, which can help to overcome these problems. (Brittain, 1992, pp. 69 - 80). Martin (1983, p. 676) suggests that 'in many corporations it has been discovered that a database implemented for one process happens to serve another process, or a different area in the organisation'. According to Martin, 'these happy discoveries ought not to happen by chance. They ought to be planned. If they are not planned, they will often not happen because different areas tend to keep to themselves and be jealous of their own data.' Martin suggests that a high-level, overall perspective of a corporation should be used in planning. However, he stresses that both top-down and bottom-up planning are needed; top-down for corporate-wide co-ordination, bottom-up for local initiative in creating subsystems. (Martin, 1983, p. 54). In a similar vein, Alter claims that when the range of involvement is too narrow, decisions are made from an excessively local viewpoint, often missing opportunities for the overall enterprise. (Alter, 1996, pp. 109 - 110).

The method of planning and implementing traceability systems can affect acceptance of the system users. Florence et al. (1993, p. 8) stress the importance of winning over internal personnel to the process changes required, as well as selecting the appropriate staff to run the system. Similarly, Sharp (1991, pp. 231 - 238) argues that human factors are a critical component of a data collection system success or failure. He claims that data collection systems are often perceived as elements of 'Big Brother' leading to suspicion towards the systems. A data collection system is normally perceived as tool for management, not a tool for workers. Sharp proposes that the motivation or ownership of the data collection system can be expanded e.g. by adding features to the data collection system which are desired by workers. Sohal (1997, pp. 583 - 591) brings up the fear of the shop-floor unions and employees on job losses resulting from productivity improvements brought by the traceability systems. In Sohal's example from Nippondenso Australia, the acceptance of the unions and employees was won with employee rewards for productivity improvements and management agreement to no job losses from the introduction of the new technology. Wall (1994a, p. 25) demonstrates in a case description that operators taking responsibility for their actions and creating sympathy with the system was achieved by not implementing full automation in the traceability system, but by retaining human interface in key areas. In addition to emphasising employee acceptance, Sohal (1997, p. 590) stresses the importance of adequate employee training. He sees it absolutely essential for the success of the traceability system. Moreover, Sohal adds that discipline must be enforced in the proper use of the system in order for it to succeed.

2.3.4 Discussion

The usefulness of traceability information or its ability to meet the application requirements depends on the quality of information. Several criteria for the usefulness of traceability information can be identified in the literature. These include comprehensiveness, accuracy, timeliness, easy availability and security of the information. These criteria are similar to the determinants of information usefulness discussed in a wider context in the information management literature. In the traceability literature, it has been suggested that the importance of the determinants of information usefulness is subject to the context the information is being used in. For example, the importance of easy availability of the information depends on the frequency of access required (cf. Steele, 1995).

A number of technical and organisational factors enabling successful traceability systems can be identified. The technical enablers include the computerisation of data processing and the use of automatic identification in data collection. Systems integration as well as the use of distributed processing are recommended. In organisational settings, both top-down and bottom-up approaches to managing traceability are recommended. Moreover, the importance of user acceptance, motivation and training are emphasised.

Although some advice for successful implementation of traceability systems as identified, the existing body of knowledge appears to be highly limited. The

recommendations are largely anecdotal, incoherent and somewhat contradictory. Moreover, they are based on pragmatism rather than scientific studies.

2.4 Traceability and other disciplines

Much of the literature portrays traceability as an independent domain. However, traceability has also been seen as a part of other disciplines. It appears that traceability has been most prominently discussed - and often seen as a part of the domain - in writings on product data and product data management (PDM), total quality management (TQM) and automatic identification. Furthermore, traceability has been discussed in conjunction with logistics, although with a less structured approach.

The question of to what extent the knowledge available in the literature under the above-mentioned domains is applicable in the field of traceability can be posed. From the perspective of this dissertation, an interesting question is, to what extent do these disciplines provide knowledge on the usage, impacts and enablers of traceability? In the following, the domains of PDM, TQM and automatic identification and the role of traceability within these domains are briefly introduced.

2.4.1 Product data management

According to Miller et al. (1997, p. 2-6), product data includes all the data related to the products of an enterprise. Thus, traceability data can be seen as a subset of product data. Product data management¹² on the other hand, can be understood as systematic planning, control and monitoring of the product data as it flows within and among organisations (cf. Frost & Sullivan, 1990, p. I; Port, 1992, p. 64).

2.4.1.1 Product data

As traceability data is needed to enable identification of products and their origins (cf. Juran et al., 1988), the role of product data is to enable products to be made and used (Frost & Sullivan, 1990, p. i). Product data defines the company's products and the processes used to define, manufacture and support products (Engineering Data Management Newsletter, 1993a, p. 4) throughout their life cycle (Engineering Data Management Newsletter, 1993b, p. 3).

Product data consists of documents such as drawing sheets, bills of materials, specifications, cost plans, process routing sheets, reports and contracts (Frost & Sullivan, 1990, pp. i - ii). Product data in the systems can be divided into two categories: product structure and workflows. A product structure consists of part

¹² According to Miller et al. (1997, p. 1-1), a set of closely related terms is used in the field of product data management including product data management (PDM), engineering data management (EDM), engineering document management (EDM), product information management (PIM), computer integrated product and program information management (PIM), technical data management (TDM), document management and image data management. They advocate the use of the term product data management (PDM) as the overall name for the field. Also in this study, term product data management (PDM) includes the above-mentioned terms.

lists, assembly data, product configuration and bill-of-materials structures. Workflow data is used to define and implement change processes and workflows based on site-defined business rules. (Miller et al., 1997, pp. 2.12-13). Product data items can also be divided into static and dynamic objects (cf. Eloranta, 1977, p. 45). Static objects (e.g. particular bill of materials) are used and maintained in the system for relatively long periods. Dynamic objects can be created in the information system and later removed following the movements of the physical objects through the manufacturing process e.g. as triggered by a customer order. Tsao (1993) suggests that product configuration data can consist of the as-marketed, as-configured, as-designed, as-built, as-delivered and as-maintained product data. Hamer et al. (1996) propose that product data has five dimensions: version, views, hierarchy, status and variants.

2.4.1.2 Functions of product data management

According to Tsao (1993), product data management functionalities include release management, change management (i.e. management of change in the registered product datasets) and distribution of datasets. Tsao states that configuration management of product structures provides a set of functions to maintain various configurations of the product definition data. Group technology and a parts library provide a set of functions to classify and group parts to increase accessibility and reusability. Data conversion presents the requested data to the user in the proper format on the target device. Program management provides a set of functions to define the business processes and manage the project based on a given process. Decision information support functions, in contrast, facilitate making the product information readily available to support decision making. (Tsao, 1993).

According to Peltonen et al. (1996, p. 196), the domain of product data management can be divided into two areas:

- In the development processes, one develops products that are manufactured in multiple identical or individually configured copies. These processes are characterised by the need to manage the life cycles of documents and their versions.
- In the delivery processes, one manufactures and delivers a specific product according to a customer order. Delivery processes are concerned with the general and order-specific documentation needed during the delivery and the documentation delivered to customers.

Traceability appears to be needed during product delivery processes for configuration identification purposes. *Effectivity* management provides traceability of product versions when product changes take place to the custom configurations of the products. In other words, it enables identification of version and configuration at the item- or lot-level. According to Miller et al. (1997, pp. 2.12-13), *effectivity* is used to determine which part revision(s) to use when a product is assembled; in other words which revisions are 'effective' at the time of the assembly. They suggest that product structure management can support multiple *effectivity* schemes within a product structure based on serial number, date, or lot. In a similar vein, Peltonen et al. (1996, p. 202) suggest that the ability

to store each configuration separately provides traceability for the data on what kind of product was actually delivered to a customer.

2.4.2 Total Quality Management

Traceability has also to some extent been seen to be a part of total quality management (TQM). According to Hannus (1993, p. 131) and Salminen et al. (1996, p. 71) total quality management is a management philosophy that has its roots in a largely similar philosophy known as total quality control (TQC). They suggest that TQM - and TQC - is based on the ideas of Joseph M. Juran, W. Edwards Deming, Armand J. Feigenbaum and Kauro Ishikawa published in the 1950's.

According to Ishikawa (1993, pp. 90 - 91), TQC means that everyone in every division in the company must study, practice, and participate in quality control. Similarly, Jablonski (1992, p. 21) states that TQM is a co-operative form of doing business that relies on the talents and capabilities of both labour and management to continually improve quality and productivity using teams. Ho (1995) suggests that the TQM philosophy provides the overall concept that fosters continuous improvement in an organisation. This philosophy stresses a systematic, integrated, consistent, organisation-wide perspective involving everyone and everything.

The process of continuous improvement is described (see e.g. Juran et al., 1980; Deming, 1994, pp. 131 - 133) as a cycle of learning and improving a product or a process. This process can be divided into four steps:

1. Plan: An idea for improvement of a product or a process is planned, leading to a plan for testing, comparison, and experimentation.
2. Do: Tests are carried out according to the layout decided in Step 1.
3. Study: The results of the test are studied in order to find out whether they correspond with hopes and expectations.
4. Act: The change is adopted.

In a similar way, Oakland (1993, p. 134) divides the process of preventive quality management into four steps. There, data is collected and analysed, major quality problems and causes are identified, the elimination of causes is planned and corrective actions are implemented. TQM literature, which emphasises statistical methods in quality improvement (see e.g. Ishikawa, 1993, pp. 197 - 205; Juran et al., 1980) appears to see traceability as a part of this data collection and feedback mechanism and thus as a requirement for a quality system (see e.g. Oakland, 1993, pp. 106 - 118; see also, European Standard EN ISO 9001, 1994). Mahoney et al. (p. 190), for example, underline that a central element in these processes is having organisational mechanisms for tapping and tracking information, followed by an organisational response. According to Juran et al. (1980, p. 270) traceability can simplify investigation of product failures. Oakland (1993, p. 112) states that identification and traceability of purchased materials and services are essential if effective methods of process control are to be applied and quality problems are to be related to cause. Lack of a sufficient

system (cf. Oakland et al., 1994, p. 78) can prevent the prompting of effective corrective action. Wall (1993b, p. 37) emphasises the importance of a clear, detailed picture of performance at every stage of the material flow processes in order to make quality improvement a practical reality. He continues that accurately tracing product flow through the process can produce the majority of TQM's practical benefits. Collected data provides the ability to track back an order and to inspect its progress from raw materials to delivery. In the event of a customer complaint, this data can be used to respond to the customer and to ensure that the mistake does not happen again. The source of error and the process stage at which the error occurred can be pinpointed.

2.4.3 Automatic identification

According to Adams (1990, p. ix) automatic identification techniques and data collection encompasses a wide range of technologies that have automation of data entry processes as their purpose. The primary benefits from automatic identification systems are accurate information, timeliness of data availability through the possibility of on-line data collection and cost reductions through automation of manual data entry. (see e.g. Adams, 1990; Sharp, 1990).

Multiple technologies used in automatic identification can be identified in the literature. These include bar codes, optical character recognition, vision systems, voice recognition, radio frequency tagging, magnetic stripes, touch screens and light pens (see e.g. Adams, 1990; Sharp, 1990, pp. 11 - 36).

Automatic identification technologies have begun in the material handling industries. Here there is a need to understand what material you have, where it is, where it came from, and where it is going. In the manufacturing area, automatic identification can be used to support material control procedures that move raw materials from the receiving dock to the manufacturing plant, to control work in process on the plant floor and to support quality-control applications. Other application areas of automatic identification are asset management, health care, personnel management and documentation tracking (Sharp, 1990).

Many of the applications of traceability discussed in Section 2.1 appear in the literature as examples of the use of automatic identification. Bar-codes and radio frequency tagging are being used in a wide range of material flow traceability applications like package (Williams, pp. 22 - 23, 1997) and livestock (Armstrong-Smith et al. 1997, p. 31) tracking. Sharp (1990) highlights the importance of automatic identification for traceability by stating that without an automatic identification system, it would be very difficult to enter the overnight package business.

2.4.4 Discussion

Although traceability plays a role in product data management, total quality management and automatic identification literature, the writings under these headings seem to provide limited help for understanding traceability.

Although traceability is often seen as a part of product data management, there seems to be a disparity in the focus areas of product data management and traceability literature. The focus of PDM literature is in the management of design data in the product development and manufacturing processes at the product or product version level. On the other hand, in the field of traceability, product development processes have no significant role. Here, the focus is on identifying individual items and lots in the material flow. Traceability discusses both tangible and intangible properties of the items such as 'has an item been stolen?' Many of these attributes fall beyond the scope of PDM. To summarise, the focus of PDM literature seems to be on the management of static, product-level data in product development and manufacturing processes rather than in the dynamic data that is connected to individual items and lots and created during the delivery processes. From the perspective of product data management, traceability could actually be seen as a tool that enables linking product data as well as other data to physical items.

In the total quality management literature, traceability is portrayed as a data collection and feedback mechanism that is used in continuous improvement. This mechanism connects product-specific failure data with the factors underlying the failures.

In contrast, in the automatic identification literature, automatic identification is seen as an enabler of traceability or somewhat differently, traceability is seen as an important application area for automatic identification.

Although traceability has its place in PDM, TQM and automatic identification literature, the role of traceability in these domains seems to be limited, as they cover only a small part of the range of issues that can be identified in the field of traceability. It is valid to state that traceability in its fullest meaning is not covered by any of these domains. Consequently, neither can the knowledge available in these domains be directly applied to the field of traceability.

2.5 Conclusions

This dissertation began with a definition of traceability. Juran et al. (1988) defined traceability as the ability to preserve the identity of the product and Jönson (1988, p. 16) defined it as the 'possibility to trace the history and the usage of a product and to locate it by using documented identification'.

The need for annotations to these definitions of traceability arose as a result of the literature review. First, the meaning of the word 'product' is ambiguous and needs to be clarified. As suggested by Florence et al., traceability is the ability to trace raw materials through the manufacturing process to the finished product, from producer to final consumer throughout the supply chain. Florence et al. continue that traceability is also the ability to trace whatever enclosure the item is contained in (e.g. carton, outer pallet) and to trace and track the vehicles of movement used in logistics, such as forklifts and lorries (Florence et al., 1993, p. 6). In the express delivery industry, the object being traced is a parcel and the enclosure the parcel is contained in. This means that not only products are being

traced, but also other physical objects in the supply chain. Thus, referring to 'physical supply chain object' seems to be more appropriate than the use of word 'product'.

Secondly, the scope of the data understood as traceability data seems to require clarification. Where Juran (1988) discusses the identity of a product, Jönson (1988, p. 16) refers to the history, usage and location of a product. In the writings on traceability, traceability data appears to be understood implicitly as all the data specific to an individual item or lot, covering the identity and the attributes of the objects. Thus, the definitions covering 'identity' or 'history, usage and location' can give a limited picture of the scope of the traceability data. Instead, the definition should cover both the 'identity' and the 'attributes' of the object.

Thirdly, 'preserving' the data - as defined by Juran - alone does not enable traceability. In traceability, equally important to the 'preservation' of data can be the 'ability to access' the information.

In summary, it can be stated that:

'Traceability is the ability to preserve and access the identity and attributes of a physical supply chain's objects.'

The presentation of data is not relevant in determining whether the data in question is - or is not - traceability data. Frequently, an identification number is marked on the traced object. Using the identification number, object-specific attribute data can be retrieved from distinct records organised according to the identification number. However, distinct records are not necessarily needed in the identification. Traceability data can also be encoded in the item's identification number, stored in a radio frequency tag that accompanies the traced object, or marked directly in human readable format on the object (see e.g. Steele, 1995, p. 54).

As discussed earlier, the definition of traceability data to some extent overlaps the definition of product data. However, traceability data is limited to that data which is specific to individual objects or lots. This means that the data common to all products or objects of a certain type is not a part of traceability data. Moreover, traceability data covers both static and dynamic data specific to individual items as the focus of product data in its traditional meaning is on static data.

Traceability is needed when the supply chain objects are not identical, i.e. there are differences in the characteristics of the individual objects, which need to be identified and managed. Traceability is enabled by data that is specific to individual traced objects or groups of objects.

By studying the literature, it becomes apparent that the use of traceability data is not limited to crisis situations, where defective products need to be identified

and recalled, and situations where evidence needs to be provided. The literature also identifies a number of examples of the possibilities to use traceability data in logistics, quality, security, accounting and after-sales applications. Moreover, it is apparent that the use of traceability data is not only limited to identification of the characteristics of individual items. This data can also be consolidated and used in various analyses, where the characteristics of individual items are not of interest. For example, data specific to a large number of items can be used e.g. for measuring lead-times.

A number of benefits which can be obtained by using traceability data can be identified in the literature. However, there is no comprehensive presentation of the benefits available. The same problem is apparent throughout the traceability literature. A comprehensive presentation of the enablers for successful utilisation of traceability data as well as the possibilities for the use of traceability data is missing.

Little help is provided by the related literature. It was observed that the domains associated with traceability, i.e. PDM, TQM and automatic identification, provide a narrow understanding on the usage, impacts and enablers of traceability. Although these domains discuss issues related to traceability, the discussion covers only a limited part of the field of traceability. Due to the differences in the focus areas of these disciplines and traceability, traceability can be considered as an independent discipline rather than as a part of any of these disciplines.

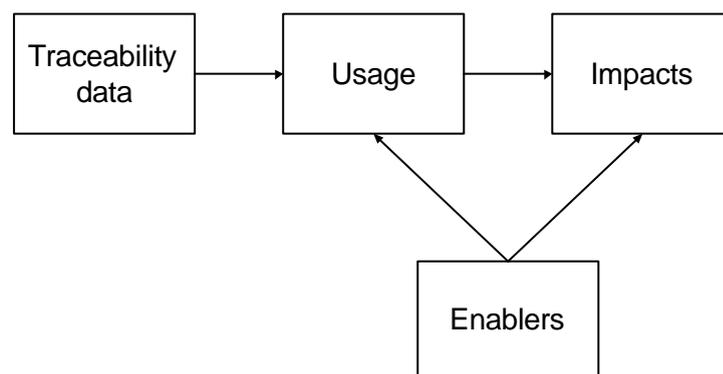
3. RESEARCH DESIGN

3.1 Research questions

As observed in the literature review, the existing body of knowledge in the field of traceability is limited. The information available is largely anecdotal and superficial in nature. Even the fundamental questions - why products are traced, how traceability data can be applied, what impacts and benefits are provided by the use of traceability data and what factors that enable realising these benefits - remain unanswered. The aim of this study is to fill in these gaps in understanding. More specifically, this study investigates:

1. How is traceability data used in business enterprises?
2. What are the impacts and benefits of using traceability data?
3. What factors enable a business enterprise to fully realise the positive impacts of traceability data?

Figure 1: The focus area of the research.



To some extent, this study has shed light on these questions by drawing together and exploring the existing body of knowledge. However, the ability of these anecdotes - in most of the cases lacking a scientific perspective - to provide reliable and valid answers to the research questions is uncertain.

3.2 Methodology

This research is inductive. It uses a case study research methodology. According to Roethlisberger (1977), case study research is particularly appropriate for problems in which research and theory are in their early, formative stages. Case study research studies independent and dependent variables in their natural context; no control or manipulation is involved (Benbasat et al, 1987, p. 370). Benbasat et al. further suggest that a case study research strategy is well suited to capturing the knowledge of practitioners and developing theories from it. The role of the scientists is to formalise this knowledge and proceed to a testing phase. Yin (1989, p. 13) advocates the use

of case studies as the strategy when “how” and “why” questions are being posed, when the investigator has little control over the events, and when the focus is on a contemporary phenomenon within some real-life context.

Case study research suits the nature of this research. The existing body of scientific knowledge in the field of traceability is scarce. How and why questions are posed to understand the mechanisms behind relationships. The researcher has little control over the events. Alternatively, a survey could have been used as a research method. However, with a survey - as suggested by Hartley (1993, p. 212) - finding processes underlying correlations could have been difficult, although associations between variables could have been found.

Eisenhardt (1989, pp. 546 - 547) lists the strengths of case study research:

1. Theory building from cases has a likelihood of generating novel theory. Creative insight often arises from juxtaposition of contradictory or paradoxical evidence. The constant juxtaposition of conflicting realities tends to ‘unfreeze’ thinking, and so the process has the potential to generate theory with less researcher bias than theory built from incremental studies or armchair, axiomatic deduction.
2. The emergent theory is likely to be testable with constructs that can be readily measured and hypotheses that can be proven false. Measurable constructs are likely because they have already been measured during the theory-building process. The resulting hypotheses are likely to be verifiable for the same reason.
3. The resultant theory is likely to be empirically valid. The likelihood of valid theory is high because the theory-building process is so intimately tied with evidence that it is very likely that the resultant theory will be consistent with empirical observation.

She suggests that some characteristics of theory building from case studies lead to weaknesses:

1. Intensive use of empirical evidence can yield theory which is overly complex. There is a temptation to build theory which tries to capture everything. The result can be theory which is very rich in detail, but lacks the simplicity of overall perspective.
2. Building theory from cases may result in narrow and idiosyncratic theory. The risks are that the theory describes a very idiosyncratic phenomenon or that the theorist is unable to raise the level of generality of the theory.

3.2.1 Case study company selection

Eisenhardt (1989, p. 537) suggests that while the cases may be chosen randomly, random selection is neither necessary nor even preferable. According to Pettigrew (1988), it makes sense to choose cases such as extreme situations and polar types in which the process of interest is ‘transparently observable’.

In this study, the case study companies were selected from five distinct industries considered to be strategically positioned in the field of traceability.

1. The food industry was selected because traceability has an important role in this industry due to the safety-critical nature of the products.
2. The pharmaceuticals industry was also taken into the case study due to the safety-critical nature of the products. However, here the role of traceability differs from the food industry due to the strict traceability requirements imposed by the authorities.
3. The electronics industry was selected because the mixture of complex and valuable products together with lack of authority requirements provides an opportunity for gaining insights into largely 'voluntary' use of traceability.
4. The automobile industry, with safety-critical, complex, diverse and valuable products, was selected due to the acknowledged importance of traceability in the industry.
5. The transportation industry was included in the study to enrich the understanding of the role of traceability in the field of logistics. Moreover, the innovative use of traceability data in the transportation industry was acknowledged when the selection was made.

The selected case study companies are shortly introduced in the following:

Company Alpha operates in the electronics industry. Organisationally, it is a part of Corporation Alpha's operations in Europe. The company manufactures electronics products for both business and private use. The products are approaching maturity. Traceability at Company Alpha is based on internal needs. There are no direct external traceability requirements. Traceability activities were started in 1992.

Company Beta is one of the main subsidiaries of an international corporation (hereafter Corporation Beta), which operates in the electronics industry. Company Beta manufactures consumer electronics products sold in over 100 countries. In terms of product life cycle, Company Beta's products are in a growth phase. Product traceability is mainly voluntary, although there are some customer requirements. On some level, products have been traced since the latter half of the 1980s.

Table 1: Case study companies.

Company	Industry	Type of operations	Turnover - range, FIMM 1000
Company Alpha	Electronics	Discrete manufacturing	1 - 10
Company Beta	Electronics	Discrete manufacturing	> 10
Company Gamma	Electronics	Discrete manufacturing	1 - 10
Company Delta	Transportation	Transportation	> 10
Company Epsilon	Transportation	Transportation	1 - 10
Company Kappa	Food	Process industry	< 1
Company Lambda	Pharmaceuticals	Process industry	1 - 10
Company Sigma	Automobile	Discrete manufacturing	> 10
Company Tau	Automobile	Discrete manufacturing	< 1

Company Gamma is an electronics company and a major subsidiary of an international corporation, hereafter Corporation Gamma. The focus of Company Gamma's operations is in the European countries. Company Gamma manufactures consumer electronics products, the life cycle of which has already reached and passed maturity. Traceability, which is undertaken on voluntary basis as a result of internal needs, was started in 1992.

Company Delta is an international package and letter distribution company operating in over 200 countries. The company is known for its advanced traceability systems. Shipment traceability has on some level always been a part of Company Delta's operations since the company was established. Internal needs and market requirements are the main reasons for tracing the shipments.

Company Epsilon is a subsidiary of the Epsilon Group, which operates in the communications market. Company Epsilon operates domestically in the messaging and small goods transport market. Shipments are traced mainly due to internal needs and market pressure. On some level, traceability has always been a part of the operations of Company Epsilon. The first computerised traceability system was initiated in 1997.

Company Kappa is one of the subsidiaries of Kappa Corporation, which operates in the food industry. Although some regulatory requirements for traceability exist, tracing activities are mainly undertaken due to internal needs. Company Kappa's product range includes baby food products and confections. Baby food is considered to be safety-critical and require high level of traceability, while, the role of confection traceability is not considered to be as critical.

Company Lambda is one of the main subsidiaries of Lambda Group. It manufactures pharmaceutical products. In addition to Company Lambda, the case study includes Lambda Distribution, the subsidiary of Lambda Group that distributes the products manufactured by Company Lambda. Traceability activities are characterised by mandatory and detailed authority and customer requirements. Traceability in its current form was initiated in the 1970s.

Company Sigma is the Automobile Division of Group Sigma. It is the largest division of the group and contributes more than half of its sales revenues. In 1995 Group Sigma was among the ten largest automobile manufacturers in the world.

Product traceability was initiated in 1990. The need for traceability is largely a consequence of the safety-critical nature of the products.

Company Tau is a subsidiary of a Tau Corporation, which operates in the metal industry. Company Tau specialises in producing small volumes of high-end automobiles for OEM¹³ customers. The products, which are considered to be safety-critical in nature, have been traced since the mid-1970s. The level of traceability is largely defined by customer requirements.

Nine case study companies were selected, two to three companies from each industry¹⁴, to enable the findings to be replicated within each industry. A single-case research methodology was not selected, because it would only have allowed limited generalisation of the results. According to Lee (1989, p. 41), the emergent theory would be generalisable to other settings only on the basis of actually being confirmed by additional case studies. A multiple-case study research methodology was chosen because it allows some generalisation although not statistically measurable results. In comparison to a survey with a high number of observations, multiple-case study still enables building of an in-depth understanding of traceability within the case companies. This was acknowledged to be necessary, as traceability can be considered to be a new research area. Still, with nine case studies, the magnitude of the effort required remained manageable for a single researcher.

3.2.2 Information collection

After the target industries and prospective companies within each industry were selected, the companies were contacted. The majority of the companies were approached through contacts of advocates of the research. In each company, the contacted persons, who were of adequately high rank, then arranged the contacts with the persons involved with traceability. One of the organisations declined to participate in the study.

Data collection started at Company Alpha. The company was used as a pilot case, in which the data collection approach was tested. Based on these experiences, the questions and the research approach were adjusted. Otherwise, a similar approach was used in all of the case companies.

Yin (1984, p. 78) identifies several sources of evidence that are suitable for case study research:

1. Documentation: written material, ranging from memoranda to newspaper clippings to formal reports.
2. Archival records: organisation charts; service, personnel or financial records.
3. Interviews
4. Direct observation: absorbing and noting details, actions, or subtleties of the field environment

¹³ Original equipment manufacturer

¹⁴ The number of cases from both food and drug industry was one. However, from traceability perspective, these industries are largely similar.

5. Physical artifacts: devices, outputs, tools.

Interviews were the primary method of data collection in this research. A questionnaire¹⁵ containing open-ended questions was used as a discussion framework in the interviews. The questionnaire was followed only to the extent it was reasonable, while still maintaining a basic similarity in the contents of all the interviews. When necessary, questions were adapted to the varying circumstances in the case study companies to keep the questions meaningful and when theoretically interesting issues that required deeper understanding emerged in the parallel data analysis. Moreover, as issues of special interest emerged during the study, the opportunity to drill down to these issues was taken. Eisenhardt (1989, p. 539) advocates flexible data collection. She suggests that a key feature of theory-building case research is the freedom to make adjustments during the data collection process. These adjustments can be the addition of cases to probe particular themes which emerge.

Often the interviewees were not able to answer the interview questions themselves. In these occasions, the data obtained in the interviews was complemented afterwards. The interviewees discussed the unanswered questions with their colleagues and delivered written answers after the discussions. When it was possible, the data collected in the interviews was complemented with observations made of actual implementation of traceability data collection and usage by actually walking on the shop floor to see how things happen. Furthermore, when available, traceability-related documentation specifying the traceability requirements, traceability policy and systems, investment appraisals, newspaper clippings and reports created using traceability data was used.

Table 2: Information sources in the case study companies.

Company	Information sources
Company Alpha	Interviews, documentation, observations
Company Beta	Interviews, documentation, observations
Company Gamma	Interviews
Company Delta	Interviews, documentation, observations
Company Epsilon	Interviews, documentation, observations
Company Kappa	Interviews, documentation
Company Lambda	Interviews, documentation on external requirements
Company Sigma	Interviews, documentation
Company Tau	Interviews, documentation, observations

To ensure as open an attitude to the research as possible, it was emphasised to the interviewees that the companies will appear anonymously in the research. The interviews were not tape-recorded. Written notes were prepared during each interview as the interview proceeded. After the interviews, descriptions were written describing the findings in each company. The description was complemented with additional interviews that were carried out in the company. A second interview round was undertaken approximately one year after the first round. It aimed at obtaining supplementary information in the areas that

¹⁵ An outline of the interview questions is presented in Appendix 2.

appeared to be theoretically interesting in the preliminary analysis and to discuss the development of traceability after the first interview round. During the writing process, interviewees were occasionally contacted to check the accuracy of the data. Moreover, the key informants in each of the case study companies reviewed the case descriptions.

Interviews were undertaken between January 1996 and July 1997. The first interview round started in January 1996 and was concluded in June 1996. The second interview round was carried out between May and July, 1997.

3.2.3 Data analysis

Data analysis comprised of two phases, within-case and cross-case analysis. According to Eisenhardt (1989, p. 540), the overall idea of within-case analysis is to become intimately familiar with each case as a stand-alone entity. Within-case analysis was carried out by describing the findings in each case study company.

In the within-case analysis, the traceability situation was separately described in each of the case study companies. These descriptions illustrated the organisational and technical settings, where traceability data was used. Moreover, the applications in which traceability data was used, the process of using traceability data and the impacts of data usage were described.

In the cross-case analysis, each of the research questions was separately studied. The cross-case analysis of the usage of traceability data was started by examining the characteristics of the applications observed in the within-case analysis. Applications with similar characteristics were then categorised to four main categories with sub-classes. The characteristics used as the basis of the categorisation were the input and output data used and the purpose of the application. The analysis was completed by drawing a synthesis of the way traceability data was used in each of the main categories.

Cross-case analysis of the impacts and benefits of traceability data was based on the application categories observed in the analysis of the usage of traceability data. The analysis aimed first at identifying the impacts and benefits of using traceability data separately within each application category and was completed by drawing a synthesis across application categories. The impact analysis was descriptive. The financial outcome of using traceability data was not quantified.

The factors enabling the case study companies to realise the positive impacts of traceability data were also studied using the same application categorisation as observed in the usage analysis. The analysis was undertaken from two perspectives. First, the dynamics underlying the relationship between traceability data and impacts of traceability data were analysed. The analysis was carried out by examining the process of using traceability data, the impact of differences in these processes on the impacts and benefits provided by the traceability data, and the factors underlying the differences in the data usage process. However, it

became evident that the analysis of the usage process alone does not explain the factors underlying the usage and resultant impacts of traceability data, as this approach emphasises the situations where traceability data is already used. Thus the analysis of the usage process was complemented with an analysis connecting organisational settings with the usage situation measured in terms of the existence and scope of traceability applications.

3.3 Reliability and validity

Validity and reliability was ensured with the actions summarised in **Error! Reference source not found.**

Table 3: Validity and reliability in the research.

Test	Methods to ensure validity
Construct validity	<ul style="list-style-type: none"> • Multiple sources of evidence • Review of the case description by key informant
Internal validity	<ul style="list-style-type: none"> • Within case analysis and pattern search between cases • Search of evidence for 'why' behind relationships
External validity	<ul style="list-style-type: none"> • Case selection • Multiple-case study
Reliability	<ul style="list-style-type: none"> • Case-study protocol • Case-study database

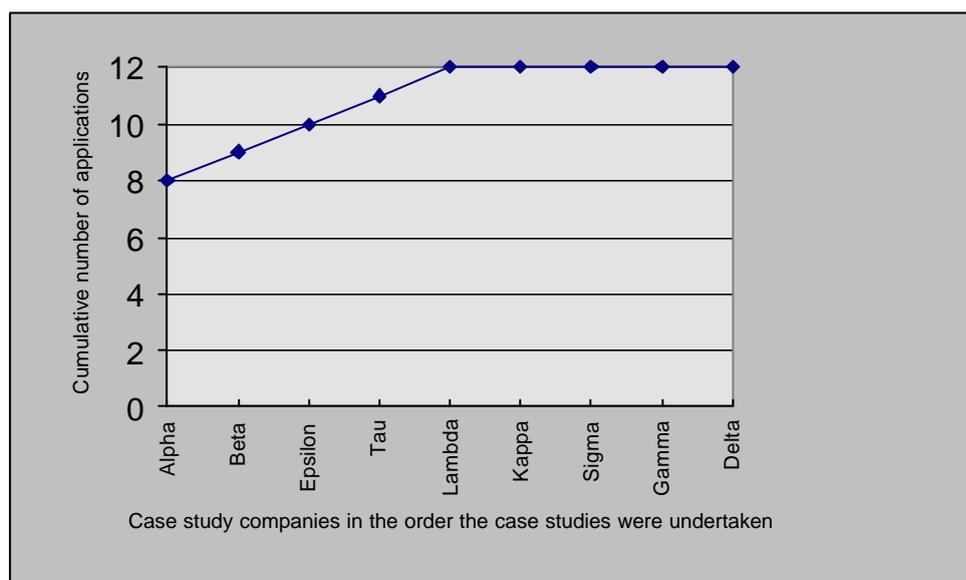
Construct validity was ensured by using multiple data collection methods, such as interview data, observational data, the case study companies' documents and specifications, and documents describing external traceability requirements. According to Eisenhardt (1989), the triangulation made possible by multiple data collection methods provides stronger substantiation of constructs and hypotheses. The case descriptions written by the researcher were reviewed by the key informants in the case study companies to ensure their accuracy. Moreover, the case descriptions were compared with available documentation originating from the case study companies.

Internal validity was ensured by within-case analysis and searching for patterns across cases. Mentzer et al. (1997) suggest that the explanatory data in the case studies can be an integral part of establishing internal validity by providing the insight necessary to clarify causal relationships. Descriptive data was used in the research to provide understanding of the factors underlying the observed relationships. According to Eisenhardt, this is crucial to the establishment of internal validity (Eisenhardt, 1989, p. 542).

The case study companies were selected through theoretical sampling, not randomly. The case study companies were chosen from industries where the role of traceability was considered to be scientifically interesting. According to Eisenhardt, theoretical sampling focuses efforts on theoretically useful cases, i.e. those that replicate or extend theory by filling in conceptual categories. Further, she recommends that the number of cases should be between four and ten. She suggests that with fewer than four cases, the empirical grounding of the generated theory is likely to be unconvincing unless the case has several mini-cases within it. With more than ten cases, she sees the risk of complexity and

too large a volume of data. According to her, the researchers should stop adding cases when theoretical saturation¹⁶ is reached. (Eisenhardt, 1989, pp. 533 - 545). In this research, incremental learning started to reduce after the first five cases. For example, as demonstrated by Figure 2, all of the application categories observed in this case study were already identified after the first five case studies. Adding cases was brought to an end when the number of cases was nine. At this point, incremental learning was clearly minimal.

Figure 2: Cumulative number of traceability applications categories observed in the case study companies after each case study.



Mentzer et al. (1997, pp. 199-216) define reliability as 'how consistently the measures yield the same results through multiple applications.' The reliability of the case study research was improved by using the same case study protocol in all of the companies. A case study database consisting of detailed written notes on interviews and observations, written answers to interview questions and documentation acquired from the case study companies was established.

However, there were limitations in this research. It was conducted by single researcher, which bears a risk of bias. The possibility of this risk was acknowledged and an attempt was made to avoid it.

Another shortcoming was related to the lack of quantitative data. The observed benefits of traceability were largely qualitative. Quantitative data on the impacts and benefits of using traceability data and associated costs was often not available. Thus, it was not possible to analyse the monetary impact of using traceability data on company performance. Nevertheless, it was still possible to identify the direction of the impacts and benefits obtained using traceability data.

¹⁶ Glaser and Strauss (1967) define theoretical saturation as the point at which the incremental learning is minimal because the researchers are observing phenomena seen before.

4. CASE DESCRIPTIONS

In this chapter, the case study companies are introduced and the traceability situation in each company is described. The description includes a presentation on the development of traceability in the company and its organisational and technical settings. Furthermore, a brief description of the use of traceability data is provided. However, a *detailed description of the usage of the data is presented in Appendix 8.1.*

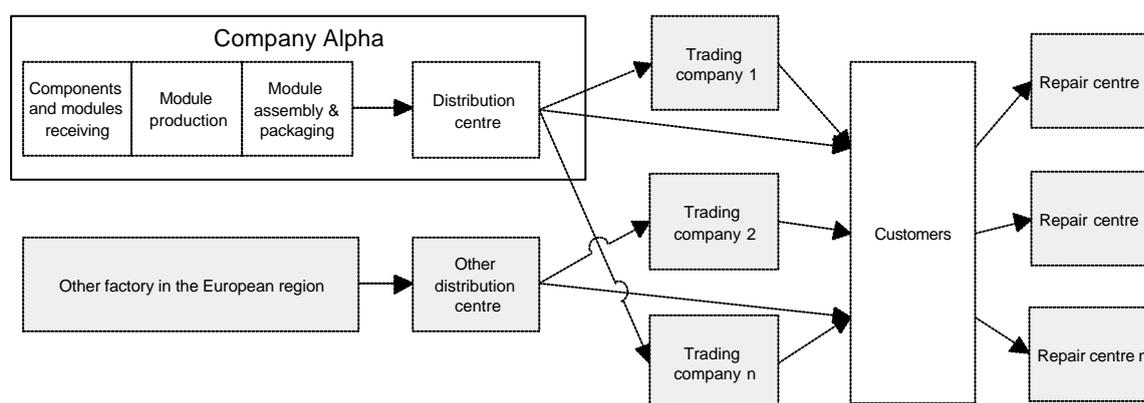
4.1 Company Alpha

The target company, Company Alpha, is a part of Alpha Corporation, and more specifically, part of its personal computer operations on European region. Alpha Corporation, a global company operating in the electronics industry, was among the International Fortune 500 companies in 1995.

Company Alpha is a legal entity that centres around a manufacturing site with manufacturing and distribution operations. In 1995, the turnover of Company Alpha was over FIMM 3 000. The average price of a personal computer was slightly under FIM 10 000. At the same time, the number of products manufactured was 350 000.

In addition to Company Alpha, Corporation Alpha's personal computer operations in European region include another manufacturing site, a network of distribution centres and trading companies, and internal and external service centres. The scope of this case study extends to these units to the extent needed to understand the use of traceability throughout the material flow.

Figure 3: Company Alpha and Corporation Alpha's personal computer operations in Europe.



Company Alpha's manufacturing operations were divided into two parts: mother board manufacturing and computer assembly. In computer assembly, products were assembled to customer order. The products were modular and they were configured according to customer specifications. There was a set of options

among which the customer could specify the configuration of the product. Excluding the mother boards, the modules and accessories were out-sourced.

4.1.1 Organisational setting

At Company Alpha, i.e. in the focus manufacturing site, traceability was managed at the site level. On the regional level, both of the manufacturing sites and each of the trading companies and service centres developed traceability locally. However, International Technical Support (ITS) of Corporation Alpha's European region had increasingly started to co-ordinate the development of traceability on regional level across the unit boundaries. From the perspective of Company Alpha, this has most notably affected information sharing between Company Alpha and the service centres in the form of delivery of warranty data from the manufacturing site to the service centres and quality feedback data from the service centres to the manufacturing site.

External requirements had not played a major role in the development of traceability. There were no authority requirements related to traceability. Moreover, the fact that Company Alpha did not have major exports to the USA had reduced the magnitude of product liability risks and thus the importance of managing the risk with traceability data. Nevertheless, there were some customer requirements. Some major customers specified the approved manufacturers of certain modules used, which indirectly set requirements for module traceability.

4.1.2 Technical setting and development of traceability

The first initiatives to implement traceability in Company Alpha were made in the end of 1980s. There were internal needs to control module assembly and packing quality, to trace products within the manufacturing process and to use process data in quality improvement.

The first project to implement traceability was started in 1992 and completed in two phases during 1993 and 1994. The project was managed at the site level by Company Alpha's quality department. The planning was carried out by a cross-functional team.

In the first phase of the project, several control-point-specific, stand-alone traceability databases were set up. The chain of control points covered the material flow from materials receiving through the manufacturing process to shipping. In the second phase, Company Alpha established a central traceability database, which received data from the stand-alone databases. The data having site-level relevance was delivered to this database. The reason why the central database was set up was to provide transparency to the entire material flow within the site.

As a part of the project, Company Alpha co-operated with the independently managed trading companies to get the logistics information system in each trading company modified to support traceability. Implementation of traceability functionalities within the trading companies' logistics information systems was

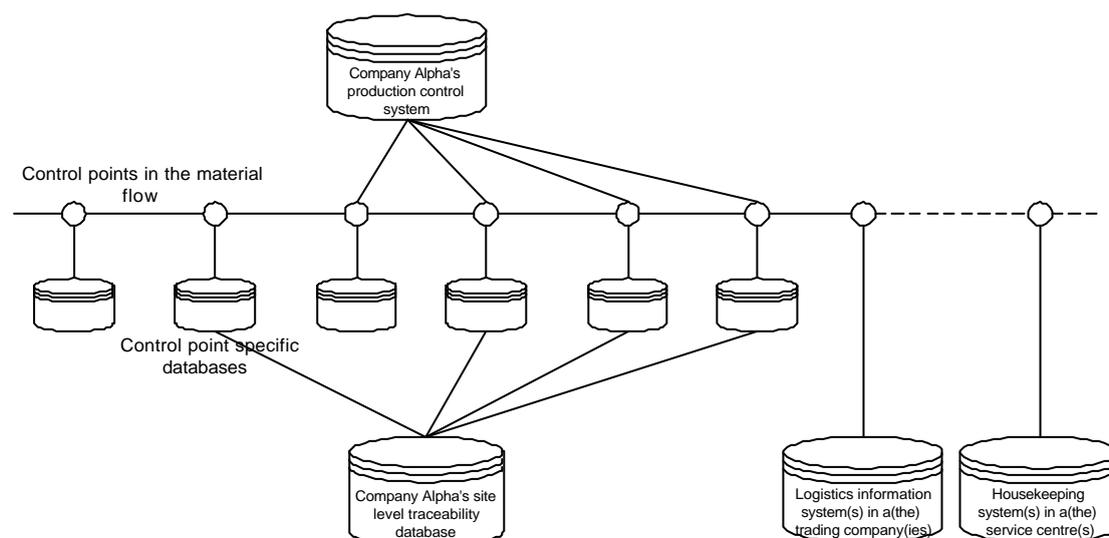
considered to be natural, because the traceability data collection was closely tied with the other data collection activities.

In 1995, a second project to improve Company Alpha's traceability systems was started. The project principally aimed at improving accessibility to the traceability data. As a result of the previous project, the data was only accessible on the shop floor. According to a consultant participating in the project, this was acknowledged as a clear shortcoming. 'Even the people working in the adjacent office building did not have access to the data.' During the 1995 project, the control-point-specific traceability systems were reprogrammed. Real-time links from certain traceability data collection points to the production control system were created. The database system used in the central traceability database was replaced with a new one. It enabled the company's other units and external service centres to access the data through the Internet. Moreover, new control points collecting traceability data were set up. The project was completed in May 1997.

The project manager in charge of traceability at the focus manufacturing site suggested that the control-point-specific databases communicating with the site's central traceability database were set up due to technical limitations in the 1992 - 1994 project. He stated that if the system would now be created from the clean slate, the control-point-specific databases would not be set up. Instead, the control points would be directly linked to site-level traceability database.

Each of the trading companies and service centres and the other manufacturing site within the same regional organisation had developed traceability locally. Each of these units had a distinct traceability system. In comparison to Company Alpha, the level of traceability was less elaborate in the other units.

Figure 4: Material flow and the traceability information systems.



4.1.3 Use of traceability data

Traceability data was principally used in applications related to product quality management. In module assembly and packaging phases, traceability data was used to prevent incorrect modules and accessories from being put in the products and product packages. In the event of a quality problem, traceability data was used to segregate and locate the products affected by the problem. Moreover, analysis were carried out using traceability data in order to provide information needed in product quality improvement. In a similar fashion, traceability data was used to support lead-time measurements and employee performance measurement for an employee reward system.

Traceability data was also used to provide status information on customer orders. Moreover, in the event of customer order cancellation, traceability data was used to identify and locate the products affected by the cancellation from the material flow.

There were also other uses of traceability data. These included providing proof of quality information for answering customer complaints, and information needed in warranty status verifications and crime investigations.

4.1.4 Future plans

According to the project manager in charge of traceability at Company Alpha, the region level priority in the near future was to upgrade the level of traceability in the other manufacturing site to the same level as existed in Company Alpha's manufacturing site. This could be followed by some form of integration of traceability systems in the region. The project manager suggested that systems integration would improve visibility through the delivery chain and speed up tracing activities. Moreover, systems integration was considered to reduce effort in data collection by eliminating the need for duplicate data entry.

4.2 Company Beta

The target company, hereafter Company Beta, is a subsidiary of an international corporation (hereafter Corporation Beta), which operates in the electronics industry. Company Beta, which operates in the consumer electronics industry, has 12 000 employees working in approximately forty countries. In 1996, the turnover of the company exceeded USDM 4 000. The products of the company were sold in over a hundred countries. The number of products sold annually was counted in millions of pieces.

Globally, Company Beta has some ten factories and ten distribution centres, and a network of sales companies and internal and external service centres. Products are delivered from the manufacturing units to the trade customers through one or several distribution centres and sales companies. Lately, the role of the sales companies in the distribution process has been decreasing. Although the scope of this case study covers traceability within the entire company, one manufacturing centre, one distribution centre and one service centre are selected as the focus of the study.

4.2.1 Organisational setting

Until 1997, the predominant approach in the management of traceability at Company Beta was functional. In the manufacturing function, the development of traceability had been centralised in functional development teams, which had developed common solutions for all of the manufacturing centres. In the distribution centre area, development was largely and increasingly centralised, although some of the distribution centres developed traceability independently. Various sales companies and the service centres had been relatively independent in the management of traceability. There had been no efforts to develop traceability centrally in these units. In the service centre selected as the focus service centre in this case study, it was emphasised that there was no dedicated owner of traceability. Issues related to traceability were managed as a part of other activities.

However, in some areas of traceability, cross-functional co-ordination was observed. Policies defining requirements for the collection of the data needed in product liability loss control and recalls had been centrally specified. Actual collection of the data was nevertheless functionally implemented. Moreover, company-wide warranty and legal-status verification applications had been set up with application-specific ownership as a result of cross-functional co-operation.

In 1997, at the time this case study was concluded, the ownership of traceability was being centralised.

External requirements have had an important role in Company Beta's traceability. Type-approval authorities have set requirements for the serial numbering of the products. Product liability legislation has indirectly affected the level of traceability throughout the company. Increasingly, customer and internal business requirements have started to play an important role in the field of traceability.

4.2.2 Technical setting and development of traceability

In the manufacturing centres, product tracing was started as a result of type approval requirements. To obtain a type approval, the company needed to be able to reliably control the allocation of product serial numbers. In addition to type approval requirements, product liability loss control required the storage of information on manufactured products and their test results. Traceability functionalities in the manufacturing units had been implemented in a tailor-made Manufacturing Test System, a system used by the test department. An installation of this system was being used in all of the manufacturing centres.

In the focus distribution centre, the first traceability functionalities were implemented in the latter half of the 1980s. Traceability data was needed to locate products in the inventory and to enable delivery of products according to the first-in-first-out principle. Registration of shipment destination information was introduced when customers started to require delivery of serial number data

with the shipments. In 1994, shipment data started to be used in warranty status verification.

The traceability information system in which distribution centre traceability functionalities were implemented was a tailor-made system. An installation of this system was used in the majority of the other distribution centres in addition to the focus distribution centre. This system was parallel to various warehouse management systems in different distribution centres, and its coverage included the material flow within the distribution centre.

Unlike the manufacturing and distribution centres, the level of traceability in the service centres varied. In the focus service centre, traceability functionalities were implemented as a part of the local housekeeping system, which was a commercial software tailored to meet the requirements of Company Beta. Part of the traceability data was maintained on Excel sheets due to technical problems in the local housekeeping system. Moreover, test result data was maintained in a distinct test system.

In addition to the functional traceability systems, subject-area databases were established to manage warranty and legal status data on a company-wide basis. A regional warranty system was established in 1997, after the service function had approached the parties controlling the distribution centre data to request making it available to the service centres. The legal-status verification application, which was integrated with the warranty-status verification application, was in the ownership of security department.

4.2.3 Use of traceability data

Company Beta primarily used traceability data to manage problem situations. In the event of quality problem, traceability data could be used to segregate the defective products and to locate them internally and particularly, to identify the destinations to which these products had been delivered. Moreover, the data could be used in the event of product liability claim to provide defence evidence.

The focus manufacturing centre used traceability data locally in detecting errors in the manufacturing process. Moreover, the data was used in quality and process improvement. More specifically, the use of data aimed at providing an early indication of the need for tuning equipment calibration.

In the focus service centre, internally collected traceability data was mainly used in managing the products to be repaired at the customer level and providing repair status information for the customers. Additionally, the warranty data collected in the distribution centres was used in warranty status verification.

Additionally, traceability data was used in measuring lead-time, identifying fraud and supporting investigations related to fraud.

4.2.4 Future plans

In 1997, at the time the case study was completed, Company Beta had two information system projects in the field of traceability. As a result of customer requirements for better change management and version control, a new traceability system for manufacturing area was being established by the manufacturing function. This system was planned to be used in all of the manufacturing centres. As well as fulfilling customer requirements, internal needs related to traceability in the manufacturing area were taken into account. In addition to the traceability system in the manufacturing area, the search for system solutions supporting traceability on a company level was being started.

Emerging needs for using traceability data in several new areas were identified. These included identification of products' countries of origin and customs clearance status using traceability data. Improvements in the level of traceability in relation to segregation and quality-data analysis capabilities were being searched for.

More distant needs were identified in the fields of relationship marketing and recycling. The sales function had considered the possibility of starting to use traceability data in support of relationship marketing efforts. The aim was to focus marketing efforts by linking end-user information with the history of the individual product owned by the customer. End-user data, including the serial number of the product was obtained through end-user registration. Product history including data on product version, accessories delivered with the product, warranty information and information on repairs carried out for the product were obtained in different locations within the company. The quality function again had been interested in obtaining product version data to support recycling activities. The manager in charge of developing recycling activities demonstrated this need with the following example:

The concentration of certain (hazardous) materials used within a module was continuously adjusted to improve product performance. If the concentration exceeds certain limits, the change had an impact on the recycling process, which needs to be adjusted to correspond with the new situation. Thus, information on product versions is needed in the recycling centre.

4.3 Company Gamma

Company Gamma is an electronics company and a major subsidiary of an international corporation, hereafter Corporation Gamma. The focus of Company Gamma's operations is the European countries. Company Gamma manufactures consumer electronics products, the life cycle of which has already reached and passed maturity. Traceability, which was undertaken on a voluntary basis as a result of internal needs, was started in 1992.

4.3.1 Organisational setting

The products manufactured by Company Gamma's manufacturing units are delivered to market through a distribution centre and/or a sales company and

repaired by internal and external service centres. Development of traceability in these units has been functionally managed. Product management has defined serial numbering principles for the products and monitored that these principles are followed in the manufacturing units.

A sales and distribution function has developed traceability in the units under its responsibility, including distribution centres, sales companies and service units.

It was claimed that 'everybody is convinced of the importance of traceability' and that there were no major motivational problems related to data collection. It was said that two per cent of the price of a product is reserved for handling and processing in the logistics pipeline. Approximately ten per cent of that, i.e. 0.2 per cent of the price of a product, was reserved for traceability costs.

4.3.2 Development of traceability

The current level of traceability was reached around 1992. Although some traceability functionalities had existed before 1992, all products were not systematically covered by traceability. Tracing the products was started to respond to internal needs in the field of traceability. Traceability was principally needed to manage quality problems and to control cross-border material flows. There were no authority requirements and only minor requirements from the customers related to the bar-codes used in the product type labels.

Safety-critical products with value exceeding c. 300 FIM were traced. Safety criticality was assessed using the operating voltage of the product as the criteria. Thus, non-electric products like wooden racks were not traced.

In the sales and distribution area, the principle was to maintain traceability systems simple to avoid costs related to information systems, telecommunications and data collection.

4.3.3 Technical setting

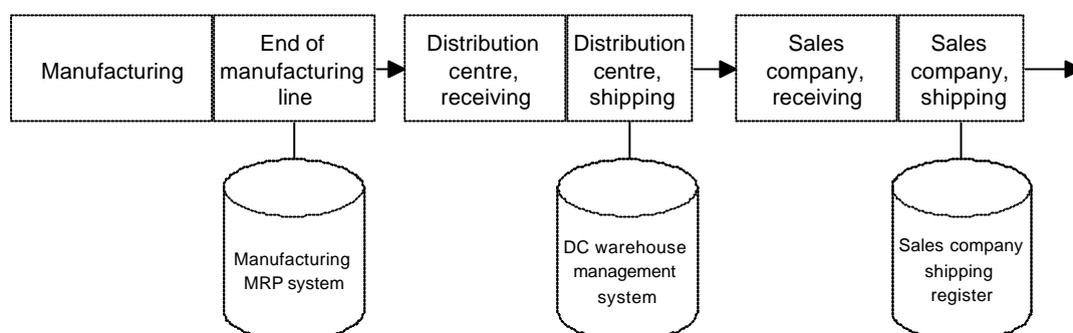
Traceability was based on the unique identification of products by serial numbers. In addition to uniquely identifying the products, the information encoded into product serial numbers indicated the date when the product was manufactured, the software version and the standard¹⁷ bill of materials version number. No other data that could have directly been linked with an individual item was recorded in the manufacturing units. However, using the product-specific date of manufacturing, certain events in the manufacturing environment could be connected with the individual products. For example, on a rough level, changes in the manufacturing process, product design and components usage could be linked with individual products, on the basis of the date.

Distribution centres and sales companies collected data on the destinations to which products had been shipped. Service centres maintained records on

¹⁷ The standard bill of materials version number is only changed when major changes in the bill of materials take place. Minor changes do not affect the version number.

repaired products and the end-users who had delivered the products to be repaired.

Figure 5: Material flow and traceability information systems at Company Gamma.



Traceability data was maintained in a number of local information systems in manufacturing, distribution centres, sales companies and repair centres. Each manufacturing centre recorded the traceability data collected in the end of the manufacturing line to the local MRP system. The distribution centres and sales companies maintained traceability data in local warehouse management systems. The number of distinct warehouse management systems exceeded ten. Each of the repair centres had its own information systems in which traceability functionalities were implemented.

4.3.4 Use of traceability data

The ways in which Company Gamma applied traceability data varied greatly. The most frequently used traceability application was warranty status verification. The date of shipping of each individual product to a customer was used to determine the start of the warranty period.

In the event of a serious quality problem, traceability data could be used to support segregation of the defective products from the total product population and to identify the destinations to which these products had been shipped.

Company Gamma had made agreements with its trade customers limiting the right of the customer to resell the products in other market areas. When illicit cross-country trade was suspected, traceability data was used to provide evidence of contractual violations.

Additionally, records on shipped items could be used in the event of loss to identify the serial numbers of the products in the shipment and to report this information to the police authorities.

4.3.5 Future plans

The use of traceability data in supporting relationship marketing activities was seen as a potential future application of traceability. The idea was that added

value could be provided by using traceability data to connect an individual customer to an individual product purchased by him or her. Using this information customer could for example be offered new products or better models e.g. one year after the purchase.

4.4 Company Delta

Company Delta is an international package and letter distribution company operating in over 200 countries and territories. It delivers several hundred thousand shipments a day. The shipments are managed with a network of approximately 2 000 service centres and 30 sorting and receiving facilities, where the shipments are unloaded, sorted, and forwarded to their destinations.

4.4.1 Organisational setting

Organisationally, the company was divided into three regions: Americas, Europe and Africa, and Asia and the Pacific. Each region is divided into a number of country organisations.

The ownership of traceability was centralised. The development efforts were run by one global and three regional development groups, which were suggested to be responsible for 'the integrated upgrade and development of the tracing capabilities'. Customer-facing functions gathered customer requirements and passed them through to the development groups. Centrally developed solutions were duplicated in the field units in different countries. The knowledge related to traceability had evolved within the company during the years traceability had been developed and was described as being kept 'between the ears'. The understanding was that the literature had no comprehensive description of traceability practices that 'you could read in front of the fireplace with a glass of whisky in your hand'.

From an organisational perspective, a business culture that values data capture activity as an integral and critical element of the service to the customer was seen as essential for the success of the traceability system.

4.4.2 Technical setting and development of traceability

According to the customer access manager at Company Delta's Europe and Africa Region, traceability 'had always been a part of Company Delta's operational policies and grown with the company'. When the company established a new unit, traceability was always among the first things to be implemented.

First, data was collected manually and telephone based information service were used to provide the information within the organisation and to the customers. Computerised, on-line traceability systems were introduced in the late 1970s. Since then, these systems have been consistently upgraded. Access to on-line tracing by customers was first provided in late 1988. In the mid-1990s, the shipment traceability system was integrated with the other shipment processing systems as a result of the problems with the old, fragmented

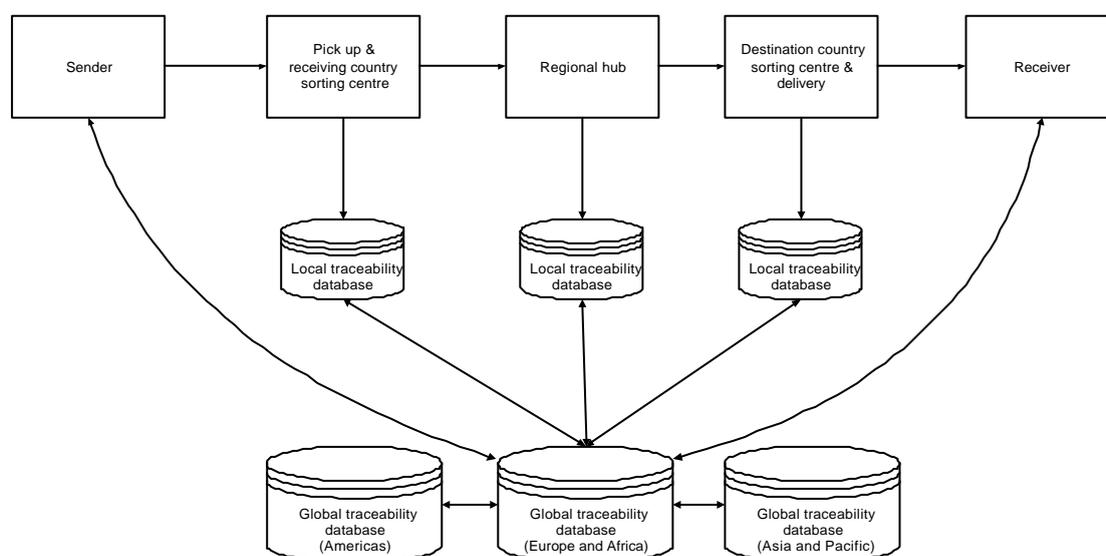
systems: 'each of the systems was developed in its own way with little overall integration. For example, each system had its own database.' The lack of integration had caused a large amount of maintenance work and led to errors.

In the new information system, traceability functionalities were implemented in the shipment traceability module. This module was one of the several system modules that included both accounting and sales and marketing, and that were sharing data with each other. The shipment traceability module was also interfaced with external, authority and customer systems.

Traceability data was maintained in global and local databases. On the global level, there were three identical databases, one in each region. These databases replicated each other. In each country, there was one local database. Traceability data captured during the shipping process was stored in the local database in each country. To the extent this data was relevant from the global perspective, it was entered into the global databases.

The basis of traceability data was formed by shipment-specific time-location data, which was collected throughout the shipment process from the point the shipment was received to be delivered through the sorting centres to the point the shipment was handed over to the receiver. Another essential element of shipment data was the shipment data manifested by the customer sending the shipment. This included the destination of the shipment and its weight and physical dimensions. Other data included shipment-specific exception data, indicating that something negative had happened to the shipment and the name of the person to whom the shipment was to be handed over. Other data related to the process through which the shipments were delivered could be indirectly linked to the shipments. This data included the persons on shift in each sorting centre and the means of transport used in different phases of the delivery.

Figure 6: Traceability information systems and an example of the distribution chain at Company Delta.



A conservative estimate of the global costs of implementing the traceability system was estimated to be USDM 250. This figure included the costs of software purchases, setting up the infrastructure, making the process changes, training personnel, implementing the system physically and starting it up. Communications and labour costs were not considered to be significant. The labour costs were reduced by the fact that most of the data was gathered automatically. The benefits of the traceability system were considered to consist of an improved company image and better customer support, comfort provided to the users, the ability to provide management information for internal and external users, the ability to monitor performance and identify faults, the ability to provide fault notification information for the customers and take corrective actions and a degree of value addition and competitiveness with all major carriers in the market. The lack of traceability was believed to lead to lost business as shipment traceability was considered to be a market standard.

A number of critical success factors in the technical setting were highlighted at Company Delta. The data in the local and global databases was not always updated in real time. All of the transportation vehicles, which among other things collected data on received and delivered shipments, did not have mobile links to the information systems. Moreover, the local databases did not quite update the global databases in real time.

The level of data collection i.e. the amount of detail available per shipment did not fulfil all of the requirements. Problems were also caused by incorrect data entry when customers sending the shipments manifested the shipments to Company Delta's system.

When systems interfaces were being built between Company Delta and its customers, problems could arise if the customer had not anticipated the possibility of the interface in the system design phase. According to the customer access manager, 'shoehorning' the traceability function to a system after it had been set up was difficult. Lack of customer EDI capabilities and proprietary standards used by the customers were also problems when setting up interfaces.

Furthermore, rapidly increasing customer requirements caused problems on some occasions. The customer access manager suggested that the time required by a global change is not always readily understood by the customers, and this frequently leads to a conflict between expectations and capabilities.

The customer access manager listed several factors that he considered to be critical in the success of a traceability system. As the most important factor, he named 'the consistency of understanding what is wished to be provided'. Secondly, he considered the consistency of the implementation across the world to be critical. Other factors mentioned included the consistency and quality of data entry, the capture, the length of storage time, the timely availability of data to potential users and the ability of all the users, internal and external, to access the information. Furthermore, security and data protection, financial resources and

technological capabilities were considered critical, as well as the ability to maintain system viability in all situations.

The integration of local traceability information systems into one global system was considered to be 'absolutely critical'. The customer access manager stated that 'if you cannot have a complete picture of a shipment's transit through the transportation cycle, you are lost. For instance, the customer service would otherwise be blind and incapable of answering to the customer questions.' Also, integrating the capturing of traceability data with the shipment process and automating it, were viewed as critical. It was seen that otherwise, there would be the danger of an additional layer of data capture and delay of the shipment. It was also suggested that if the data capturing process was not a part of the shipment process, there was the danger that traceability data was intentionally not captured when time was critical.

The use of a positive confirmation philosophy was considered critical for the reliability of the captured data. In this approach, the information was related to the physical presence of the shipment. When the traceability data was collected as a part of the physical shipment transactions, it could be ensured that the collected data was accurate and based on actual transactions.

4.4.3 Use of traceability data

The use of traceability data was centred around managing shipments during the delivery processes. The destination information manifested by the customer was used to route the shipments to customer-specified destinations. The data collected during the shipment processes was used to provide delivery status information for the customers and to provide a set of evidence related to the delivery. The data was used to show that the shipment had been delivered and that the delivery had taken place on time. Moreover, in the future the data was planned to be used to justify the adjustments made to the amount invoiced from the customer.

The other uses of traceability data during the shipment process included error and loss prevention. The data was used to ensure that items in multiple item shipments were jointly delivered to their destinations. In the sorting centres, the data was used to identify items lost during the sorting process. In order to ensure undelayed delivery of shipments through customs, shipment-specific data was delivered to the customs authorities to allow them to avoid lengthy manual procedures.

The accumulated shipment data was employed in various logistics and security analysis. The data was used to measure and analyse on-time delivery rates, lead-times and delivery patterns¹⁸. In the field of security, the data was used to analyse the factors underlying losses and weak points in the material flow.

¹⁸ Delivery patterns refer to the deviations in the times, between when the shipments are picked up to be delivered and when they are delivered to the destinations. From the customer

4.5 Company Epsilon

Company Epsilon is a subsidiary of the Epsilon Group, which operates in the communications market. Company Epsilon operates in the messaging and small goods transport market. It delivers approximately eight million shipments a day. These shipments are delivered through a network of 35 sorting centres and terminals and approximately 1 000 service points.

Only the items in the highest service categories are traced. Traced items are divided into three categories. Express and insured shipments are traced throughout the delivery chain. Other packages are traced at the point of delivery and at least at one other point within the delivery process. Other deliveries, including letters and magazines, are not traced.

4.5.1 Organisational setting

The development of traceability at Company Epsilon was based on internal needs and market pressure. Although a strong customer perspective was suggested as being present in the development of traceability, there were no direct customer or authority requirements related to the level of traceability. The ownership of traceability and traceability information systems was centralised.

The investments in traceability were justified by the ability to provide better customer service with improved process control. This was considered to enable the company to maintain the price level of its services in the competitive environment and to improve its company image. It was stressed that most of the major competitors already had similar systems. The collected data was seen as important for managing and analysing the delivery processes. Cost savings would be obtained through, among other things, reduction in the amount of errors and effort in locating lost shipments, ability to optimise processes and capacity usage and the elimination of old manual traceability systems. The total amount of working time required to trace an express shipment from receiving to delivery was estimated to average 15 to 20 seconds. Nevertheless, a comprehensive traceability system was considered necessary for the company to remain competitive.

Major problems in implementing the new systems were considered to be human, not technical. Several thousand people participated in data collection. Thus, there was a need to train people in how to work with the system and also to get everybody to use it.

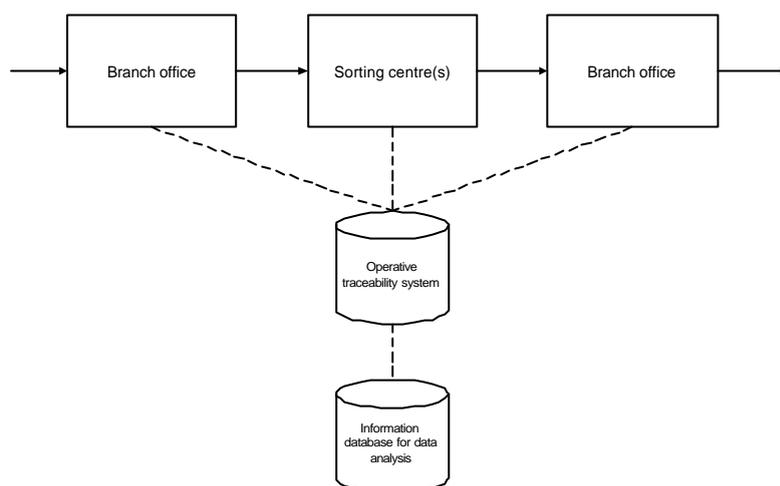
4.5.2 Technical setting and development of traceability

Traceability was based on unique identification of shipments and handling units and address labels attached to the shipments.

perspective, the later in the evening the shipments were picked up, and the earlier in the morning they were delivered to their destinations, the better.

Before 1997, manual methods had been used to implement shipment traceability. Only insured and registered shipments were traced. When a traced item was handed over from one process phase to another, the transaction was recorded using paper documentation. The documents were archived locally in the units, that had carried out the transactions.

Figure 7: Material flow and traceability information systems at Company Epsilon.



A project to set up a computerised traceability system was started in 1995. The system installations began in April 1997 and the system was taken into use by the end of 1997 in all of company's sorting centres, terminals and branch offices. System development was driven by the IT department. However, there had been wide, cross-functional representation in planning the use of the data. The system was designed internally after an extensive benchmarking of other companies using similar systems. The programming work was outsourced.

The traceability system implemented in 1997 had been planned to cover the entire distribution network, including the material flow from shipment receiving to delivery to destination. Thus, the system covered or was going to cover all the units that were physically handling shipments.

The number of control points in which shipment data was collected depended on the service category of the shipment. Express and insured shipments were traced at a number of control points throughout the material flow from the points at which they were received from the customers to the points at which they were delivered to their destinations. Normal parcels were traced individually when they were delivered to their destinations and at one control point within the delivery process. A third group, letters and magazines, were traced only at the handling unit level, but not individually. Within a sorting centre, there were a maximum of three control points in which traceability data was collected: on arrival at the sorting centre, during the sorting process and on departure from the sorting centre.

The data collected in a control point consisted of time-location data. Additionally, data on the employees responsible for the shipments in each process phase was collected. In the event of an exceptional situation delaying the delivery, information on the delay was also recorded. The collected data was directly stored in the company's central traceability database. The maximum number of transactions per hour in the central database was estimated to exceed 70 000 when the system was fully operative. This was considered to be a potential future problem. Parallel to the production database, a replicate database was maintained for analysis purposes.

The central traceability database was interfaced with external traceability systems. In the event of a cross-country delivery where a shipment was jointly delivered by Company Epsilon and an external partner, traceability data could be received from the partner to enable end-to-end transparency of the delivery.

4.5.3 Use of traceability data

Most importantly, traceability data was used to manage and monitor shipment processes. Destination data provided by the customers enabled the company to route the shipments to customer-specified destinations. During the shipment process, traceability data was also used to prevent incorrect routing of the handling units.

The data collected during the shipment process was used to provide shipment status information for the customers. When a shipment was late, information on the delay could be made available to the customers. The evidence showing that the company had delivered the shipment and that the delivery had taken place on time were of particular importance.

Traceability data collected during the shipment process was maintained for several months. The accumulated data was used in various types of logistics- and security-related measurements and analysis. Most importantly, the data was used to measure lead-times and on-time delivery rates and to analyse the factors underlying the deviations in performance. In the event of loss, traceability data was used to investigate where and why the loss had taken place.

4.5.4 Future plans

Pressure for increased data collection during the following few years was perceived by the company. The demands to start tracing letters and magazines were acknowledged. The availability of shipment destination data in an electronic format was perceived to enable increased automation in shipment routing.

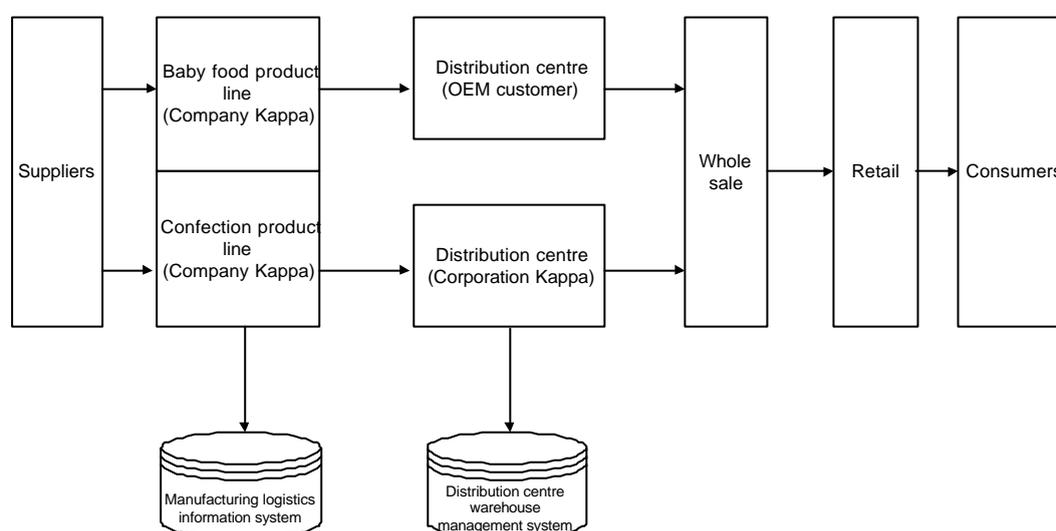
Additionally, the needs for improving invoicing with traceability data were acknowledged. If the shipments would be systematically registered at the receiving point, the accuracy of the bulk related shipment invoicing could be increased. In 1997, bulk shipments were invoiced as manifested by the customers. Verification was based on sampling and weighing. It was suggested that this approach was prone to errors.

4.6 Company Kappa

Kappa Group is a family business whose home market covers all the Nordic countries. The Group also has production and sales companies in central and eastern Europe. Kappa Group's main business areas are confectionery, bakeries and restaurant services.

Company Kappa, which operates in the confectionery industry, is a subsidiary of Kappa Group. Additionally, Company Kappa manufactures baby food for an OEM customer. Both product lines are manufactured in the same manufacturing facility. Confections are distributed by a distribution centre at Corporation Kappa. The distribution of the baby food products is organised by the OEM customer.

Figure 8: Material flow and Company Kappa's main traceability information systems.



4.6.1 Organisational setting

Traceability at Company Kappa had primarily originated from internal business needs. The main needs were related to customer service and quality management including the requirements set in ISO 9000.

Additionally, some legal requirements affected the level of traceability. Food legislation required the company to indicate the best-before date of the products with markings on the products. Similarly, suppliers were required to indicate the best-before dates of the raw materials provided by them. In organic products, traceability to the source of the raw materials was required. Moreover, authorities required that the manufacturer needs to be able to show that the raw materials and finished products are edible. To fulfil this requirement, the manufacturers needed to have a quality control system which ensures the quality of the materials and products. This system was audited by the authorities.

Indirectly, this requirement affected the level of traceability. For example, the company had traceability to the materials' lot-level inspection results.

The management of traceability was functionally organised. The product lines in charge of baby food and confections managed traceability independently. In both product lines, manufacturing traceability was controlled by the quality department. The sales and marketing department was in charge of traceability in the distribution centre distributing the confections. The OEM customer distributing the baby food managed its traceability independently.

Some motivational problems had been experienced in the field of traceability. It was suggested that occasionally, employees ignore the instructions to record the required set of traceability data.

4.6.2 Technical setting

Traceability at Company Kappa was based on finished product manufacturing and packaging lot numbers. Work in progress and finished products were traced starting from the manufacturing and packaging process through quality analysis and storage to the point of shipping. The raw materials used in the manufacturing process were traced from the point of receiving through inspections and storage until they were issued to the manufacturing and packaging processes. In addition to raw materials data, the data collected during the manufacturing process included the manufacturing recipe version, process parameter values, observations made during the manufacturing process, the personnel on shift as well as the best-before date of the manufactured lots. Data related to results of the material and end-product analysis and approvals given for these lots were recorded. Moreover, manufacturing traceability data was complemented by maintaining a sample of each manufacturing lot.

In Corporation Kappa's distribution unit, which distributed the products manufactured by Company Kappa, the lot numbers of the received and shipped lots were recorded. Furthermore, the destination to which each lot was delivered was also recorded.

The level of traceability between the unit manufacturing baby food and the unit manufacturing confections differed to some extent. The differences were caused by the more safety-critical nature of the baby food. Unlike the baby food manufacturing, confection lots could not be directly linked to the data on changes in process parameters in manufacturing. The products could only be roughly linked to the changes by using the estimated time of change implementation.

In the manufacturing area, traceability data was maintained in several systems. The logistics information system being used by both product lines also managed the majority of the traceability functionalities in the manufacturing area. This system was described as an aged mainframe system. Stand-alone, PC-based systems were used in the raw material and end-product analysis. Lot-specific inspection results were recorded in these systems. Analysis systems were not integrated with the mainframe system due to incompatible technology.

Additionally, traceability data from the manufacturing area was manually collected in paper-based records.

In the distribution centre at Corporation Kappa, traceability data was collected in the local warehouse management system.

4.6.3 Use of traceability data

In addition to fulfilling the requirements set by laws and standards, the use of traceability data was largely related to quality management. In the event of a major quality problem, traceability data could be used to segregate the affected products from the total product population. Moreover, traceability data was employed when non-conforming material and product lots were withdrawn from the internal and/or external material flow. The use of traceability data enabled the company to identify the internal locations of given lots and external destinations to which the majority of these lots had been delivered.

When customer complaints were received, manufacturing traceability records were studied to identify the sources of the problems and further to enable answering of customer questions and claims. In a similar vein, manufacturing data was used in connection with quality feedback data to analyse the impacts of factors in the manufacturing process and raw materials usage on product quality. This aimed at improving product quality and optimising manufacturing processes.

In the manufacturing and distribution processes, traceability data was applied to prevent the use and delivery of non-conforming products and materials. The application controlled the usage of unapproved, expired and rejected lots. Similarly, traceability data was used to detect expired products and materials in the inventory.

4.6.4 Future plans

The need for improved risk management and process control are driving the development of traceability. The safety-critical nature of the products was stressed as a factor to determining the speed of development. Moreover, the need for brand image management was considered to affect the development of traceability. Development needs were said to be reflected in more detailed data collection.

4.7 Company Lambda

Lambda Group is a European company that operates in the health care sector. Its largest division, Company Lambda, develops and manufactures pharmaceutical products in several manufacturing and R&D centres. The products manufactured by Company Lambda are distributed by Lambda Distribution. Lambda Distribution, another division of Lambda Group, is a wholesaler and distributor of pharmaceutical and other products. Lambda Distribution has trading companies in six countries.

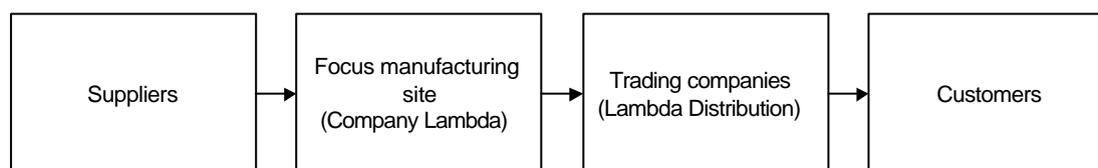
The focus of this study was to investigate the traceability of the products manufactured by one of the major manufacturing sites at Company Lambda. To the extent relevant, the material flow from the suppliers to the focus manufacturing site and from this site to the market through Lambda Distribution was investigated.

Organisationally, the focus manufacturing site at Company Lambda was categorised into two functions: raw materials receiving and manufacturing. Lambda Distribution was divided into a number of distinct trading companies operating in different European countries.

4.7.1 Organisational setting

Strong external requirements defined the level of traceability at Company Lambda. These requirements could be divided into mandatory authority requirements defined in the Good Manufacturing Practice for Medicinal Products in the European Community¹⁹, hereafter GMP, customer requirements and commitments made to authorities and licensees when the production of a new medicine was initiated. Customer and licensee requirements were largely derived from the authority requirements.

Figure 9: Material flow at Company Lambda.



The manufacturing company and the site needed to have a manufacturing licence as a pharmaceutical plant before the company could start operating in the pharmaceuticals business. Then, each product had to receive a sales licence before that particular product could be sold on the market. To obtain the licence, the company often needed to commit to a level of traceability exceeding the requirements set in the GMP. Similarly, to obtain permission to manufacture a licensed medicine on a licensee, the company needed to commit to fulfil the requirements set by the licensee. Among other things, the licensees set requirements for the level of traceability.

The factory manager at Company Lambda suggested that the above-mentioned requirements were detailed enough to fulfil the requirements set e.g. in ISO 9000 and product liability legislation. Thus, no additional adjustments to the level of traceability were needed due to these requirements.

The manufacturing site at Company Lambda and the trading companies at Lambda Distribution managed traceability independently at the site level. At the manufacturing site, the Quality Department ensured compliance with the external

¹⁹ Commission Directive 91/356/EEC of 13 June 1991

requirements. Raw materials receiving and manufacturing functions then defined the working instructions for implementation of traceability within their areas. The availability of the instructions was required by the authorities. The factory manager underlined that traceability has not been seen as a distinct issue requiring a dedicated owner. Instead it was considered to be an integral part of normal operations, which are cross-functionally planned and developed at both the company and manufacturing-site levels.

4.7.2 Technical setting and development of traceability

In accordance with authority requirements, traceability had been based on the concept of lot traceability since the 1970s. Since then, only slow development has taken place in the level of traceability.

The focus manufacturing site collected traceability data in a production planning and control system (hereafter PPCS) and in paper-based batch records. PPCS contained data on materials and their locations in the material flow as a batch record contained the manufacturing and packaging details related to individual manufacturing lots.

The production planning and control system was set up in 1984. According to the factory manager, traceability data was considered to be an integral part of the production control data, and thus it was natural to implement materials traceability in this system. In 1992, a project to replace PPCS with a new system was initiated. In the area of traceability, the target of the project was to start maintaining more data in an electronic format than was possible in the old system. Availability of the data in the electronic format was considered to improve usability of data in process and quality improvement. The system was designed by a cross-functional team, and the number of participants was approximately 100.

In the trading companies, traceability was implemented as a part of local warehouse management systems. The focus manufacturing site and the trading companies were connected with EDI links. This connection enabled the advance delivery of traceability data related to the shipments from the focus manufacturing site to the trading companies.

Raw materials, manufacturing and packaging lots formed the basis of the traceability system at Company Lambda. In the focus manufacturing site, the collection of traceability data covered the material flow from raw materials receiving through manufacturing and packaging to delivery to the trading companies. In addition to the above-mentioned phases, data was recorded when materials were sampled, approved, stored and issued for use and when end-products were analysed, quarantined, and granted in the final approval. In the trading companies, received and stored products were traced, but shipped products were not. Thus, the destination customer was not known. In addition to the records maintained at Company Lambda and Lambda Distribution, raw materials suppliers maintained detailed traceability records related to their products.

Manufacturing-lot-specific records consisted of the recipe of the medicine, the raw material lots used in the manufacturing process, and the machines and premises used in each of the process steps. The process parameter values in each process phase and the employees who had been involved in the manufacturing process were also registered. The analysis made for finished product and raw material, measurement results, and the conformity of these results with specifications were also recorded. According to the factory manager at Company Lambda, 'the size of a batch record corresponds to the size of a telephone catalogue'. Furthermore, equipment- and facility-specific records were maintained, in which data on equipment- or facility-specific events was manually recorded in chronological order. For example, a set of records specific to a piece of equipment could contain data on the maintenance and cleaning of the equipment and auditing of these tasks.

The level of detail of the data collection was demonstrated by the factory manager in the focus manufacturing site when he stated that *'there is full traceability on everything that has been done'*.

In addition to data collection, traceability was supported by strictly following the first-in-first-out principle throughout the material flow. Moreover, samples of each of the manufacturing lots were stored.

4.7.3 Use of traceability data

Traceability data was principally used at Company Lambda to enable responses to authority and customer requirements. As required by the GMP, traceability data was used in the event of customer complaints to investigate whether the problem had originated in the company and whether a possible product defect existed. If the existence of a product defect was confirmed, traceability data could be used in analysis when possible other lots affected by the problem were identified. If a decision to withdraw products internally and from the market was made, the traceability data could be used to identify the internal locations within the company and the destination countries to which these products had been delivered.

Traceability data was used on a continuous basis in material-flow-management-related applications. The data was used to provide lot-specific manufacturing status information needed in the monitoring of manufacturing processes. Traceability data was also used to prevent unapproved and expiring products and materials from being used. Furthermore, traceability data collected during the manufacturing process was used to ensure that the manufacturing process and related tests were carried out satisfactorily and to prevent the release of non-conforming lots. Moreover, the data was used to identify expiring products and materials stored in the inventory.

In addition to using traceability data in quality-problem analysis as required by the authorities, traceability data was also used voluntarily in process and quality improvement. The aim of using the data was to identify relationships between

process parameters and product quality and thus to obtain information needed in process and quality improvement.

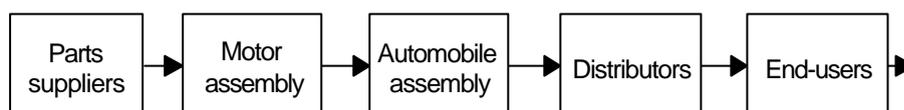
Although never used, the possibility of using traceability data to identify counterfeit products was also recognised.

4.8 Company Sigma

The target company, hereafter company Sigma, is the automobile division of Group Sigma. It is the largest division of the group, contributing more than half of its sales revenues. In 1995, Group Sigma was one of the ten largest automobile manufacturers in the world.

Company Sigma has over 30 production sites globally. Some 15 of these are automobile factories, and four of these motor plants. Distribution is carried out by the sales units, which are subsidiaries of Sigma, exclusive dealers and agents. The focus of the case is on studying the traceability in motor plants and automobile factories, although the materials chain as a whole is examined.

Figure 10: Example of a material flow at Company Sigma.



4.8.1 Organisational setting

Traceability at Company Sigma has been developed by functional project organisations. The top management of the company had initiated projects to tackle traceability problems as they had emerged. There was no permanent owner for traceability with company-wide responsibilities.

In addition to the internal needs, there were some indirect external requirements. The product safety legislation of the European Union²⁰ and good manufacturing practice (GMP) were named as the most important legal requirements concerning traceability. The manufacturer has to be able to prove fulfilment of good manufacturing practice - which includes a certain level of traceability - to the authorities. On request, the manufacturer also needs to be able to provide information on the characteristics of specific automobiles to the authorities. The information needs to be on the unit level, i.e. the manufacturer needs to be able to provide information on the custom characteristics of a single automobile. It was suggested that authorities could impose fines on the manufacturers failing to provide the information.

²⁰ Council Directive 92/59/EEC of 29 June 1992 on general product safety.

4.8.2 Development of traceability

In 1990, there was a joint project with another major automobile manufacturer to improve traceability in the manufacturing function. A few years later, a second project to set up a traceability information system in sales and after-sales units was initiated. In 1996, another project to improve traceability in manufacturing was started. The project manager had a logistics background. Additionally, there were three IT people setting up the system and one person organising the training and use of the system. The system was going to be used and controlled by local quality departments in the plants. After the project was completed, the project organisation was going to be dissolved, which had already occurred in the earlier two project groups.

The importance of traceability for the company was generally accepted. However, the direct benefits of traceability were not always visible to the units, and hence traceability systems had not spontaneously evolved from the bottom up. There had also been some opposition to the company-wide development projects because of the operating costs involved with the traceability system. In the 1996 traceability development project, taking the traceability system into use was a voluntary decision made independently by the management in each plant.

4.8.3 Technical setting

Until the 1996 project was started, most of the factories did not have a traceability system. One axle factory had a traceability information system and one motor factory collected traceability data on paper. Finding the information from the archives was difficult as there were 'tons of paper'. The target of the 1996 project was to introduce a standard traceability information system (TSS - Traceability System of Sigma) to be used in all of the automobile and motor factories. The exclusive purpose of the system was to be the later tool for collecting traceability information, which then could be used in case of recalls.

As a result of the 1996 project, each of the plants implementing the system was going to have a distinct, independent information system installation. In other words, the separate TSS installations in various plants were not going to be integrated with each other nor was there going to be any computerised data interchange. In some of major plants, the departments of the plants were going to have their own TSS installations, i.e. there were probably going to be two or three independent traceability systems in these factories.

The data collected in the new system was going to consist of lot numbers of the components used in manufacturing uniquely traced major parts and vehicles. The first version of the new system was piloted in an automobile factory in June 1996 and in a motor factory in October 1996. Although TSS was offered to all of the factories, its use was not going to be mandatory. The factory or department management could decide whether or not the system was going to be used, because data collection was seen as a major effort. In the factories that decided to start using the system, the system was only going to be implemented in the new manufacturing lines. Thus it was going to take several years before all the manufacturing lines would be included.

In the latest version of the traceability system, the lot codes or the serial numbers of the materials used for manufacturing a parent item (e.g. a motor or a vehicle) were registered against the parent part serial numbers. At first it was decided that only the safety-critical parts would be registered. However, it was determined that it would not be possible to determine the risk levels of the various components, so, all the components were going to be traced in the long run. In the first phase, the components already marked with a lot code were going to be traced. In the long term, all the components were going to be traced as the suppliers started providing lot number information to company Sigma. In the automobile assembly, the serial numbers of the major components like motors and gearboxes were going to be recorded and linked to the serial numbers of the automobiles to which they were entered. The other parts used in the assembly were going to be traced at the lot-level.

Some problems arose after traceability had been planned and implemented. The complexity of the material flows impeded traceability. Frequently, there were a number of work centres within a workshop carrying out the same tasks. A product could be routed through any of the alternative work centres. Hence, the exact route of a product in a workshop was unknown. This was a problem when there was a need to identify the products processed in certain work centres. In data collection, motivating employees to register the data was also considered to be difficult. Frequently, data was either not registered at all or it was registered incorrectly. In some of the factories, the opinion of the management was that the benefits of traceability do not justify the amount of work required to collect the data.

In the motor plant that had already had a manual traceability system for years, traceability data had only been needed three times within the past six years. As the data was only infrequently needed, the management had decided that there was no need for traceability. Emphasis was not put on data collection.

In the sales function, traceability focused on identifying the end-user to whom each individual product had been sold. The data was collected by a network of distributors in various countries. When a car was sold, the contact information on the customer was recorded and linked to the serial number of the automobile. Traceability was limited to the first owner of the car. When a car was sold on the second-hand market, the connection to its owner was lost.

Traceability data was maintained for ten years. It was considered that in ten years, the link between manufacturing quality and the quality problems in the automobiles were going to be lost due to the changes and repairs made to the automobiles. Also the ten-year liability expiration time affected the decision on the length of the data storage time.

4.8.4 Use of traceability data

In Company Sigma, traceability data was suggested to be used exclusively for managing quality problems and the related legal requirements. Traceability data

was used to segregate the defective products from the total product population and to locate the end-users to whom these products had been sold.

4.9 Company Tau

Company Tau is a subsidiary of Tau Corporation, which operates in the metal industry. Company Tau specialises in producing small volumes of high-end automobiles for OEM customers that are also automobile manufacturers. The design of the automobiles is owned by the customers. The production plant of Company Tau, where the automobiles are manufactured, includes a welding shop, a paint shop, and an assembly plant. The products are mainly sold in Europe and in the United States.

4.9.1 Organisational setting

When Company Tau implemented the first traceability functionalities in the 1970s, the quality department was at first responsible for the development and control of traceability at the entire manufacturing site. Later, the responsibilities were decentralised to the manufacturing and materials departments. At the time of the interviews in 1996 and 1997, the materials department was in charge of materials traceability, i.e. traceability from materials receiving to the point the materials were used in the manufacturing process. The manufacturing department again was in charge of traceability of work in progress in the manufacturing process.

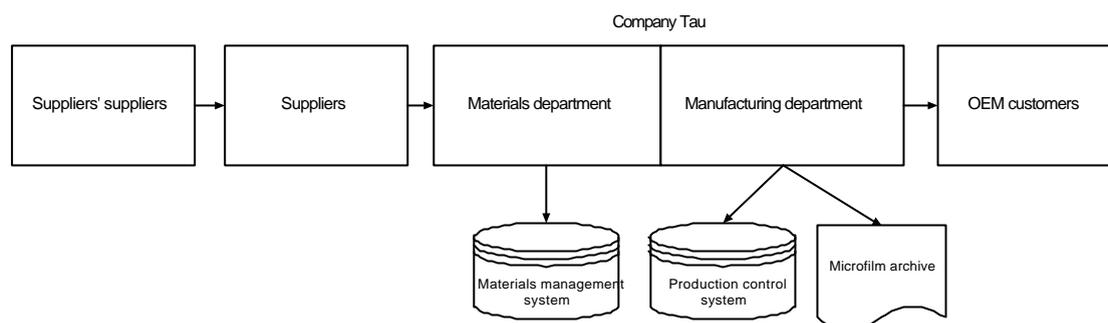
Customer requirements played a central role in the development of traceability at Company Tau. As customers set new requirements, the company tried to adapt to them. Customer requirements again had in turn mainly been derived from authority requirements.

4.9.2 Technical setting and development of traceability

As a result of customer requirements, the traceability of documentation parts²¹ was started in the mid-1970s. During the first years, a manual traceability system based on paper documentation was used. In 1978, when the information systems were renewed, computerised systems were set up to manage increasing amounts of traceability data. In 1995, the materials management system containing materials traceability function was changed to a new system. With the new system, part traceability was extended to cover all the parts in comparison to the previous system's tracing of documentation parts only. The new system also increased data accessibility in two ways. First, it was now possible to provide access to the system to wider audiences and to maintain data in the active database for a longer time, for three to four years, enabling easy data retrieval. Earlier, the data had been transferred to magnetic tapes from the active database soon after manufacturing. The latest development project automating the retrieval of the microfilm cards, in which part of the vehicle-specific data was maintained, was going to be completed during the 1997.

²¹ Documentation parts refer to parts considered to be safety critical.

Figure 11: Material flow and information systems at Company Tau.



Traceability was centred around car bodies, which could be uniquely identified. Each car body was traced through the manufacturing process. The time when the body of a car passed through various process phases was recorded in several material flow control points. Material lots were traced when they were received, stored and issued to the manufacturing process. In the manufacturing process, data on process parameters, process changes and the employees on shift, test reports, and work and inspection instructions affecting the vehicles were collected. Data on materials usage as well as process-specific data could be linked to individual vehicles using time and location data as the linking factors.

Additionally, a set of vehicle-specific data, including data on a vehicle-specific bill of materials, quality approvals and exceptions like part changes, was recorded. This data could be directly linked to individual vehicles. The collection of traceability data was supported by the use of the first-in-first-out principle both in materials usage and the manufacturing process.

In 1997, traceability data was maintained in three systems. Data on individual vehicles and their journey through the different control points in the manufacturing process was traced in the production control system. In a similar vein, vehicle-specific customer order data was maintained in this system. The materials management system traced the raw materials from the point at which they were received to the point at which they were assembled into the vehicles. Vehicle-specific quality approval and exception data, including data on part changes made to individual vehicles, was collected on vehicle-specific paper cards, which were later microfilmed. A vehicle card travelled through the manufacturing process with the vehicle. Data was manually entered on these cards.

Traceability data on outsourced materials was also maintained by Company Tau's suppliers and its suppliers' suppliers. Suppliers were required to have a similar level of traceability as Company Tau had.

Quality feedback data was received from the OEM customers. One of the OEM customers had even made a field-failure system available to Company Tau.

4.9.3 Use of traceability data

The use of traceability data largely resulted from OEM customer requirements. These requirements were in particular related to the management of quality

problems. On such occasions, traceability data was used to identify the products affected by the problem and to locate these products in the internal material flow. However, locating the products that had already been delivered to the market was the responsibility of the OEM customers.

Traceability data played a central role in make-to-order manufacturing. It was used to communicate customer requirements to automated and manual manufacturing process phases and to monitor individual items in the manufacturing process. Item-specific target data was also used to prevent the use of incorrect materials in parts assembly.

Moreover, traceability data was used to analyse the factors underlying quality problems. When a quality problem was identified, traceability data could be used to identify the factor underlying the problem. The data was also used to analyse the impacts of process changes on product quality.

4.9.4 Future plans

Future plans in the field of traceability aimed at reducing manual work in the manipulation of traceability data. Some level of integration between the production control and materials management systems was being planned. The aim was to eliminate manual steps and thus to reduce the effort and time needed in data retrieval and manipulation.

5. CROSS-CASE ANALYSIS

The chapter 'Cross-case analysis' is divided into three parts. Section 5.1 discusses the use of traceability data in the case study companies and aims at answering to the first research question. Section 5.2 is related to the second research question and analyses the impacts of using traceability data. Section 5.3 answers the third research question by analysing the enablers in realising the impacts of traceability data.

The cross-case analysis is based on the description of traceability applications that appears in Appendix 8.1 and the description of the organisational and technical settings in the field of traceability illustrated in Chapter 4.

5.1 Use of traceability data

A large number of ways to use traceability data were observed in the case study companies. Traceability data was applied in diverse product- and material-flow-related activities, including logistics, manufacturing, quality, security, marketing and legal activities. The question of how to generalise this multitude of applications can be posed in order to understand what traceability data is actually used for.

From a theoretical viewpoint, traceability applications can be categorised by dividing them based on the type of input data the application uses and the type of output data it provides. When traceability data is divided into information that identifies an individual item or lot, i.e. a traced object, and into the attributes of these objects, the four application categories presented in Table 4 emerge.

Table 4: Input/Output Data Matrix - Application categorisation based on input and output data.

INPUT/OUTPUT	Traced object	Attribute
Traced object	1. Object -> Object	2. Object -> Attribute
Attribute	3. Attribute -> Object	4. Attribute -> Attribute

1. Object-to-object identification: Given the ID of an object, other objects connected with the target object can be identified. Objects can be connected, for example, due to lot or item transformation in an assembly process. An example of the use of item transformation data is Company Alpha, which used manufacturing records to identify the serial numbers of the child parts (child objects) assembled into the parent item (parent object). Service centres then used this information to verify and provide evidence identifying whether a failing part is an original part covered by warranty or not.
2. Object-to-attribute identification: Traceability data enables identification of the attributes of a given traced object. For example, companies Delta and Epsilon used traceability data to enable identification of the location (attribute) of an individual parcel (object) in the material flow. At companies Alpha, Beta

and Gamma, traceability data was used to identify the warranty statuses (attributes) of individual product items (objects).

3. Attribute-to-object identification: Given an attribute value, traceability data enables identification of those traced objects that have a given characteristic. For example, several case study companies used traceability data to segregate the products (objects) with defective components (attribute) from fault-free products.
4. Attribute-to-attribute identification: Traceability data enables linking attribute values related to given objects with each other. For example, when customer complaints were received at Company Kappa, traceability data was used to identify which one of the suppliers (attribute) had delivered the raw materials used in the non-conforming (attribute) lot.

Consequently, ***traceability data is used:***

- to identify item and lot transformations, i.e. items and lots that are connected to each other
- to identify attributes of individual items and lots
- to segregate those individual items and lots which have a given characteristic, and
- to relate a piece of attribute information connected to an individual item or lot with other pieces of attribute information connected to the same item or lot.

From a pragmatic viewpoint, but still following the guidelines of the Input/Output Data Matrix, the applications observed in the case study companies can be grouped into the following four categories:

1. Material flow management applications use traceability data to control and identify traced objects in the material flow. Applications in this category are largely based on using the identification number of an individual item or lot to identify item- or lot-specific attributes.
2. Legal verification applications, like material-flow applications, mainly use the identification numbers of traced objects to identify object-specific attributes, and in some cases, to identify objects connected with each other. This information is then used as legal evidence. Although these applications are similar to material-flow applications, the nature of legal verification applications clearly differs from the material flow management applications in frequency, time and purpose of usage.
3. Segregation applications are used to identify traced objects with a given property. Thus, they are closely related to the 'attribute-to-object' application category.
4. Measurement and analysis applications use link attribute data connected to a traced object in order to provide measurement results and to identify causal

relationships in product and material data. Applications in this category are principally related to the 'attribute-to-attribute' applications.

These application categories can approximately be placed into the Input/Output Data Matrix, as suggested by Table 5.

Table 5: The approximate position of traceability applications in the Input/Output Data Matrix.

INPUT/OUTPUT	Traced object	Attribute
Traced object	2. Legal verification	1. Material flow management 2. Legal verification
Attribute	3. Segregation	4. Analysis

However, the use of traceability data is often not limited to one type of identification linkage. Instead, multiple identification linkages may be combined in order to achieve a desired result. For example, when defective products are being segregated from the total product population, the following identification linkages may be needed. First, components affected by the attribute causing the defect are identified. Secondly, final products where the component has been used are identified. Then, the analysis can be continued by locating the products from the material flow and the market. Thus, three linkages are needed in the identification - first, attribute-to-object, then, object-to-object, and finally, object-to-attribute identification.

Regardless of its limitations, Input/Output Data Matrix provides a solid basis for categorising real-life traceability applications into logical categories. In the following sections, this pragmatic categorisation is used to analyse the usage and impacts of traceability data in the case study companies.

5.1.1 Material flow management applications

5.1.1.1 Error-detection and -prevention applications

Seven of the case study companies (Alpha, Beta, Delta, Epsilon, Kappa, Lambda, Tau) used traceability data to identify errors in material-flow-related processes. These applications compared the item's or lot's actual, 'as is' status with its targeted, 'should be' status.

Two of the companies used an application that noted when parts and components not in accordance with the item-specific bill of materials were being used (Alpha, Tau) or when the supplier of the items was not approved by the customer (Alpha). Two of the companies (Kappa, Lambda) used traceability data to verify the quality statuses of the lots being used and to notify when lots were unapproved. Similarly, these two companies used traceability data to notify when expired lots were being used. At Company Delta, traceability data was used to identify multiple-item shipments and to ensure that the items in the shipment stay together throughout the shipment delivery. At Company Epsilon,

handling units and their routes were identified to prevent misroutings in transportation.

When an error had already occurred, traceability data was used to detect the problem. In two of the companies (Beta, Lambda), traceability data collected during the manufacturing process was analysed to identify that the product had been processed according to specifications.

5.1.1.2 Material flow control applications

Material flow control applications were used in four of the case study companies (Beta, Delta, Epsilon, Tau). With one exception, these applications were used in situations where an individual item was owned by a customer and/or assigned to a customer order. Here, traceability data was used to identify the unique requirements specific to this item. More specifically, traceability data was used to provide item-specific processing instructions and information for the manufacturing and delivery processes.

In one of the case study companies (Tau), the application supported make-to-order manufacturing. In several process phases, the traceability system was used to identify the body of the vehicle, to retrieve the assembly or processing instructions specific to this body, and to marry sub-components to it or otherwise process the body in accordance with the requirements.

At Company Delta, information on the characteristics of individual parcels being shipped were delivered to the customs authorities. Using this data, the customs authorities could carry out the paperwork and select the items to be inspected before the physical items arrived.

The focus service centre at Company Beta used traceability data to identify the sender of a repaired product in order to return this specific product back to the sender.

At companies Delta and Epsilon, shipment-item-specific address information was used to route the shipments to their destinations. At Company Epsilon and with part of the shipment items at Company Delta, the address information was marked on the shipped item in a human-readable form. At Company Delta, the destination of the shipment items could also be identified in the information systems by using the shipment number marked on the shipment.

Furthermore, in Company Beta, the future need to use traceability data to support recycling activities was acknowledged. It was suggested that item version information was needed to adjust the recycling process according to the chemical concentration of the item.

5.1.1.3 Location- and status-identification applications

Traceability data was used in all of the case study companies in some way to support item-level location or status identification and monitoring. These

applications were based on item- or lot-level location and status data collected at several functional, cross-functional or cross-organisational control points.

Four of the case study companies used traceability data to provide location and status data for the customers. Company Delta and Company Epsilon provided shipment location and status information for the customers. Status data was also used to inform the customers about shipment-related problems. At Company Beta, traceability data was used to provide customers with information on repair status and estimated time of completion. Similarly, Company Alpha used the traceability system to provide customers manufacturing status information on products manufactured to order.

In five (Alpha, Beta, Kappa, Lambda, Tau) of the seven manufacturing companies participating in the case study, traceability data was applied in the locating and/or monitoring of items in internal manufacturing and/or distribution processes. Several companies (Alpha, Beta, Kappa, Lambda, Tau) used traceability data to support withdrawal of the materials and end-products from the material chain. At Company Lambda and Company Tau the data was used to monitor item or lot statuses in the manufacturing process.

Traceability data was also used in the event of recall to support location of the affected products on the market. Locating was based on item- or lot-level shipment destinations and end-user information. Five of the companies used traceability data to identify shipment destinations (Alpha, Beta, Gamma, Kappa, Lambda) as a primary or secondary method of locating recalled products. At Company Lambda for instance, traceability records were used to identify the countries to which affected products had been delivered. In each of the identified countries, all the potential pharmacies were contacted. At Company Kappa, traceability records were used as the principal method of locating only when the quality problem requiring recall was not safety-critical. When the problem was safety-critical, the main method used in recalling the items from the market was public advertising. One of companies (Sigma) used end-user records in the recalls. Also, the products manufactured by Company Tau could be recalled using end-user records. However, the OEM customers organised the recalls.

5.1.1.4 Alarm applications

In alarm or alert applications, traceability data was used in material-flow-related processes to warn about emerging problems and to detect deviations exceeding expected or allowed limits. These applications are closely related to error-detection and -prevention applications, but the items are not physically present during the verification.

Alarm applications were used in three of the case study companies (Delta, Kappa, Lambda). In two of the case study companies (Kappa, Lambda), periodical reporting was used to detect items in the inventory, the age of which had exceeded the minimum allowed time to expiration and at one (Kappa) to detect items that had reached the maximum allowed time at a given inventory

location. These applications were based on lot-specific expiration date data and time of arrival and departure at a given inventory location.

At Company Delta, traceability data was used in the sorting centres to identify missing items. An item was reported as missing, if it had been received at a sorting centre but had not been registered to be forwarded by the end of the shift. The application was based on the data on received and logged out items.

5.1.2 Legal verification applications

5.1.2.1 Warranty-status-verification applications

Three of the case study companies (Alpha, Beta, Gamma) used traceability data in warranty status verification. Service centres used the application to identify the warranty status of products being repaired. Warranty validity was calculated based on the date that the product had been shipped from the company to its customer.

Traceability data was used to provide companies with a primary or secondary means of warranty verification. It was used as a primary method of warranty determination when the start of warranty period was determined by the date the item was shipped from the company to its direct customer (Alpha, Gamma).

When the receipt used as a primary proof-of-warranty was not available or its validity was suspected, traceability data was used to provide the company (Beta) with a secondary means for warranty verification.

Furthermore, one of the case study companies (Alpha) used traceability data to verify the origin of the modules in the computers being repaired. The purpose of the application was to identify whether the modules were the original modules assembled by the company and covered by the warranty or whether the modules had been changed after the product had left the company.

5.1.2.2 Fraud identification applications

One of the case study companies (Beta) used traceability data in the service centres and other after-market units to identify stolen or otherwise illegal products brought in to be repaired.

In three of the case study companies (Alpha, Beta, Gamma), item-level shipment records were used to identify the serial numbers of items lost in delivery. Serial numbers of the lost products were reported to the police authorities and/or insurance companies.

Moreover, two of the companies (Alpha, Beta) delivered police authorities traceability information to support crime investigations. The information delivered to authorities included the serial numbers of the modules originally used in a given product (Alpha). Moreover, traceability data was used to answer inquiries as to whether a given product was manufactured by the company (Beta), and when and to whom it was delivered (Alpha, Beta).

5.1.2.3 Proof-of-quality applications

Five of the case study companies (Alpha, Delta, Epsilon, Kappa, Lambda) used traceability data to provide information and evidence needed in answering customer complaints.

Company Alpha used data recorded in module assembly and packaging to validate that correct modules and accessories had - or had not - been delivered to the customer with the product. The use of the data was demonstrated by the following example:

A customer complaint claiming that the ordered amount of random access memory had not been delivered with the computer was received. The complaint was analysed using the records collected in the module assembly. The records showed that the required amount of memory had been installed in the computer. Moreover, it was discovered that the manufacturer of the memory circuits originally entered in the computer and the manufacturer of the memory circuits in customer's computer were different. Thus, it became obvious that the original memory circuits had been removed and replaced.

In the event of a customer complaint, Company Lambda and Company Kappa used traceability data to analyse whether a problem had originated within the company or whether it had emerged after the product had left the company. The data used in the application included a wide range of manufacturing details on materials used, process changes and analyses made. At Company Lambda, the use of the application was demonstrated with the following example:

The most common customer complaint is that incorrect tablets have been mixed up with the correct contents of the package. When this kind of complaint is received, we first investigate, whether our company has manufactured the incorrect tablets. If this is the case, we then analyse whether the tablets were manufactured in the same factory. If they were manufactured in the same factory, it is finally analysed whether the tablets have been manufactured in two consecutive production runs or whether a particular employee was involved with the manufacturing of both of these lots. If the incorrect tablets do not have anything to do with each other, it is likely that the problem did not originate in the company.

Companies Delta and Epsilon used traceability data to show whether a shipment was delivered to the destination, to whom it was handed over at the destination and whether the shipment was delivered on time.

In Company Delta, the physical dimensions and weight determined the cost of the delivery for the customer. In the event of an argument with customers on the actual weight of the shipment, traceability records were used to identify the weight Company Delta had measured when the shipment had been received and other commentary information.

5.1.2.4 Miscellaneous legal verification applications

Company Beta prepared for product liability claims by collecting manufacturing test result and shipping records. The data was used to identify whether a product has been manufactured and put to circulation by the company, when the product has been put to circulation, the condition of the product when it was put into circulation and whether it is probable that the defect which caused the damage did not exist at the time when the product was put into circulation.

At Company Gamma, shipment destination data was used to provide evidence on cross-country trade when it was suspected. Due to differences in prices in the different countries to which Company Gamma sold its products, it had made agreements with customers prohibiting cross-country trade under certain circumstances. Traceability data was used to identify breaches of contract, i.e. cases in where a product delivered to a particular customer in a particular market area appeared in a different market area.

At Company Lambda, it was suggested that traceability data could be used - although it had never been needed - to show that a product is a counterfeit product. Among the other things, conflicting manufacturing and packaging lot numbers could reveal counterfeit products.

5.1.3 Segregation applications

Segregation applications were used to identify items with a given property. Mainly item- and lot-level manufacturing details, including materials usage data and data on process changes, were used in segregation.

All of the manufacturing companies used or had the capability to use the traceability data on some level to identify defective items in the total product population. Identification was needed, among other things, in the event of major quality problems.

Additionally, the application was used to identify products owned or ordered by a particular customer. At Company Alpha, traceability data was used to segregate products being manufactured at a particular customer's order. This application was employed in the event of order cancellation when the products being manufactured for the cancelled order were being withdrawn from the manufacturing line.

At Company Beta, traceability data was used to enable identification of the serial numbers of the products sent to be repaired by a particular customer.

5.1.4 Measurement and analysis applications

5.1.4.1 Logistics measurements and analysis applications

Five of the case study companies (Alpha, Beta, Delta, Epsilon, Sigma) used traceability data in logistics performance measurements and/or analysis. The measurements were principally based on item-level time-location data recorded

at a varying number of control points. The analyses were carried out by various item properties, e.g. by country, product or customer.

Companies Alpha, Beta, Delta and Epsilon used traceability data to measure internal lead-times. The total lead-times and lead-times in particular process phases were measured. Moreover, lead-times were measured by different factors, e.g. by customer, by product type or by destination country. One of the companies (Beta) measured external lead-times from delivery to customer purchase.

Two of the companies used traceability data in measuring on-time delivery rates (Delta, Epsilon) and in analysing factors underlying deviations in logistics performance.

At Company Sigma, traceability data had occasionally been used to map the material flows within the manufacturing process.

5.1.4.2 Quality-data analysis applications

Individual item- and lot-level quality data was used in the manufacturing companies (Alpha, Beta, Kappa, Lambda, Tau) to identify sources of quality problems and/or to optimise manufacturing processes in relation to product quality. Manufacturing details, including data on materials usage, employees, and process and design changes, were used in the analyses. This data was cross-referenced with quality feedback data and test and inspection results.

Traceability data was applied in the study of causal relationships between design, process and material changes and product quality. Analysis of the impacts of process changes on product quality (Kappa, Lambda, Tau) were made in three of the case study companies. One of the case study companies (Beta) used traceability data to identify inconsistencies in the tuning values an item was targeted to have and in the measurement results indicating the actual tuning value. Inconsistencies indicated need for equipment calibration. In two of the companies (Alpha, Kappa), supplier quality was evaluated using traceability data. Similarly, the data was used to support identification of the root cause of the problem in a given item or lot (Alpha, Beta, Kappa, Lambda, Tau). These applications were based on item- or lot-level manufacturing and test history.

Furthermore, Company Alpha applied traceability data to measure employee-specific production volumes and to connect problems identified at the quality inspection points to the employees. This information was further used as the basis of an employee reward system.

5.1.4.3 Security-data analysis applications

Two of the case study companies (Delta, Epsilon) used traceability data in security-related analysis. Traceability records were used to identify the points in the material flow where losses were taking place and the circumstances - including responsibilities - that prevailed at the time of the loss.

5.1.4.4 Relationship marketing applications

Although not yet used, two of the companies (Beta, Gamma) had considered the use of traceability data as a part of relationship-marketing activities. Traceability records could have been used to identify the details and history of the product owned by an individual customer.

5.1.5 Discussion

The traceability applications in the case study companies can be divided into four categories: material flow management, legal-verification, segregation, and measurement and analysis applications.

In the material flow management applications, traceability data was used in three ways. First, traceability data was used to compare the *actual status* of an individual item or lot with item- or lot-specific *target* values and to enable identification and notification of *deviations* from the targets. The deviations that the applications were used to control resulted from theft, age, the origin of the items and their components, and customer-specified requirements related to the items. Secondly, individual item-specific, customer-defined *target data* was used as *instructions or information* according to which the item was controlled in the process. Thirdly, traceability data was used to *identify the location and status* of an item or lot in the material flow. The need for locating mainly resulted from errors and variations in product quality and make-to-order nature of the processes.

Table 6: Use of traceability data in the case study companies.

Application categories	Applications	Variants	Companies using the application
Material flow management	Error detection and prevention	Detection and prevention of <ul style="list-style-type: none"> Misroutings in manufacturing and delivery processes Use of incorrect materials Use and delivery of non-conforming materials 	Alpha, Beta, Delta, Epsilon, Kappa, Lambda, Tau
	Material flow control	<ul style="list-style-type: none"> Manufacturing control Routing 	Beta, Delta, Epsilon, Tau
	Location and status identification	<ul style="list-style-type: none"> Status identification Location identification Destination identification 	Alpha, Beta, Gamma, Delta, Epsilon, Kappa, Lambda, Sigma, Tau
	Alarm	Alarms on <ul style="list-style-type: none"> Expired items Missing items 	Delta, Kappa, Lambda
Legal verification	Warranty status verification	<ul style="list-style-type: none"> Verification of warranty period Verification of module origin 	Alpha, Beta, Gamma
	Fraud identification	<ul style="list-style-type: none"> Legal status identification Identification and reporting of missing products Use of traceability data in crime investigations 	Alpha, Beta, Gamma
	Proof of quality	<ul style="list-style-type: none"> Evidence on the details of the product or service provided 	Alpha, Delta, Epsilon, Kappa, Lambda
	Miscellaneous legal verifications	<ul style="list-style-type: none"> Product liability evidence Evidence of counterfeits Evidence of customer breach of contract 	Beta, Gamma, Lambda

Segregation	Segregation	Item segregation by a given attribute (e.g. source of problem, customer)	Alpha, Beta, Gamma, Kappa, Lambda, Sigma, Tau
Measurement and analysis	Logistics measurements and analysis	<ul style="list-style-type: none"> • Lead-time measurement • On-time delivery rate measurement and analysis • Routing analysis 	Alpha, Beta, Delta, Epsilon
	Quality-data analysis	<ul style="list-style-type: none"> • Design, process and material analysis • Troubleshooting 	Alpha, Beta, Kappa, Lambda, Tau
	Security-data analysis	<ul style="list-style-type: none"> • Analysis of responsibilities and losses 	Delta, Epsilon

Traceability records provided item- and lot-level information on the *origin, configuration, quality and age* of the products. This information was used as *evidence* in arguments between the company and its customers. The usage was related to situations where the companies needed to show that the company has manufactured and/or delivered the items according to the commitments made to the customer. Also, traceability data was used in the event of quality problems to show whether the problem in an individual item has originated from within the company, and if it has, whether the company is responsible for the item. The audit trail provided by traceability data for individual items was used to show contractual violations and crimes related to individual items.

Segregation applications were used to *segregate items with a given attribute value from the total product population*. Also in the use of segregation, the need for item-level identification was either related to quality problems or to the items being owned or ordered by a particular customer. Traceability data was used e.g. in the case of a problem with quality to identify defective items in the total product population or in the case of customer order cancellation, to identify the items in the material flow that were dedicated for the customer.

Individual item- or lot-specific data was used in various *measurements and analyses*. In these applications, data items that were collected at different points of time and/or at different locations, but still related to the same item or lot were combined. The data was used in the logistics measurements where item-level material flow performance was being measured. Moreover, the data was used in logistics-, quality- and security-related analyses, where causal relationships between the attributes related to individual items and lots and variations in the attribute values were being studied.

To summarise the findings, the case study companies used traceability data to identify and manage differences in item and lot properties. In the majority of cases, the differences were due to differences in age, origin, errors and variations, customer requirements, and theft and other violations.

Differences in the usage of traceability data between the *different industries* could be identified. In food and drug industries, traceability data was used primarily in quality management related applications in the manufacturing area. These applications targeted preventing the occurrence of quality problems, minimising the impacts of realised problems, and analysing the root causes of the problems. Also in the automobile industry companies, quality management

had a major role. Additionally, traceability data was used for production control purposes. In the electronics industry companies, the use of traceability data was heterogeneous. In addition to quality management, traceability data was used for logistics, security and after-sales purposes. In the transportation industry companies, the emphasis of using traceability data was in the fields of logistics and security. Here, the use of traceability data focused on material flow control and management, providing location and status information, and data for logistics and security-related analysis. Although industry-specific characteristics could be observed, the ability to draw generalised conclusions based on the findings is limited, due to the small number of cases per industry.

5.2 Impacts of using traceability data

The direct impacts and benefits provided by the use of traceability data observed in the case study companies are discussed in this section. Using the classification by Lillrank (1997, pp. 39 - 46), benefits are divided into three categories: cost savings, customer-perceived value and business option value. Business option value refers to benefits that are optional or that do not materialise without human action. Ultimately, obtained benefits are reflected in the financial performance of the company. However, the discussion does not go beyond the direct benefits.

5.2.1 Material flow management applications

5.2.1.1 Error detection and prevention applications

Use of error prevention applications was observed to enable case study companies to prevent or reduce errors due to the use of incorrect, unapproved or expired materials (Alpha, Kappa, Lambda, Tau) and due to incorrect handling (Delta, Epsilon). Error detection applications enabled companies to detect processing errors at an early phase (Beta, Lambda). The use of traceability data in error detection and prevention was suggested to be positively reflected in product and/or delivery quality and thus, to improve customer satisfaction. Moreover, the use of the applications were suggested to provide cost savings through reduction in the costs of corrective actions and disturbances in the manufacturing and distribution processes.

The impacts of the error prevention applications were demonstrated by the following examples:

At Company Beta, there were recurring problems with products that skipped a process phase. It was possible to detect the problem in the final test, but at this point, the assembly had already been completed. The products needed to be returned to the passed process phase, disassembled and reprocessed. This caused unnecessary effort and disturbance to the manufacturing process. An error detection system, which verified product history in each process phase, was established. It enabled fast detection of the errors and largely eliminated the problem.

At Company Alpha, recurring problems were experienced in the packaging and module assembly. Incorrect modules and accessories were being used and some items were mistakenly left out. As the error prevention application that verified the items being put in to each product was set up, the problem was largely eliminated.

At Company Lambda, the manufacturing history of each lot was verified in the finished product assessment before the lot was released for sale and supply. It was stated that as a result of this verification, it is basically impossible for a failure in the manufacturing routines to go unnoticed and for non-conforming products to be delivered for the customers.

Company Epsilon used traceability to prevent unintentional errors leading to misroutings of shipments in the delivery processes. Misrouting delayed shipment deliveries and thus, to reduced customer satisfaction. Moreover, misroutings were seen to increase distribution costs as the misrouted shipments were not delivered to their destination through an optimal route.

5.2.1.2 Material flow control applications

The use of traceability data was observed to enable case study companies to individually control items in the manufacturing, distribution and other processes. This then enabled case study companies to provide customised products and service for the customers, providing the customer-perceived value.

The applications used in the case study companies enabled the companies to customise the products to order (Tau) and deliver shipments to customer-specified destinations (Delta, Epsilon) and repaired products (Beta) back to the parties that had sent them in to be repaired.

The ability of the customs authorities to select the shipments to be inspected based on shipment-specific data was reflected in the operations of Company Delta in form of shorter delays in the customs inspections. Moreover, this reduced the need to handle and store undeclared materials and supported better route and delivery planning, which was reflected in cost savings.

5.2.1.3 Location and status identification applications

The use of location and status data enabled case study companies to provide order status information for the customers (Alpha, Beta, Delta, Epsilon) and for internal material flow management purposes (Lambda, Tau).

The availability of order status information for the customers was suggested to be critical element of customer service in both of the express industry companies (Delta, Epsilon). Both of the companies viewed this application as a market standard that must be available in order to not to lose market share or to be able to maintain price levels. At Company Delta, customers were considered to need status and location information particularly, when the timely arrival of the

shipment was critical. For instance a bid for business contract that needed to arrive at the destination before the due date or a letter of credit that may lose interest if not delivered on time. Moreover, status information indicating problems with the shipments was important for the customers as it provided an opportunity to get advance warning on late deliveries and other problems. However, despite the fact that traceability data was available for all Company Delta shipments, only in one to five per cent of the shipments did customers actually use the application and check shipment status. In a similar vein, data on repair (Beta) and manufacturing status (Alpha) enabled the provision of status information to the customers and thus, improved customer service. At Company Tau and to some extent at Company Lambda, the ability to identify location and to monitor manufacturing status was suggested to support production control.

In the event of certain exceptional situations affecting only specific items in the material flow and on the market (e.g. a quality problem or a customer order cancellation), the case study companies were able to reduce the negative impacts of the situation by using traceability data in locating the items. In the manufacturing companies, the ability to identify given materials and products from the internal material flow (Alpha, Beta, Kappa, Lambda, Tau) reduced the effort needed for locating products. This was the case particularly at companies Kappa, Lambda and Tau, where detailed traceability records enabled precise locating of the affected items. At Company Alpha, the inventory levels in the distribution chain were low, and thus, the added value of individual-item-level locating in relation to product-code-level locating was limited. The ability to quickly withdraw defective products (Tau) and products being manufactured for cancelled orders (Alpha) was emphasised. This was important in order to stop labour and material inputs from being used for undesired products, and thus to reduce the costs incurring from the defect or cancellation.

In the event of a critical quality problem requiring the withdrawal of the products from the market, the use of item- and lot-level shipment data (all manufacturing companies in the case study) enabled the focusing of the locating efforts and thus reduced the costs of a recall. Moreover, the ability to focus the effort enabled minimising public advertising of, and consequently, the adverse publicity caused by, the recall. For instance at Company Lambda, traceability data enabled the focusing of the recall efforts on specific countries. At Company Kappa, in the event of non-safety-critical recalls, it was often possible to recall the majority of inferior products from the external distribution chain, as the shipment destinations could be identified. Thus, the loss of good will caused by the inferior products ending up in the market could be minimised without carrying out a public recall.

Company Tau's OEM customers and Company Sigma were also able to identify the owner of each individual product. At Company Sigma, the ability to directly contact the owners of the products being recalled and thus, the resulting ability to avoid public advertising was important in reducing the publicity and the resulting damage a recall would cause to the company's image.

5.2.1.4 Alarm applications

Expiration-alarm applications (Kappa, Lambda) enabled companies to get early warnings on expiring materials in the inventory. The use of the application improved the ability to reduce waste and thus the costs resulting from expiration of raw materials and products.

Company Delta's application providing information on missing items in the sorting processes, gave the company the possibility of taking timely measures to study and rectify problems. Indirectly, this application was considered to improve security in the material flow and customer satisfaction and confidence through improved delivery reliability.

5.2.2 Legal verification applications

5.2.2.1 Warranty-status-verification applications

Warranty-status-verification applications provided cost savings through improved precision in warranty status verification (Alpha, Beta, Gamma). The application used at Company Alpha was able to identify the modules originally put into the product during the manufacturing process and covered by the warranty.

At Company Beta, the application was considered to have a positive impact on customer satisfaction as the need for a receipt as a proof-of-purchase was reduced. Moreover, the latest version of the application was identified as providing option values. It was seen to enable the sales of item-specific extended warranties and the creation of global warranties.

5.2.2.2 Fraud identification applications

The delivery of traceability data to the police authorities (Alpha, Beta, Gamma) was targeted at supporting authorities in crime investigations and thus, at discouraging crime. For instance at Company Alpha, the information provided to the authorities was demonstrated to have played a decisive role in solving a case. At Company Beta, providing the information was considered to support discouragement of crime-related to the products manufactured by the company. Providing the information was also considered to have a positive impact on public relations.

At Company Beta, as a result of using traceability data to identify stolen and otherwise illegal products in the service and repair processes, it was possible to repeatedly catch such products and in some occasions also to catch the thief. This application was considered to discourage crime-related to Company Beta's products, and in the long run, to have a positive impact on insurance premiums and customer satisfaction.

In one of the companies (Beta) ability to provide the serial numbers of the stolen items for the insurance companies was suggested to be a prerequisite for getting compensation from the insurance company.

5.2.2.3 Proof of quality applications

In five of the case study companies (Alpha, Delta, Epsilon, Kappa, Lambda), the availability of traceability data provided the companies with a means of providing proof of quality and/or showing the fulfilment of contractual commitments made to the customers.

At companies Delta and Epsilon, where the evidence data was frequently needed, the data gave the capability of showing that the shipment had been delivered to destination and that the delivery has taken place on time in relation to the time the customer had brought the shipments to be delivered. Moreover, at Company Delta, the availability of the measured shipment weight data enabled the company to show that a correct price has been charged to the customer. This information provided the means to respond to compensation claims and customer reclamations. Both Delta and Epsilon had a money-back guarantee. If the shipment was not delivered on time, the delivery was free of charge. Moreover, the ability to provide the information was considered to be important in maintaining customer confidence.

At Company Alpha, traceability records enabled identifying and demonstrating whether the configurations of the products delivered to the customers had been in accordance with the customer orders. Availability of the information was considered to be important in maintaining customer confidence and tackling compensation claims.

At companies Kappa and Lambda, traceability data provided the means to study and show whether a quality problem had - or had not - originated from the company. At Company Kappa, the ability to provide a comprehensive answer to the customer was suggested to play an important role in maintaining company image. Moreover, the availability of the data supported the management of product liability risks, which are also discussed in the following section.

5.2.2.4 Miscellaneous legal verification applications

At Company Beta, traceability data was used to provide evidence needed in product liability loss control. The application was considered to support the reduction of product-liability-related risks. It provided the evidence needed to show the liability of the company in relation to the origin, age and quality of the products.

At Company Gamma, the use of traceability data on some occasions enabled the company to show that a trade customer was carrying out cross-country trade and thus, that this customer was violating the agreements made between Company Gamma and the customer. The use of the data was suggested to have been successful in fighting cross-country trade and its negative consequences.

At Company Lambda, although never needed, the possibility of enabling identification of counterfeit products using traceability data was perceived. It was suggested that even the suspicion of a counterfeit product can halt sales, and

thus it is important for a company to be able to show whether a product is a counterfeit.

5.2.3 Segregation applications

The use of traceability data (in all of the manufacturing companies) in segregation enabled the case study companies to precisely identify items affected with a certain characteristic or to reduce the number of these items. This seemed to have two implications:

First, in make-to-order environments, the use of segregation enabled companies (Alpha, Beta) to identify items being repaired/manufactured to particular customer order. Thus, it was possible to provide customers with order status information at the order and customer level. Secondly, in the event of product quality problems (all manufacturing companies) or customer order cancellation (Alpha), the companies were able to minimise the magnitude of the negative impacts of these events.

In the event of a quality problem, the number of defective products to be located within the company, to be recalled from the market and to be inspected, repaired, reworked and/or scrapped was minimised. This provided cost savings and reduced the damage to the company image. The impacts of availability or unavailability of traceability data during the segregation was demonstrated by the following examples:

In the event of part quality problem at Company Tau, as the lot number of the parts used was known, it was possible to identify the affected automobiles within a margin of one or two per cent.

On the other hand, at Company Sigma, due to the lack of traceability, it was not possible to segregate the defective products from the non-defective ones. Thus, 90 per cent of the products were recalled unnecessarily. The direct costs of recalls peaked at FIMM 700 in 1991 and had remained at a high level until 1996. The majority of these costs could have been avoided with a precise traceability system. In addition to direct costs, the recalls were considered to have damaged the company image.

During a recall at Company Beta, one of the distribution centres needed to open all the sales packages of a certain type to find the faulty products. In the operation, some of the sales packages were damaged and the products needed to be repackaged. Direct labour costs of this operation were estimated to be several million FIM. Additional costs incurred as this operation delayed deliveries to the customers.

When a customer order was cancelled, the ability to quickly identify the products being manufactured in this order together with the ability to locate these items on the shop floor was suggested (Alpha) to be important in minimising the costs

incurring from the cancellation. Savings were obtained through the ability to stop resources from being tied to undesired products.

5.2.4 Measurement and analysis applications

5.2.4.1 Logistics measurements and analysis applications

Logistics measurements and analysis applications provided management information on internal (Alpha, Beta, Delta, Epsilon) and external lead-times (Beta), on-time delivery rates (Delta, Epsilon), and flow of materials (Sigma).

In comparison to the alternative methods providing management information, the use of traceability-data-based logistics measurements were considered to provide the ability to calculate deviations in the performance and to enable breaking the measured values down to details (Beta). As expressed differently, traceability-based logistics measurement applications were suggested (Delta) to enable 'microanalysis' of the data. Moreover, it was suggested (Alpha) that it is not possible to obtain adequately precise results with alternative inventory-cycle-time-based methods.

At Company Beta, traceability data was suggested to enable the calculation of total lead-times and lead-times in different process phases. Using the data, it was possible to calculate lead-times by customer, destination country or product type. These results were complemented with information on deviations in the lead-times. Moreover, the data enabled the company to calculate lead-times from the point of shipping through the external distribution chain to the point of sales, which would have been difficult to measure using alternative methods. The availability of this information was suggested by a regional Senior Vice President of Sales to be 'extremely important'.

At companies Delta and Epsilon, traceability data enabled performance analysis separately on different routes of the distribution network. Moreover, the use of traceability data provided item-level information on the underlying factors behind the failure to deliver a shipment on time. The data was also stressed as providing the capability to analyse the impacts of different factors in the distribution process on delivery performance.

At Company Sigma, the improved transparency of the material flows provided by traceability data had helped in pointing out problems in the shop-floor process and in simplifying the material flows.

5.2.4.2 Quality-data analysis applications

Analysis carried out using item- and lot-level quality data seemed to minimise the negative impacts of quality failures in two ways. First, the use of quality data supported corrective actions in repairing the defective items. At Company Beta, the availability of item-specific test result data supported manufacturing repair teams in troubleshooting. The use of the data reduced the troubleshooting time and consequently improved repair work productivity.

Secondly, the use of quality data supported the reduction of failures and defects in future products (Alpha, Beta, Kappa, Lambda, Tau). The availability of the item- and lot-level quality data provided business option values, which were realised in root problem analysis, supplier evaluation, and process and quality improvement.

Traceability information was used in manufacturing process improvement in five of the case study companies (Alpha, Beta, Kappa, Lambda, Tau). The way how the business option value was realised in quality and process improvement, varied from case to case, as demonstrated by the following examples. At Company Kappa, the use of traceability data enabled the tuning of a candy wrapping machine's rotation speed. Lot-specific rotation speeds were cross-referenced with lot-level quality feedback. Thus, it was possible to identify the impact of different rotation speeds on product quality and optimise the rotation speed. At Company Beta, item-specific final test results were cross-referenced with the item-specific tuning values in an earlier process phase. Using this information, it was possible to rapidly identify discrepancies between target and actual tuning values and the need for tuning equipment calibration. Together with the other functionalities provided by an application using test result data, this contributed to an increase in the yield of the manufacturing process by several percentage units. At Company Kappa, traceability data enabled the tracing of randomly recurring quality problem back to a specific part of the manufacturing process.

Two of the companies (Alpha, Kappa) demonstrated the impacts of using traceability data in supporting employee learning. At Company Kappa, the use of traceability data was suggested to have supported improvements in working methods. Moreover, it was underlined that personnel can learn how their actions affect subsequent process phases and end-product quality. In one occasion at Company Alpha, customer complaints were received regarding product quality. It was possible to trace back the problem to one of the employees. The employee was instructed in new working methods and the problem was eliminated. Furthermore, by using traceability records, Company Alpha was able to prepare reports which combined the quantity of products assembled by an employee with employer-specific quality inspection results. The employees could be rewarded accordingly.

Traceability data also supported efforts to improve supplier quality. At Company Alpha, traceability data enabled supplier-specific field-failure rate calculations. At Company Kappa, it was possible to trace a product quality problem back to one of the company's multiple pea suppliers and eliminate the problem.

5.2.4.3 Security-data analysis applications

In two of the case study companies (Delta, Epsilon), the use of traceability data in the field of security enabled identification of the weak points in the distribution network. Moreover, the data enabled identification of responsibilities and problem solving in the event of losses.

5.2.5 Discussion

The impacts of using traceability data could be divided into the following categories:

1. The use of traceability data *enabled* case study companies to provide *customised products and services* in accordance with customer requirements. More specifically, it enabled manufacturing, delivering and otherwise processing the items according to customer-defined, item-specific requirements and providing customers with item status information. The use of traceability data also provided an opportunity to create services related to individual products (e.g. sales of extended warranties). Customisation functionalities appeared either to have a positive impact on customer-perceived value or to be must-be functionalities which must be available in order for the company to be competitive.
2. The use of traceability data *prevented or reduced the number of undesired events with negative consequences in relation to an individual item or lot*. The ability to reduce errors in manufacturing and distribution processes and losses due to theft and deterioration reduced the disturbances in the manufacturing and distribution processes, the need for corrective actions, the number of errors visible to the customers and material waste. Thus, the use of traceability data provided cost savings and had a positive impact on customer-perceived value.
3. When an undesired event had already taken place or was suspected, the use of traceability data enabled companies *to reduce the magnitude of negative impacts*:
 - a) In the event of a quality problem or a customer order cancellation requiring withdrawal of the affected products from the material flow and market, traceability data enabled companies to minimise negative impacts. Case study companies were, with varying precision, able to segregate the affected items, minimising the number of items to be handled, and to identify the locations of the affected items, minimising the effort and time needed to find the affected items internally. Varying from case to case, this reduced further damage from being accrued, the costs of corrective actions and the negative publicity due to the withdrawal.
 - b) In the event of a quality problem, the use of traceability data enabled identification of product characteristics and thus reduced the effort and costs of troubleshooting during the repair activity.
 - c) In the event of customer complaint or legal action, traceability data enabled or supported showing the liability of the company in relation to the product's quality, age and origin, and contractual commitments made in relation to a product. The use of traceability data for this purpose appeared to reduce the amount or the risk of compensations. Moreover, the ability to provide the evidence was suggested as important in maintaining customer confidence in

the company. Thus the ability to provide item-specific evidence provided cost savings and customer-perceived value.

- d) In the event of theft or other illicit activity, the availability of traceability data supported companies in taking counter-measures. It was possible to get compensation from the insurance company by showing that an illicit activity had taken place and by indicating the affected products, and by supporting investigations of crime with this information and by identifying illicit items among the items the company was engaged with. This enabled the companies to achieve cost savings, business option value and customer-perceived value.
4. The results of measurements and analysis carried out using traceability data provided the case study companies with business option value, as it enabled them to identify current performance and deviations in performance on the item-level and to identify factors underlying the deviations and problems in logistics performance, product quality and material flow security. Thus, the use of traceability data provided an opportunity *to improve current performance and to prevent and reduce future problems*.

Table 7: Impacts of using traceability data.

Application categories	Applications	Impacts	Benefits	Companies using the application
Material flow management	Error detection and prevention	Reduced the number of errors in manufacturing and distribution processes	Cost savings Customer-perceived value	Alpha, Beta, Delta, Epsilon, Kappa, Lambda, Tau
	Material flow control	Enabled customised processing of individual items in manufacturing and distribution processes	Customer-perceived value	Beta, Delta, Epsilon, Tau
	Location and status identification	Provided availability of order status information for the customers and for internal parties. Reduced the negative impacts of problem situations (e.g. quality problem or customer order cancellation) by reducing the effort, speed and publicity of locating.	Cost savings Business option value Customer-perceived value	Alpha, Beta, Gamma, Delta, Epsilon, Kappa, Lambda, Sigma, Tau
	Alarm	Reduced the losses in the material flow due to theft and ageing.	Cost savings Customer-perceived value	Delta, Kappa, Lambda
Legal verification	Warranty status verification	Provided evidence needed in showing the age and origin of products, thus improving precision in warranty status verification, reducing the need for other means of evidence. Provided possibility for establishing customer-specific warranties.	Cost savings Business option value Customer-perceived value	Alpha, Beta, Gamma
	Fraud identification	Supported the efforts to reduce the negative impacts of crime by supporting crime investigations, by providing information required by insurance companies and by enabling the companies to catch illegal products.	Cost savings Business option value Customer-perceived value	Alpha, Beta, Gamma

	Proof of quality	Provided evidence needed in showing the level of product and service quality, how its price has been determined and fulfilment of commitments made towards customers, thus reducing the risk of compensation claims and loss of customer confidence.	Cost savings Customer-perceived value	Alpha, Delta, Epsilon, Kappa, Lambda
	Miscellaneous legal verifications	Provided evidence needed in showing the level of product quality, age and origin, thus reducing the risk of compensation claims and loss of customer confidence and preventing illicit activities.	Cost savings Customer-perceived value	Beta, Gamma, Lambda
Segregation	Segregation	Enabled segregating the items affected by a specific factor (e.g. quality problem, customer order), thus reducing the negative impacts of undesired events and providing an opportunity for customer-specific identification of products.	Cost savings Customer-perceived value	Alpha, Beta, Gamma, Kappa, Lambda, Sigma, Tau
Measurement and analysis	Logistics measurements and analysis	Provided detailed information supporting in-depth measurements and identification of causal relationships related to item-specific variations in logistics performance	Business option value	Alpha, Beta, Delta, Epsilon, Sigma
	Quality-data analysis	Provided detailed information supporting identification of causal relationships related to item-specific variations in product quality	Cost savings Business option value	Alpha, Beta, Kappa, Lambda, Tau
	Security-data analysis	Provided detailed information supporting identification of causal relationships underlying losses of individual items	Business option value	Delta, Epsilon

To summarise the findings, the use of traceability was observed to enable companies to manage physical items on the individual level in accordance with the differences in the properties of these items. Companies were able to differentiate products and services desired by the customers, to prevent or decrease the emergence of undesired deviations and to minimise the negative impacts of undesired deviations which had already been realised. The benefits of the above-mentioned impacts were realised in the form of cost savings, business option value and customer-perceived value.

5.3 Enablers

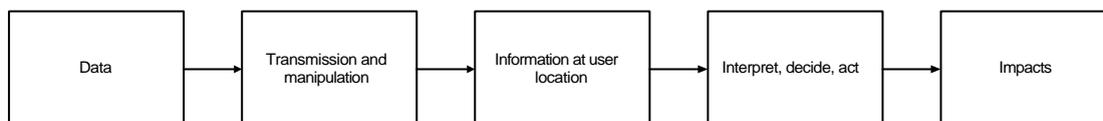
The third research question is related to the factors affecting the impacts of using traceability data. The following two sections aim at answering this question. The discussion on the enablers is divided into two parts. First, the factors that affect the impacts of traceability within the data usage process are studied. Secondly, the factors in the organisational setting affecting the existence and scope of traceability applications are examined.

5.3.1 Enablers in data usage process

The data usage process refers to the process by which the data is transmitted and manipulated in order to obtain required information at the user location. This information then, as a result of interpretation, decisions and actions, has various

impacts on the business enterprises. This section analyses the factors within the data usage process that affect the impacts of traceability data.

Figure 12: Data usage process - relationship between data, information, and impacts²².



The technical setting underlying traceability data transmission and manipulation did not seem to enable the case study companies in or prevent them from carrying out identification using traceability data. In other words, it was - at least in principle - possible to use traceability data for a given purpose, independent of the setting. However, the technical setting in which the data was used seemed to indirectly affect the usage of traceability data and the impacts that the use of this data had.

The technical setting in which the data was transmitted and manipulated was observed as affecting the usefulness of information through affecting

1. the speed of information availability
2. the amount of manual work, and
3. the accuracy of the information²³,

which again was identified as affecting the value of the information, the feasibility of carrying out the identification, and thus the impacts of using traceability data.

In the following section, first the role of information usefulness in realising the impacts of traceability is discussed. Then the factors in the technical setting affecting and enabling information usefulness through the process of data manipulation and transmission are discussed.

Table 8: The role of effort and speed in traceability data usage process.

Application	Impacts of the application	The role of effort and speed	Companies using the application
Error detection and prevention	Improved accuracy in manufacturing and distribution processes	<ul style="list-style-type: none"> • Speed is critical particularly in high-volume operations, in order not to delay the material flow processes • The amount of manual work may be critical in high-volume operations 	Alpha, Beta, Delta, Epsilon, Kappa, Lambda, Tau
Material flow control	Enabled customised handling of items in manufacturing, distribution and other processes	<ul style="list-style-type: none"> • Speed is critical particularly in high-volume operations in order not to delay operations • The amount of manual work may be critical in high-volume operations 	Beta, Delta, Epsilon, Tau

²² Cf. Alter, 1996, p. 29

²³ Discussion on the accuracy of information is limited to the extent the accuracy of the information provided by traceability applications is dependent on the data usage process. Accuracy of the raw data used in the traceability applications is excluded from the discussion.

Alarm	Provided early warnings on emerging problems	<ul style="list-style-type: none"> • Speed is important only when the verification is on the critical path in the (manufacturing or) distribution process • The amount of manual work important but not critical 	Delta, Kappa, Lambda
Status and location identification for customer service	Improved customer service through improved information	<ul style="list-style-type: none"> • Application speed is critical, as the value of the information for the customers depends on the speed of information availability • The amount of manual work may be significant in frequently used applications 	Alpha, Beta, Delta, Epsilon
Internal locating	Reduced the time and effort needed in locating given items internally	<ul style="list-style-type: none"> • Speed is critical to minimise the waste of resources when withdrawing WIP from the manufacturing process • Speed is important in process status monitoring • Speed is normally not critical when locating items in stock • Increase in the amount of manual work may reduce application usage as alternative locating methods are used instead • In most of the cases, the importance of the amount of manual work is trivial due to infrequent application usage 	Alpha, Beta, Delta, Epsilon, Kappa, Lambda, Sigma, Tau
External locating	Reduced the time and effort needed in locating given items externally through the ability to focus locating efforts	<ul style="list-style-type: none"> • The role of speed and manual work limited due to infrequent application usage 	Alpha, Beta, Gamma, Kappa, Lambda, Sigma
Proof of quality	Provided evidence on product and delivery quality	<ul style="list-style-type: none"> • The amount of manual work can be important in frequently used applications • In the infrequently used applications, the amount of manual work is not significant • Normally, application speed is not critical 	Alpha, Delta, Epsilon, Kappa, Lambda
Fraud identification	Enabled identification of and providing evidence on illegal items	<ul style="list-style-type: none"> • Speed is important in the high-volume identification of illegal items in enabling undelayed operations • Increase in the amount of manual work may reduce application usage or the coverage of the data used • The amount of manual work has limited importance when the application is infrequently used 	Alpha, Beta, Gamma
Warranty status verification	Enabled precise identification of warranty status	<ul style="list-style-type: none"> • Speed is important in the high-volume verifications in order not to delay operations • Increase in the amount of manual work may reduce the frequency of application usage and the coverage of the data used • The amount of manual work is important due to frequent usage of the application 	Alpha, Beta, Gamma
Miscellaneous legal verifications	Provided evidence on miscellaneous cases	<ul style="list-style-type: none"> • Speed is not critical • The amount of manual work is not significant due to infrequent usage of the application 	Beta, Gamma, Lambda
Segregation	Enabled identification of products with a	<ul style="list-style-type: none"> • In most cases, the amount of manual work is not significant due to infrequent usage of the application 	Alpha, Beta, Gamma, Kappa, Lambda, Sigma, Tau

	given property on precise basis	<ul style="list-style-type: none"> Speed critical to minimise the waste of resources when withdrawing WIP from the manufacturing process 	
Logistics measurements and analysis	Provided improved management information on a logistics performance	<ul style="list-style-type: none"> The amount of manual work may be notable Speed of data availability is not critical Increase in the amount of manual work appears to reduce the frequency of application usage Application usage may become biased to those parts of the material flow where the data is easily available 	Alpha, Beta, Delta, Epsilon
Quality-data analysis	Enabled identification of causal relationships and provided information needed in root problem analysis	<ul style="list-style-type: none"> The amount of manual work is important in some occasions Application speed is not particularly critical Increase in the amount of manual work may reduce the frequency of application usage The amount of manual work does not have an impact on the frequency of usage in customer-complaint-related analysis 	Alpha, Beta, Kappa, Lambda, Tau
Security-data analysis	Enabled identification of causal relationships behind losses and weak points in the material flow	<ul style="list-style-type: none"> Observations do not allow making comparisons of the importance of speed and effort. The importance of these factors was not emphasised in the case study companies in question 	Delta, Epsilon

5.3.1.1 Speed of information availability

The speed of information availability was observed to have the following implications:

1. Real time or a fast application speed could *enable application existence* or be critical in the environments where a delay caused by the application was not acceptable. In these occasions, the speed of the application enabled obtaining the positive impacts of traceability. This was the case, for example, in many of the error detection and prevention applications: a delay in the verification would have delayed the material flow processes. For instance, at Company Epsilon, a delay of few seconds in error prevention verification was considered unacceptable due to its impact on material flow processes.
2. Real time or fast speed could *increase the value* of the information provided by the application. This appeared to be the case in many of the customer-service-related status- and location-monitoring applications, where fast speed was considered to improve customer service. The importance of speed for the value of the information was demonstrated by Company Delta's money-back guarantee in shipment deliveries. The company promised to deliver the shipment for free if delivery status information could not be provided within 30 minutes of a request. In the case of delayed deliveries, early warning on a delay gave customers the opportunity to anticipate the problem. When products needed to be withdrawn from the material flow e.g. as a result of product defect or a cancelled customer order, the ability to quickly segregate

and locate the affected products helped to minimise the waste of resources caused by manufacturing of undesired products.

Altogether, the instant availability of data seemed to be critical in the frequently used operative applications, where a delay in the functionality of a traceability application would be reflected as a delay in the flow of materials. This was the case in the majority of the error-detection and -prevention, material flow control, and warranty- and legal-status-identification applications.

On the contrary, speed seemed to be unimportant in the applications where relatively small delays in data availability did not have any direct negative impacts. The applications in this category included, for example, those segregation and locating applications where the items were being searched for in internal storage and external locations. These applications were infrequently needed, and a small delay did not have notable negative impacts. Similarly, in many of the infrequently used but important legal verification applications, fast availability of the data was relatively unimportant.

5.3.1.2 Amount of manual work

The amount of effort needed to obtain the information in the desired presentation appeared to have the following impacts:

1. Reduction in the amount of manual work could provide savings in effort and thus in the costs of application usage. Occasionally, these savings could be notable. On these occasions, the amount of manual work affected the feasibility of using traceability data, i.e. the costs of using traceability data in relation to the benefits provided by it. For example at Company Epsilon, a notable amount of manual work had been needed in tracing the shipments until the computerised traceability system was introduced, as the data was retrieved from paper archives scattered among multiple units along the material flow. In some of the companies, traceability data was not used in internal locating applications due to the effort required in application usage.
2. The reduction in the amount of required effort could on some occasions increase the frequency of application usage. Moreover, this could also increase the scope of the application. For example, at companies Alpha and Beta, the logistics measurements were focused on that part of the material flow from which measurement data was easily available. Similarly, the high effort required in the use of traceability data in logistics measurements in these companies as well as in quality-data analysis at Company Lambda reduced the frequency of application usage. In the focus manufacturing site at Company Beta, the use of traceability data in quality-data analysis was only started when proper reporting tools were introduced eliminating the manual work in reporting. Thus, the amount of manual work in the usage of the application affected the amount of positive impacts provided by traceability data. In the warranty and legal status identification applications at companies Alpha and Beta, as a result of the difficulties in accessing the data, only the easily available part of the data was used or the data was not used at all.

The amount of manual work seemed to be important in frequently used applications, most of which were operative in nature. These applications included applications dealing with customer-related locating and status-monitoring, proof of quality, warranty- and legal-status-verification, logistics measurements and analysis, and in some of the companies, quality-data analysis. Moreover, in the majority of the error detection and prevention and material-flow control applications, the lack of manual work was presumably important.

On the contrary, the amount of manual work seemed to be unimportant in the applications, in which usage was infrequent or the applications were of potentially high importance or necessary. The applications in this category were largely the same as those, in which the speed of information availability was not critical. These applications included segregation applications, where the ability to segregate defective products from the total product population could have significant financial impacts (e.g. Company Sigma) and in the applications required by the authorities (e.g. defect analysis at Company Lambda) or customers (e.g. segregation at Company Tau). Applications in this category also included segregation and locating applications where the items were searched for in internal storage and external locations. Similarly, in many of the infrequently used, but important legal verification applications, the amount of manual work was relatively unimportant. Notably, the applications in which the role of effortless and fast information availability seemed to be among the 'traditional' traceability applications, i.e. among the applications that were already used in the 1960s and 1970s.

5.3.1.3 Information accuracy

Information accuracy seemed to play the following role:

1. Increased accuracy of the information obtained by manipulating and transmitting data increased the positive impacts achieved by using traceability data. For example at Company Epsilon, where traceability data was used to prevent misrouting of the shipments, replacement of manual error prevention mechanism with automated verification increased verification accuracy and enabled the company to largely eliminate routing errors.

It is feasible to suggest that the accuracy of the information in most of the applications plays an important role in realisation of the positive impacts of traceability data. However, the accuracy of information was not widely emphasised in the case study companies²⁴.

5.3.1.4 Technical enablers underlying information usefulness

The previous sections presented the relationship between the different components of information usefulness and the positive impacts of using

²⁴ On the other hand, the accuracy of the raw data used in the applications was considered a problem. However, quality of the data was not in the scope of this study.

traceability data. As suggested by Figure 12, in order to obtain the (positive) impacts of using traceability data, useful information provided by data manipulation and transmission is needed at the user location. In this section, different technical solutions observed in the case study companies are assessed in terms of:

- Input/Output Data Matrix application categories,
- The span of identification, and
- The complexity of identification (in terms of combined identification linkages and volume of data) supported.

Applying the application-specific criteria for information usefulness introduced earlier in this chapter, this then enables assessing the extent to which various real-life traceability applications are supported by different technical solutions.

Method of data storage

Electronic and paper records and product markings were used in storing traceability data at the case study companies. When the data storage was paper based, the data was typically organised by object. For instance at Company Lambda, traceability data was collected into paper-based batch records, i.e. books indicating a lot-specific manufacturing history. The history included lot-specific attribute data and information on material lots used in the manufacturing process.

When the usage of data on paper records (as opposed to data which is stored in electronic format) is analysed applying the Input/Output Data Matrix introduced in Table 4, the following observations can be made. The area in which paper records seemed strongest was in supporting object-to-attribute and object-to-object identification. For example, the batch records at Company Lambda were used in finished product assessment. With some effort and time, the object-(manufacturing-lot-) specific attributes could be analysed to verify conformance with requirements. In contrast, if the same records would have been used in attribute-to-object identification, the identification would have required the use of multiple object-specific batch records.

It is feasible to suggest that when attribute-to-object or attribute-to-attribute identification or identification requiring multiple input/output data linkages is desired, and/or the number of records to be gone through is large, the process of retrieving the information could become cumbersome. For example, in one of the factories at Company Sigma, finding the data needed for segregation was considered difficult, as there were 'tons of paper'. In a similar vein, at Company Lambda, the availability of manufacturing lot data only in paper format complicated quality-data analysis. The factory manager stated that '*when an analysis is undertaken, the required data is collected piece by piece.*' He continued that as a result of the effort needed, there needs to be a major reason before the analyses are initiated.

It is feasible to suggest that the limitations of using paper-based records remain, even if the data is organised by attributes instead by objects. In this case, the object-to-attribute and object-to-object identification becomes the cumbersome area.

When looking at the feasibility of paper-based data storage methods from the perspective of traceability applications, paper-based data storage (organised by object) seemed to be strongest in many of the legal verification applications. Here object-to-attribute identification could be relatively easily carried out although often, instant availability of data was not critical. For example in product liability loss control at Company Beta, the company policy allowed 48 hours for retrieval of the data. Thus, instant availability of the data was not critical.

In segregation and various analysis applications, where the instant availability of information was not necessary, paper-based storage of data could also be sufficient if the importance of the identification need could justify the possibly large effort needed to retrieve the data. With material flow management applications, the effort and time needed to retrieve the data could often be too long when the data was not available at the user location, even though these applications were largely based on object-to-attribute type of identification.

Material flow management was better supported when the traceability data was marked on or attached to the traced object. This enabled instant and effortless object-to-attribute identification when the traced object was physically present. For example, at Company Tau, the problem of providing easy availability of product-specific manufacturing instructions to shop-floor workers was solved by attaching the instructions to the products being manufactured. However, as with the paper-based documentation, a limitation of product markings was in the way they supported applications where an attribute was used as input data or where multiple identification linkages were needed.

In contrast, when the data was stored in electronic format, computerised methods of accessing and manipulating the data could be used²⁵. Examples of instant and effortless availability of information at user location could be observed in all of the categories of Input/Output Data Matrix. In addition, electronic storage of data appeared to enable fast availability of the information, even when complex chains of identification (in terms of multiple identification linkages or large volume of data - like many of the data analysis applications observed) were needed.

To summarise the findings, in comparison to paper- and product-marking-based data storage methods, electronic data storage methods appear to enable the largest portfolio of traceability applications. However, in many applications, paper- or product-marking-based methods are sufficient to support the use of traceability data for the desired purpose. Thus, the appropriate data storage

²⁵ One observation of applying computerised methods to paper-based data was made. At Company Epsilon, optical character recognition was used to enable computerised manipulation of written data.

method depends on desired application portfolio and the costs associated with the method.

Reporting tools

The availability of reporting tools supporting the use of traceability data varied from company to company and from application to application. For example, at Company Beta, elaborate reporting tools were available for manufacturing quality-data analyses, while for segregation purposes, no proper reporting tools were available. When the required data was available in an electronic format and at the location of usage, the availability of adequate reporting tools was observed to reduce the time and effort needed in data manipulation. For example, at Company Beta, traceability data which was easily accessible was not used to support the quality-data analysis application until the above-mentioned, ready-made reporting tools were introduced. This was due to the effort needed in the analysis. After the reporting tools were introduced, effortless and real-time availability of quality data was achieved, and the data was started to be used on a continuous basis in the analysis.

It appears that the difficulty of retrieving the required information increases as the complexity of the data usage in terms of the number of combined linkages and the volume of data needed in data manipulation increases. This is particularly the case with the data analysis applications, as is suggested by the example from Company Beta.

It is feasible to suggest that from the application perspective, the role of reporting tools is important in those applications where the 1) easy and/or effortless availability of information is critical from the application usage perspective and where the 2) introduction of reporting tools can support reducing the effort and/or time needed in manipulating the information. In addition to data analysis applications, the role of reporting tools can be critical also in the majority of the material flow management applications and some legal verification applications used in operations that require instant information availability, although the number of identification linkages is normally smaller than in the data analysis applications. In contrast, part of the legal verification applications as well as the segregation applications appear to allow some time and effort in data usage.

Altogether, the availability of sufficient reporting tools can be suggested to enable the largest portfolio of traceability applications. Still, in many application areas of traceability data, the identification can be carried out with ad hoc methods. Thus, the appropriate availability of reporting tools depends on the desired application portfolio and costs associated with establishing the tools.

Data accessibility

The fragmentation of traceability data into multiple, inaccessible information systems, as opposed to availability of data in one integrated and accessible information system was observed to increase the time and effort needed in data retrieval. This was the case when 1) the span of the identification linkage and/or

when 2) the combined identification linkages extended to the area covered by two or more information systems.

For example, the first case was clearly apparent in the comparison between Company Delta's locating applications being used in an integrated information system setting and the similar applications at companies Alpha and Beta, which had fragmented information systems. At Company Delta, if given the ID of the object being traced, its current and past locations throughout the material flow could be instantly identified. In contrast, at companies Alpha and Beta, locating a product in the material flow required the data to be separately retrieved from multiple information systems along the material flow. This again delayed the locating and required user effort.

The second case, i.e. integration supporting combined identification linkages, was apparent for example at Company Delta. Here, alerts were given if an item received at a sorting centre at a given time (attribute-to-object) was not registered to be shipped out by a given time (object-to-attribute). In this case, the required information collected at two distinct points along the material flow was available in the same information system, enabling timely and easy identification of problems. In contrast, for example, segregation at Company Sigma could require time and effort in order to combine data maintained in multiple data storages. Attribute-to-object identification (defective components) at the component manufacturer location, object-to-object identification at the motor manufacturer location (motors in which the components are used) and finally, object-to-object identification at automobile assembly (automobiles in which the affected motors were used) was needed to segregate defective automobiles from the total product population.

Consequently, increasing information system integration or providing other mechanisms supporting data accessibility appear to be needed 1) to the extent the span of the desired traceability applications can be covered, 2) in the cases where easy and/or timely availability of information is necessary for the application, and 3) when the possible costs incurred by improving data accessibility can be economically justified.

As observed in the previous sections discussing the role of speed and effort in traceability data usage, instant and effortless accessibility to the data is important in the majority of the material flow management, in operative legal-verification, and in a part of the data analysis applications. In the legal-verification applications that were not used in operations and in segregation applications, instant and effortless availability of the data was not as critical.

5.3.1.5 Discussion

The technical setting was observed to affect the impacts of using traceability data through affecting information usefulness. It appears that traceability data can be used for a given purpose independent of the technical setting, if an unlimited amount of time and resources is available for data transmission and

manipulation. The technical setting becomes relevant when constraints in relation to time and resources exist.

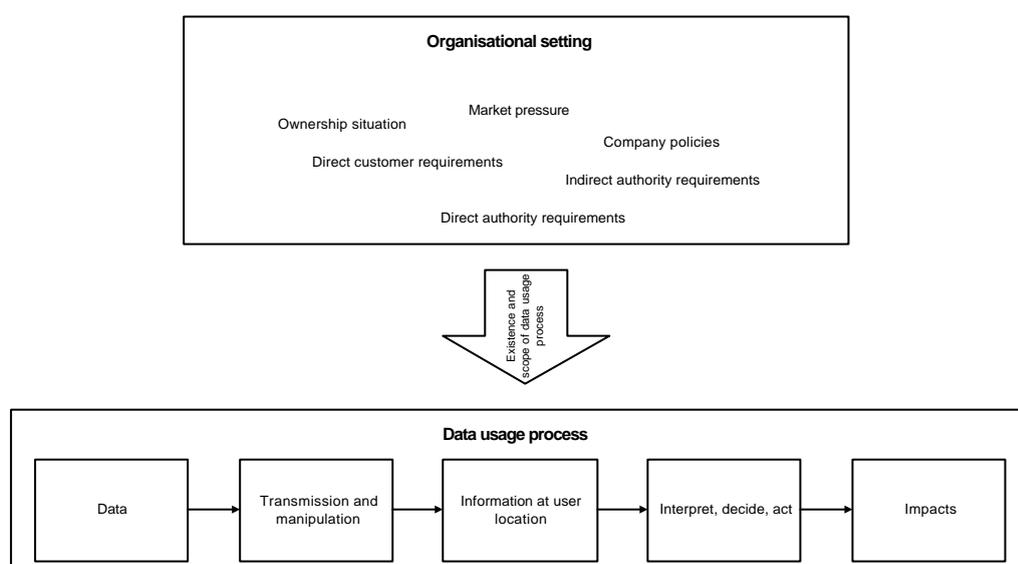
As presented in Table 8, time and effort are critical in the majority of the material flow management application and in many of legal-verification applications used in operations. In the data analysis applications, the amount of effort needed to carry out the analysis seemed to be relevant. In contrast, in less frequently used legal verification applications that were not used in operations, and in segregation applications with high importance, instant and effortless availability of information did not appear to be critical.

Consequently, the technical setting - in terms of method of data storage, level of data accessibility, and availability of reporting tools supporting instant and effortless availability of information - is relevant in enabling those applications where fast and effortless availability of information is important. However, the appropriate technical setting depends on the desired application portfolio, taking into consideration the costs and benefits incurred by introduction of the changes to the technical setting.

5.3.2 Organisational enablers

Unlike the role of the technical factors, it is ambiguous whether the role of organisational factors can fully be seen during the process of data usage. Instead, it is probably more likely that the factors in the organisational setting affect the extent to which the possibilities to use traceability data are perceived and decisions to use the data are made. Thus, the factors in the organisational setting would affect the usage and realisation of the impacts of traceability data through the way traceability data is used.

Figure 13: Organisational setting embracing the data usage process²⁶.



In the following, the role of the organisational setting is analysed by first investigating the organisational settings in the case study companies and by secondly analysing the occurrence and scope of the traceability applications in different organisational settings.

5.3.2.1 Organisational settings in the case study companies

The degree of centralisation in the organisational setting in which traceability data was used varied among the case study companies. In two of the companies, the ownership of traceability was centralised. In the other companies, the ownership was divided between two or more functions or sites through which the products and materials traversed. Parallel to the formal ownership structure, subject-area-specific ownership and company policies affected the use of traceability. In addition to the internal setting, external factors affected the use of traceability data. These included various authority requirements, direct customer requirements and market pressure. Organisational factors affecting the use of traceability data in each of the case study companies are presented in Table 9.

²⁶ Cf. Alter, 1996, p. 29

Table 9: Organisational settings affecting the use of traceability data in the case study companies.

Company	Organisational setting
Alpha	<ul style="list-style-type: none"> • Traceability is dominantly in local, site-level ownership • Some regional co-ordination in the field of traceability • In the focus manufacturing site, which includes the material flow within the receiving, module manufacturing, module assembly and distribution areas, traceability managed at the site level • In the other regional manufacturing site, trading companies' and service centres' traceability locally managed • No major requirements from external parties
Beta	<ul style="list-style-type: none"> • Traceability principally in functional ownership • Manufacturing units centrally managed by the manufacturing function • Distribution units centrally managed by the sales function • Service centres locally managed without central co-ordination. No explicit owner for traceability in the focus service centre • Centrally specified company policies govern traceability cross-functionally in the areas related to product liability loss control and product recalls • Application-specific ownership in the warranty-status-verification application • Application-specific ownership in legal-status-verification application • Product liability legislation indirectly affecting the use of traceability data in product-liability-related applications • Direct customer requirements playing an increasing role in the field of traceability • Some insurer requirements
Gamma	<ul style="list-style-type: none"> • Functional ownership • Product management has defined requirements for manufacturing units • Sales and distribution function has defined requirements in sales and distribution area • In addition to certain insurer requirements, no major requirements from external parties
Delta	<ul style="list-style-type: none"> • Ownership of traceability centralised in one global and three regional development groups • Market pressure affecting the use of traceability data in customer-bound applications
Epsilon	<ul style="list-style-type: none"> • Ownership of traceability centralised in a cross-functional development group and IT department • Market pressure affecting the use of traceability data in customer-bound applications
Kappa	<ul style="list-style-type: none"> • Functional ownership • Quality department responsible for traceability in the manufacturing area • Sales and marketing function responsible for traceability in the distribution centres • Some direct requirements related to traceability in the food legislation, although the requirements are usually indirect • Traceability requirements in ISO 9000
Lambda	<ul style="list-style-type: none"> • Traceability managed separately in Company Lambda and Lambda Distribution. Within these companies, traceability managed at the company and the site levels. • No explicit owner for traceability in the focus manufacturing site as traceability is managed as a part of other activities. However, the quality department ensures regulatory compliance and each function instructs implementation of traceability. • Trading companies manage traceability independently • Strong regulatory requirements for the level of traceability affecting the use of traceability data in several applications • Strong licensee requirements (derived from authority requirements)
Sigma	<ul style="list-style-type: none"> • Functional ownership • Traceability in the manufacturing units centrally co-ordinated, although manufacturing units can independently decide whether to implement traceability. • Traceability in the distribution units centrally co-ordinated by the sales function. • Product liability legislation and good manufacturing practice have some impact on the level of traceability.
Tau	<ul style="list-style-type: none"> • Functional ownership • Responsibilities divided between the materials department in charge of the receiving area and manufacturing department in charge of the manufacturing area. • Earlier, when traceability was established, quality department had company-wide responsibility for co-ordinating the activities in the field of traceability • Strong customer requirements for the level of traceability affecting the use of traceability particularly in safety-related applications (e.g. segregation)

In two of the case study companies, ownership of traceability was *centralised* (Delta, Epsilon). In both of the companies, cross-functional teams specified the requirements for traceability and developed solutions, which were then copied to the field units. In six of the case study companies (Beta, Gamma, Kappa, Lambda, Sigma, Tau), responsibilities in the field of traceability were divided between several *sub-units*. The following classes of sub-unit ownership situations existed:

- Centralisation of ownership within a functional area across multiple sites,
- Centralisation of ownership within a site across multiple functions, and
- Functional (or departmental) ownership within a site.

Additionally, at Company Lambda, the management of traceability was partially centralised within the manufacturing and distribution companies.

Nevertheless, the approach used in the management of ownership could vary between the different areas within a company. For example, Company Beta's manufacturing and distribution units were functionally managed as the service centres were managed at the site level. Moreover, the approach could be a combination of the above-mentioned classes. This was the case at e.g. Company Sigma's manufacturing function, where traceability was centralised at a functional level, but the manufacturing sites could make local decisions on the implementation of traceability.

Parallel to a formal ownership structure, external requirements affected the area of traceability. They could be divided into:

- Direct and indirect legal and authority requirements
- Licensee requirements
- Insurer requirements
- Customer and market requirements, including requirements in quality standards

Most clearly, direct traceability related legal and authority requirements in the form of the Good Manufacturing Practice affected the level of traceability at Company Lambda. At Company Kappa, requirements - although mostly indirect - were set by food legislation. At Company Sigma, Good Manufacturing Practice set requirements for the level of traceability. In companies Beta and Sigma, product liability legislation indirectly affected the level of traceability.

As a result of authority requirements, licensees set strong requirements for the level of traceability of the products Company Lambda manufactured under the licence. Insurance companies required data on lost products in two of the companies (Beta, Gamma). Direct customer requirements and market pressure affected the level of traceability in four of the case study companies (Beta, Delta, Epsilon, Tau). Particularly at Company Tau, but also increasingly at Company Beta, customers had set direct requirements for the level of traceability. In companies Delta and Epsilon, the level of traceability was affected by market

pressure. Furthermore, at Company Kappa, requirements set in ISO 9000 affected the level of traceability.

5.3.2.2 Organisational setting and the use of traceability data

Material flow management applications

Error detection and prevention applications were used in seven of the case study companies. This was mainly due to internal needs, but also due to authority requirements. The data used by the case study companies in these applications either originated from the material flow within ownership boundaries or was obtained from external parties (i.e. suppliers or customers). At companies Delta and Epsilon, cross-functional error detection and prevention applications were in the ownership of centralised development teams. Functional applications were observed in the companies with functional or site-level ownership (Alpha, Beta, Lambda, Kappa, Tau).

Table 10: Organisational setting and the use of traceability data in the error-prevention and -detection applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Customers, manufacturing process	Locally in the manufacturing area	Manufacturing site ownership
Beta	Manufacturing units	Locally in the manufacturing units	Manufacturing function ownership
Delta	Customers, unit receiving the shipments to be delivered	In the units throughout the distribution process	Centralised ownership
Epsilon	Distribution process	In the units throughout the distribution process	Centralised ownership
Kappa	Manufacturing function	Locally within the manufacturing function	Manufacturing function ownership
Lambda: finished prod. assessment, quality status verification	Manufacturing site	Locally within the manufacturing site	Manufacturing-company/site ownership, applications required by the authorities
Lambda: age verification	Suppliers, manufacturing process	Locally within the manufacturing site	Manufacturing-company/site ownership, marking of the expiration date required by the authorities
Tau	Customers, manufacturing function	Locally within the manufacturing area	Manufacturing function ownership

In all of the case study companies using traceability data in material flow control (Beta, Delta, Epsilon, Tau), the traced object-specific target data used by the applications originated directly or indirectly from the customers. Otherwise, the observed applications were implemented within ownership boundaries. Sub-unit-level applications were detected in companies Beta and Tau, where traceability was managed on the sub-unit level. Cross-functional applications were observed in companies Delta and Epsilon, where traceability was in centralised ownership.

Table 11: Organisational setting and the use of traceability data in the material flow control applications.

Company	Data sources	Use of the data	Organisational setting
Beta	Customers / incoming inspection in the service centre	Locally in the service centre	Service centre level ownership
Delta Routing application	Customers / points of receiving	In the units throughout the distribution process	Centralised ownership
Delta Customs application	Customers / points of receiving	Data delivered to customs authorities consolidated from multiple points of receiving	Centralised ownership
Epsilon	Customers	In the units throughout the distribution process	Centralised ownership
Tau	Customers / order entry	Locally within the manufacturing function	Manufacturing function ownership

Three of the companies (Delta, Kappa, Lambda) used traceability data for alarm purposes. In all of these companies, applications with functional scope were used by multiple units within the material flow. The application in one of the companies (Delta) was implemented within ownership boundaries, and in two of the companies (Kappa, Lambda), traceability data was used across ownership boundaries. Here, the availability of the data with the products was demanded by authority requirements.

Table 12: Organisational setting and the use of traceability data in the alarm applications.

Company	Data sources	Use of the data	Organisational setting
Delta	Sorting centres	Locally collected data used locally in the sorting centres	Centralised ownership
Kappa (manufacturing unit)	Suppliers	Used in the manufacturing function area	Functional ownership in manufacturing unit, availability of the age data required by the authorities
Kappa (distribution unit)	Manufacturing process at Company Kappa	Used in the distribution unit area	Functional ownership in the distribution unit, availability of the age data required by the authorities
Company Lambda	Suppliers	In the focus manufacturing site at Company Lambda	Manufacturing-company-/site-level ownership, availability of the age data required by the authorities
Lambda Distribution	Manufacturing process at Company Lambda	In Lambda Distribution's trading companies	Manufacturing-company-/site-level ownership in the focus site at Company Lambda and company/site-level ownership in the trading companies at Lambda Distribution. Availability of the age data required by the authorities.

Customer-service-related location and status identification applications were used in four of the case study companies (Alpha, Beta, Delta, Epsilon).

Table 13: Organisational setting and the use of traceability data in the customer-related status and location identification applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Material flow in the manufacturing and distribution area within the focus manufacturing site	Used by the customer service in the focus manufacturing site	Manufacturing-site-level ownership
Beta	Material flow within the focus service centre	Used by the customer service in the focus service centre	Service-centre-level ownership
Delta	Units throughout the distribution process	Data from multiple units used by customers and customer service	Centralised ownership Market pressure for the application
Epsilon	Units throughout the distribution process, partnering carriers	Data from multiple units used by customers and customer service	Centralised ownership Market pressure for the application

In addition to the customer-service-oriented locating applications (Alpha, Beta, Delta and Epsilon), products and raw materials were being located in the case study companies to respond to internal locating needs (Alpha, Beta, Kappa, Lambda and Tau) and to identify shipment destinations (Alpha, Beta, Gamma, Kappa, Lambda, Sigma). All of the shipment destination identification applications had emerged within ownership boundaries within a site or function (Alpha, Beta, Gamma, Kappa, Lambda, Sigma). At Company Beta, the locating application, which was controlled by the Sales function, was affected by the company policy requiring the ability to identify individual item-specific shipment destinations. External requirements for destination identification were observed only at Company Lambda, where authorities required the company to trace shipment destinations.

Table 14: Organisational setting and the use of traceability data in the internally used status and location identification applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Manufacturing site or trading companies	Local data used locally in the manufacturing site and in the trading companies	Site-level ownership in the manufacturing site and in the trading companies
Beta	Distribution centres	Local data used in the distribution centre	Functional ownership in the distribution centre, availability of the data required by a company policy
Kappa	Manufacturing site or distribution centre	Distinct applications using locally collected data in the manufacturing and distribution units	Functional ownership in the manufacturing and distribution units
Lambda	Manufacturing site or trading companies	Used in local applications in the manufacturing site and in the trading companies	Company/site-level ownership in the manufacturing site and in the trading companies
Tau	Materials and manufacturing departments	Used in distinct applications in the materials and manufacturing departments	Functional ownership

In all, traceability data seemed to be used in location and status identification largely due to internal needs. In two of the companies (Delta, Epsilon), market pressure played a major role in the emergence of the applications providing status information for the customers. In one of the companies (Lambda) authority requirements while in another of the companies (Beta) company policy set requirements for location and/or destination identification. In all of the companies, the locating applications had been implemented within the boundaries of ownership. At companies Delta and Epsilon, location and status identification applications were in centralised ownership and covered the entire material flow. In the companies with sub-unit ownership, distinct locating applications aligned with ownership boundaries were used in the independently managed sites and functions. Nevertheless, in the majority of these companies, the locating applications also covered the material flow throughout the company.

Legal verification applications

Three of the case study companies used traceability data in warranty status verification (Alpha, Beta, Gamma). No external requirements governing the use of traceability data in warranty status verification were discovered. The use of traceability data was observed both within (Gamma) and across (Alpha, Beta) ownership boundaries. At Company Alpha, the use of traceability data across sub-unit boundaries in warranty status verification was propelled by the company's International Technical Support, which had a co-ordinating role over traceability at the regional level. Similarly, at Company Beta, the use of traceability data across sub-unit boundaries started as service units perceived the existence of the data needed in warranty verification available at the distribution units. In 1997, a proper application supporting the use of this data was set up as a result of service unit requests.

Table 15: Organisational setting and the use of traceability data in the warranty-status-verification applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Manufacturing and distribution area in the focus manufacturing site	In the service centres	Manufacturing-site-level ownership in the focus manufacturing site, local ownership in the service centres, centralised co-ordination on regional level
Beta	Distribution units	In internal and external service centres	Distribution units functionally managed, local ownership in the service units
Gamma	Distribution centres and sales companies	In the sales companies	Functional ownership covering the distribution centres and sales companies

Fraud identification applications were used in three of the companies (Alpha, Beta, Gamma). The use of traceability data in other fraud-related applications appeared to be ad hoc in nature and used to the extent data happened to be available in different functions. However, in two of the companies (Beta, Gamma) the data needed in the application required by the insurance companies as a prerequisite for compensation for lost products.

Table 16: Organisational setting and the use of traceability data in the fraud-identification applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Manufacturing and distribution area in the focus manufacturing site	Retrieved locally in the manufacturing site and delivered to external parties	Manufacturing-site-level ownership
Beta Legal status verification	Internal and external sources throughout the company	Used in the service centres	Application-specific ownership of the global security department
Beta Loss identification and support of crime investigations	Manufacturing and distribution units	Data separately retrieved for users (security department) in affected manufacturing and distribution units	Functional ownership in the manufacturing and distribution area, serial number data on lost items required by the insurers
Gamma	Distribution centres and sales companies	Used within the sales and distribution function	Ownership of sales and distribution function, serial number data on lost items required by the insurers

Traceability data was used as a proof of quality in five of the case study companies (Alpha, Delta, Epsilon, Kappa, Lambda). In all of the companies, the data used as evidence was collected within ownership boundaries. In one of the companies (Lambda), in addition to internal needs, authority requirements affected the use of the proof of quality application.

Table 17: Organisational setting and the use of traceability data in the proof of quality applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Manufacturing area within the focus manufacturing site	Retrieved locally by the manufacturing site customer service to be delivered to the customers	Manufacturing site ownership
Delta	Units receiving and delivering shipments throughout distribution network	Data collected from multiple distribution units used directly by the customers or retrieved by the customer service	Centralised ownership
Epsilon	Units receiving and delivering shipments throughout distribution network	Data collected from multiple distribution units used directly by the customers or retrieved by the customer service	Centralised ownership
Kappa	Manufacturing function	Used by the customer service in the manufacturing site	Manufacturing function ownership (quality department)
Lambda	Manufacturing process within the manufacturing site	Retrieved locally in the manufacturing site and delivered to internal or external users	Manufacturing-company/site ownership, required by legally binding good manufacturing practice

Miscellaneous legal verification applications were implemented within ownership boundaries, in a sub-unit, in two of the case study companies (Gamma, Lambda) and across ownership boundaries in one of the companies (Beta). At Company Beta, the existence of the application was affected by a company policy defining the data, which needed to be available to support product liability management.

Table 18: Organisational setting and the use of traceability data in the miscellaneous legal verification applications.

Company	Data sources	Use of the data	Organisational setting
Beta	Manufacturing and distribution units, and service centres	Used centrally by the quality department	Traceability in functional ownership in the manufacturing and distribution units and service centres, availability of the data required by a company policy
Gamma	Distribution centres and sales companies	Used by the Sales and Distribution function	Traceability in this area in the ownership of Sales and Distribution function
Lambda	Focus manufacturing site	Ability to use the data although never used	Manufacturing-company-/site-level ownership of traceability

Segregation applications

Segregation applications were used in all of the manufacturing companies. Excluding the data from the suppliers, the data used in the segregation applications was with one exception in the ownership of one owner. At Company Tau, the data needed for segregation was collected by two departments. However, here the existence of this data was required by the OEM customers. In

addition to Company Tau, the direct external requirements were observed in Company Lambda, where the segregation capability was required by the authorities. At Company Beta, company policies affected the level of data collection.

Table 19: Organisational setting and the use of traceability data in the segregation applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Suppliers, Manufacturing area in the focus manufacturing site	Customer-order-related data retrieved and used within the unit. In the event of recall, data retrieved locally and delivered to the regional party organising the recall.	Manufacturing-site-level ownership
Beta	Suppliers, Manufacturing units	Internal data separately retrieved by distinct manufacturing units and delivered to a central quality department organising the recalls or other parties using the data.	Functional ownership in the manufacturing units. Requirements set by company policies.
Gamma	Manufacturing units	Data locally retrieved and delivered to the party organising the recall.	Functional ownership in the manufacturing units reflecting the requirements of product management
Kappa	Suppliers, Manufacturing function	Used locally in the manufacturing function by the quality department	Functional ownership in the manufacturing function
Lambda	Suppliers, Manufacturing unit	Internal data retrieved locally in the manufacturing unit. In the event of recall, the data is delivered to the Qualified Person organising the recall.	Traceability within the manufacturing-company/site in local ownership. Application required by the authorities.
Sigma	Suppliers, Manufacturing units	Internal data from distinct manufacturing units separately retrieved and used at company level	Manufacturing function centrally co-ordinating traceability in the manufacturing units
Tau	Suppliers, Materials and manufacturing departments	Internal data from materials and manufacturing departments can be separately retrieved and combined by the quality department. In case of recall, the data can be delivered to the OEM customer organising the recall.	Ownership of traceability divided between materials and manufacturing departments. Application required by the OEM customers.

The data used in segregation was locally retrieved by the units controlling the data. In the event of recall, this data would be delivered to the company-level owner of recall activities. The only exception was Company Alpha, where other units could themselves retrieve and use the data collected by Company Alpha.

Measurement and analysis applications

Five of the case companies (Alpha, Beta, Delta, Epsilon, Sigma) used traceability data in logistics measurements and analysis. No external requirements for logistics measurements were observed in the case study

companies. In three of the companies (Beta, Delta, Epsilon), data collected throughout the material flow was used in the measurements. In two of the companies (Delta, Epsilon), this data was available within ownership boundaries, and in one of the companies (Beta), the data was in functional ownership. In two of the companies (Alpha, Sigma), the scope of measurements covered the material flow within the ownership boundaries in a manufacturing site.

Table 20: Organisational setting and the use of traceability data in the logistics measurements applications.

Company	Data sources	Use of the data	Organisational setting
Alpha	Material flow within the manufacturing site	Local usage within the manufacturing site	Manufacturing-site-level ownership
Beta	Manufacturing and distribution units, end-user registration through relationship marketing	Retrieved locally by various units and delivered to be used centrally by the logistics department	Functional ownership in the manufacturing and distribution units. End-user data in the ownership of relationship marketing.
Delta	Distribution units throughout the company	Used both centrally in company level measurements and locally by the distribution units	Centralised ownership
Epsilon	Distribution units throughout the company	Used both locally and on company level	Centralised ownership
Sigma	Manufacturing units	Used locally in the manufacturing units	Traceability in the manufacturing units co-ordinated by the manufacturing function

Traceability-based quality-data-analysis applications were observed in five of the manufacturing companies (Alpha, Beta, Kappa, Lambda, Tau). Traceability data was used in the quality-data analysis largely as a result of internal needs. Only at Company Lambda, were certain analyses required by the authorities. The data used in the quality-data analyses was largely obtained within ownership boundaries in the manufacturing units. In two of the companies (Alpha, Tau), feedback data was systematically received across ownership boundaries from the field service units. The delivery of the data to support analysis was organised by an OEM customer at Company Tau and on a regional level by the company's International Technical Support at Company Alpha.

Table 21: Organisational setting and the use of traceability data in the quality-data analysis applications.

Company	Data sources	Use of the data	Organisational setting
Alpha Quality-data analysis application	Manufacturing area in the focus manufacturing site, service centres	Used by the quality department in the focus manufacturing site	Local ownership of traceability in the manufacturing site and service units. Company's International Technical Support co-ordinating traceability on regional level in quality-feedback-related issues

Alpha Employee reward application	Manufacturing area in the focus manufacturing site	Used locally within the manufacturing unit by the shop-floor supervisors	Traceability in the manufacturing site in site-level ownership
Beta	Part of the manufacturing process in the focus manufacturing unit	Used locally in the focus manufacturing unit	Traceability in the manufacturing units in the ownership of manufacturing function
Kappa	Manufacturing function	Used locally by the quality department in the manufacturing unit	Traceability in the manufacturing function in functional ownership
Lambda	Process from receiving to completion of manufacturing in the focus manufacturing site	Used locally in the manufacturing site	Traceability in manufacturing-company-/site-level ownership in Company Lambda. Problem analysis required by the authorities.
Tau	Materials and manufacturing departments at Company Tau	Data from both departments used by the quality department at the company level	Traceability in departmental ownership in the materials and manufacturing departments. Indirect customer requirements.

The use of traceability data in security-data analysis was observed in two of the case study companies (Delta, Epsilon), in both of which traceability was centrally managed. In both of the companies, the scope of the analysis covered the material flow and units throughout the distribution network.

Table 22: Organisational setting and the use of traceability data in the security-data analysis applications.

Company	Data sources	Use of the data	Organisational setting
Delta	Distribution units throughout the company	Used on company level	Centralised ownership
Epsilon	Distribution units throughout the company	Used on company level	Centralised ownership

5.3.2.3 Discussion

External authority and customer requirements played a central role in the use of traceability data in the case study company in the pharmaceuticals industry (Lambda) and to a lesser extent in the food (Kappa) and automobile industry companies (Sigma, Tau). In the electronics and transportation industry companies (Alpha, Beta, Gamma, Delta, Epsilon), the role of direct external requirements was limited.

External requirements could largely be attributed to the safety-critical nature of the products. As a result of the requirements, the affected companies needed to set up traceability applications preventing the emergence of quality problems and the sale and supply of non-conforming products. In the event of quality problems, the affected companies needed to study the problems and segregate and locate the defective products in order to minimise the impacts of the problem. In the areas governed by external requirements, the role of the other factors affecting the usage and impacts of traceability data appeared to be limited.

However, external requirements alone did not explain the existence of traceability applications in any of the traceability application categories. In all of the main application categories, the applications had primarily emerged as a result of internal needs²⁷.

When the use of traceability data was voluntary, the span of traceability applications seemed to be connected to the ownership structure. The applications appeared to be aligned with the ownership structure in terms of the area within which the applications were used. When the area of traceability ownership was aligned with function or site boundaries, the span of the traceability applications seldom exceeded the boundaries of the function or site. With few exceptions, company-wide applications or applications exceeding the function's or site's boundaries were observed only in the companies where ownership of traceability was centralised or where other co-ordinating factors were present²⁸.

When external requirements for the usage of traceability data across organisational boundaries existed, the use of data was typically fragmented so that each functional area or site had its own application. For example, in many of the case study companies' alarm and locating applications, the applications were used throughout the material flow, but they were based on sub-units independently collecting and using traceability data.

Increasing the span of traceability data usage appeared to be desirable due to two reasons:

1. It enabled increasing the scope of a given identification linkage (see the Input/Output Data Matrix in Chapter 5). For example, the focus manufacturing site at Company Alpha and the focus service centre at Company Beta delivered customer order status information to the customers. The location and/or status attributes of the object in question could be identified to the extent the data originated from within the site-level ownership boundaries at the sites in question. However, status information could not be provided to the customers from the area where the delivery of completed products was undertaken by the other units of these companies.
2. It enabled an increased number of combined identification linkages. For example at Company Alpha, increased regional co-ordination enabled quality-data analysis, where product-specific field-failure data collected in the service centres (attribute-to-object identification) was combined with product-specific manufacturing data (object-to-attribute).

Thus, it can be suggested that the organisational structure should (when no other co-ordinating factors are present) be aligned with desired maximum span of

²⁷ External requirements may have indirectly affected the emergence of some of these applications.

²⁸ Co-ordinating factors observed included company policies and customer and authority requirements.

traceability data usage in order to enable construction of the desired application portfolio, and consequently, bring the desired impacts of using traceability data. If cross-functional applications are desired, the ownership structure should be cross-functional.

In fact, the trend in the case study companies appeared to be towards increased centralisation of the ownership of traceability. In two (Delta, Epsilon) out of nine case study companies, the ownership of traceability was centralised, and in two other companies (Alpha, Beta), the functional or site-level ownership of traceability was being centralised during the study.

6. RESULTING THEORY

This chapter summarises the results of the dissertation, introduces the resulting theory and evaluates the contribution of this study by comparing the results to the existing body of knowledge. The comparison is carried out by discussing the research questions, which were the following:

1. How is traceability data used in business enterprises?
2. What are the impacts and benefits of using traceability data?
3. What factors enable a business enterprise to fully realise the positive impacts of traceability data?

Suggestions for further research are given at the end of the chapter.

6.1 Use of traceability data

Prior research and literature

A large number of ways to use traceability data have been identified in the literature. The applications presented in the literature use traceability data in logistics, quality, security, cost accounting and legal applications. However, the existing literature has made no attempt to comprehensively understand how traceability can be used.

A number of applications where traceability data is used in *analysis and measurements* related to product quality and cost, process performance and security exist in the literature. Several authors recognised an opportunity here in to cross-reference product-manufacturing data with data on quality problems and process performance in order to identify *product-quality and process-performance-related cause-effect relationships* (Jacobs et al., 1975; Juran et al., 1988; Wall, 1993a; Kendrick, 1994). Similarly, the possibilities of using traceability data to identify causal relationships in security and logistics contexts were identified. For example, the opportunity to cross-reference the route and responsibility data on *losses* and other material flow events in order to identify reasons for deviations was acknowledged (see e.g. Violino, 1995; Armstrong-Smith, 1997; Hook, 1997; Swerdlow, 1997).

In the field of logistics, opportunities to use traceability data collected during the manufacturing and distribution processes to *measure logistics performance*, including lead-times (Moulding, 1993) and machine capabilities (Kendrick, 1994), was identified. Furthermore, the possibility of using this data to *measure costs and value added* between each point in the supply chain was recognised (Florence et al., 1993; Swerdlow, 1997).

Moreover, the literature identifies several applications where traceability data was used to *identify product characteristics*. These applications included warranty status verification (Jacobs et al., 1975; Juran et al., 1988) and

identification of products and their configurations (Juran et al., 1988; Caplan, 1989). The possibility of identifying product history and to use it as legal evidence, proof of quality or proof-of-origin was emphasised by several authors (Williams, 1990; Kendrick, 1994; Wall, 1994a).

Furthermore, several material-flow-management-related applications used in operations were identified. According to Juran (1988), traceability data can be employed to prevent the use of non-conforming materials. Parker (1992) illustrated the use of traceability data in ensuring that products have gone through all the required process steps. The use of traceability data in identifying the status and location of items in the manufacturing and shipping processes, and managing items which are delayed or gone astray (Dutton, 1993; Dobler, 1996; Dürr, 1997) were emphasised. Florence et al. (1993) identified the possibility of using traceability data to control shipments in terms of their best-before date. In the event of product recall, traceability can be applied to identify the affected products from among the total product population (Jönson, 1985; Caplan, 1989) and to identify the end-users of these products (Williams, 1990).

This study

This study comprehensively analysed the uses of traceability data in the case study companies. As a result of the analysis, it was found that traceability data used as application's input or provided as its output either specifies a traced object or its attributes. Based on this observation, a generic model for categorising traceability applications emerged. The four categories that emerged were the following:

Table 23: Application categorisation based on input and output data.

INPUT/OUTPUT	Traced object	Attribute
Traced object	1. Object -> Object	2. Object -> Attribute
Attribute	3. Attribute -> Object	4. Attribute -> Attribute

1. Identification of connected objects: Traceability data can, for example, be used to identify in which individual product item an individual child part has been used.
2. Identification of the attributes of an object: Traceability data can, for instance, be used to identify the location of an individual item.
3. Identification of objects with a given attribute: Traceability data can, for example, be used to identify those items that have been affected by a manufacturing process that has caused a defect in the items.
4. Identification of connected attributes: Traceability data can, for instance, be used to identify causal relationships between the attributes related to an individual item. For example, process parameters in the manufacturing process can be connected to failure data on the individual-item level.

Following the theoretical categorisation, but acknowledging its limitations and looking pragmatically at the real-life applications of traceability data, the uses of traceability data can be divided into four categories, which are the following:

1. **Material flow management:** In the material flow context, traceability data can be used operatively to identify the attributes of individual items and lots. The applications in this category are used in three ways. First, they are used to identify deviations from targets by comparing individual-item- or lot-specific target values with actual values. Secondly, they are used to provide target data or instructions for handling items in the material flow. Thirdly, they are employed to identify the location and status of an item or lot in the material flow. Here, the time between the creation of the data and its usage is often relatively short.
2. **Legal verifications:** Traceability data can be used to identify the attributes of individual items and lots in order to provide item- or lot-specific information or evidence. Normally, these applications are not used in operations, where the time range between the creation and usage of the data is long.
3. **Segregation:** Traceability data can be used to identify products with certain attributes from among the total product population.
4. **Measurements and analysis:** Traceability data can be used to identify connections and causal relationships between the attributes of individual items and lots. In various measurement and analysis applications used in quality, security, logistics, accounting and marketing, traceability data can be employed in order to obtain measurement information and to identify cause-effect relationships between the attributes related to individual items and lots.

Notably, the use of traceability data in these applications is related to managing illegal activities and variations in item age, origin, and destination, in customer requirements and in product and service quality.

Contribution to the prior body of knowledge

This dissertation comprehensively studied different ways of using traceability data. The individual applications of traceability observed in the case study companies largely coincide with the applications already suggested in the literature. However, new insights in to the use of traceability data within various application areas arose. Particularly the possibilities to use traceability data as evidence seem to be more diverse than is suggested in the literature. Although still in the planning phase, emerging applications in the fields of marketing and recycling were observed.

Nevertheless, *the main contribution of this study is a presentation of a structured, comprehensive and detailed framework of the ways traceability data can be used.* This has been achieved through introducing a theoretical and a pragmatic framework for categorising the uses of traceability data.

The theoretical framework provides an understanding of the uses of traceability data in a generic setting. Additionally, recognising the categories of this framework is critical when designing traceability systems in order to establish solutions that support the full scope of traceability applications. This issue is further discussed in Section 6.3.1, which deals with technical enablers in the data usage process.

The pragmatic framework provides a road map for identifying opportunities to use traceability data. In other words, this framework can be used as a benchmark when selecting the applications to be implemented in a traceability system.

Hopefully, the findings of this study suppress the last conceptions of traceability as historical record-keeping having importance only in crisis situations and emphasise its role as a source of management information and as an enabler and facilitator of operations.

6.2 Impacts and benefits of using traceability data

Prior research and literature

In the prior research and literature, the discussion on the impacts and benefits provided by the usage of traceability data is limited, as the main focus of the literature seems to be in the usage of traceability data. Like in the review of the literature on the usage of traceability data, the existing literature makes no effort to comprehensively analyse the impacts of using traceability data. Consequently, the understanding remains fragmented and is based on anecdotes.

Nevertheless, the existing body of knowledge identifies positive impacts, mainly in the fields of quality, logistics and security. Several authors emphasise the role of traceability data in supporting quality and process improvement by providing the means to *identify factors underlying deviations in product quality* (Jacobs, 1975; Caplan, 1989; Wall, 1993a; Kendrick, 1994) and *process performance* (Wall, 1993a).

Moreover, traceability data can *provide proof-of-origin and proof of quality* information required by customers and legal evidence needed by the company (Williams, 1990). Availability of proof-of-origin information can have implications on marketing and price formation (cf. Fausti, 1995; Hobbs, 1996; Maitland, 1996).

In the event of product recall, traceability can *support minimisation of the number of products to be recalled* (Jönson, 1985; Caplan, 1989) and locating the products on the market (Williams, 1990). This again (Williams, 1990) to reduces the costs of the recall and the damage caused to company image.

In material flow management, the use of traceability data provides early *warnings* on delays (Dürr, 1997) and supports *prevention of errors* and thus, assures the

quality of the manufactured products (Juran, 1988; Parker, 1992). The *transparency* across the supply chain provided by traceability is described (Florence et al., 1993; Dürr, 1997) as affording an opportunity for logistics partnerships through creation of seamless supply chains and improving operational flexibility when reacting to changes in demand. Visibility also improves customer service (Ballou, 1992) and resource utilisation (Armstrong-Smith, 1997; Dürr, 1997). It is also pointed out (Moulding, 1993; Kendrick, 1994) that the use of traceability data provides *data on performance in logistics processes*.

Florence et al. (1993) and Swerdlow (1997) discuss the opportunity of obtaining accurate *cost information* using traceability data.

Security-related traceability applications are *enable identification and analysis of losses* (Armstrong-Smith, 1997; Swerdlow et al., 1997) and can *prevent fraud* (Knill, 1994; Violino, 1995; Hook, 1997) and *piracy* (Sharp, 1990).

This study

In this study, the impacts of traceability applications were systematically analysed. The synthesis from this exercise was a categorisation of the impacts of using traceability data. According to this study, the use of traceability data:

1. *Enables the creation of customised products and services* in accordance with customer requirements. More specifically, the use of traceability data enables manufacturing, delivering and otherwise processing individual items according to customer-defined, item-specific requirements and providing customers with information related to the item's statuses in these processes. Moreover, the use of traceability data enables the creation of services that are related to individual items.
2. *Prevents or reduces the number of undesired events*. More specifically, the use of traceability data enables preventing and reducing errors in manufacturing and distribution processes and losses due to theft and deterioration.
3. *Reduces the negative impacts of undesired events* that have already taken place. a) In the event of recall or other withdrawal of products from the material flow or market, the use of traceability data enables timely withdrawal and minimisation of the number of items to be withdrawn, thus minimising the costs of withdrawal and damage caused to public image. b) In the event of a quality problem, the use of traceability data supports minimisation of troubleshooting efforts, thus minimising the costs of repair activity. c) In the event of customer complaint or legal action, traceability data provides the information and evidence needed to respond to the customer complaints. This supports maintenance of customer confidence and minimisation of compensation claims. d) In the event of theft or other illicit activity, availability of traceability data supports companies in taking counter-measures. For

example, traceability data provides information needed in insurance claims, supports investigations of crime, and also in identification of stolen and counterfeit items.

4. *Reduces and prevents future problems:* By using traceability data in analysis and measurements, it is possible to uncover factors underlying deviations and problems in logistics performance, product quality and material flow security. This provides the opportunity to improve current performance and to prevent and reduce future problems.

In other words, the use of traceability data enables companies to identify and manage differences in the properties of individual items and lots. The differences observed in the case study companies and in the literature were differences in product age, origin and destination, customer requirements, and undesired errors and variation in quality and illicit activities.

Contribution to the prior body of knowledge

The main contribution of this study is not the identification of the impacts of individual applications. Although this study increases the richness of detail in understanding the impacts, the impacts observed in the literature are largely similar to those observed in the case study companies. More importantly, this study:

- Provides a comprehensive understanding of the impacts of using traceability data in different applications through systematic and comprehensive analysis.
- Creates a categorisation of the impacts of using traceability data as a synthesis of the impact analysis.

Until now, the existing body of knowledge of the impacts of using traceability data has been fragmented, and comprehensive presentations²⁹ of the impacts have not been available.

6.3 Enablers for realising the positive impacts of traceability data

6.3.1 Usage process

Prior research and literature

Traceability-related literature has identified a number of factors affecting the usefulness of traceability data. Looking from the data usage perspective and excluding the characteristics of data itself, the following criteria of data usefulness emerge in the literature. Real-time (see e.g. Feigenbaum, 1991; Dürr, 1997; Lord, 1997; Swerdlow et al., 1997; Williams, 1997) and easy (see e.g. Feigenbaum, 1991; Kendrick, 1994; Wall, 1994a) availability of data has been underscored. It has been suggested that requirements depend on the frequency

²⁹ See Appendix 8.1

of access required and the retrieval time permitted (cf. Steele, 1995). Cheng et al. (1993) emphasise the importance of data accuracy and quickness of data availability in the success of short-term control mechanisms, while in the planning, design and strategy applications, quickness is not seen as critical. Security through access restrictions in inter-organisational systems is also emphasised. Restrictions offer security and protection and provide confidence for all users of the system (cf. Armstrong-Smith et al., 1997, p. 32; Dürr, 1997, pp. 1528 - 1529; North, 1997, p. 34).

Several technical enablers to meet the criteria are identified. The use of computerised records is advocated, because traceability based on manual records is both complex (North, 1997) and time-consuming (Steele, 1995). However, manual records are considered to be sufficient when infrequent access is needed (Steele, 1995). Goodhue (1992) demonstrates how data integration improves traceability. Plant-wide systems (cf. Kendrick, 1994; Steele, 1995) enable quick and easy analysis of data. Florence et al. (1993) advocate a certain level of integration of traceability systems in order to support an end-to-end view of traceability in the material flow. Wilson et al. (1998, pp. 127 - 133) emphasise one data store, a common means of access, and a system whereby the data is defined by consensus across the industry to ensure traceability in fragmented supply chains with a large number of players. It has been suggested that centralised systems increase security by reducing the threat of fraud (North, 1997). On the other hand, Sharp (1990) prefers the use of distributed systems due to the reliability and accessibility offered by them.

This study

In this study, the technical setting in which traceability data was used, was observed to be reflected in the impacts of traceability data by affecting information usefulness. Information usefulness means whether the information is useful for given purpose. The following criteria for information usefulness were observed:

1. Speed of information availability. This is a) critical for application existence in the situations, where instant or fast availability of information is required and b) can increase the value of the information provided by the application, e.g., in customer service-related activities.
2. Ease of information availability. This a) can notably reduce the amount of manual work needed to access the data and thus the costs of application usage. b) Ease of information availability can increase the usage of traceability data and thus increase the positive impacts of using the data.
3. Information accuracy can increase the value of the information and thus the benefits obtained by using the information.

The amount of effort needed to access and manipulate the data is critical in frequently-used operational applications and to some extent in analysis and

measurement applications. In these applications, an increase in the amount of effort needed reduced the frequency of application usage and the amount of data used in the application. Like the amount of effort needed, timely availability of data is critical in frequently used applications used in operations and also in some measurements and analysis applications. In the applications used in operations, slow speed could delay the operations. Moreover, the speed of information availability affects the utility provided by the application, e.g. in the applications providing early warnings of shipment delays or applications providing status information for the customers.

In contrast, in applications that are infrequently used, where instant availability of data is not necessary and/or where a single instance of data usage has important implications, the amount of effort and speed does not play as critical a role. These applications include many of the locating applications used in operations, legal verification and segregation applications.

Information timeliness and accuracy as well as the effort needed to obtain the information is influenced by the technical setting. In this study, the method of data storage, the level of systems integration and the availability of ready-made reporting tools were observed to affect information usefulness. Because the criteria for information usefulness varies between the traceability applications, the appropriate technical setting is dependent on the desired application portfolio. With respect to the above-mentioned factors in the technical setting, the largest range of traceability applications is supported by:

1. The use of *electronic data storage*, enabling usage of information technology to manipulate and distribute data, reducing the time and effort needed in data manipulation and transmission.
2. The availability of sufficient *reporting tools*, reducing the effort and time needed to provide accurate information with the right presentation.
3. The use of *Integrated information systems* covering the span of traceability data usage, thus reducing the number of manual steps and the effort and time needed to access the data. Reduction in the number of manual steps also reduces the likelihood of errors in data manipulation. Furthermore, the availability of data in one accessible system facilitates the creation of reporting tools.

Contribution to the prior body of knowledge

The contribution of this study is that it comprehensively and scientifically clarifies the role of the components of information usefulness in reaching the positive impacts of traceability data in each traceability application category. Specifically, the importance of speed and ease of information availability and to some extent, the role of information accuracy, were highlighted by this study. These findings, which are also in line with the information management literature, support and

complement the current understanding of the elements of information usefulness in the traceability literature.

Furthermore, this study links the factors in the technical setting to information usefulness and thereby to the impacts of using traceability data. By analysing the role of technical setting, this study provides insights to the questions regarding what kind of technical setting is appropriate for enabling or supporting the use of different traceability applications. The discussion on electronic vs. paper or product-marking-based methods of data storage, integrated vs. functional information systems, and the availability of reporting tools vs. archiving data without establishing reporting tools is relevant, because all of these approaches are common in the case study companies.

More importantly, the results of this study provide generic guidelines for evaluating the feasibility of different technical solutions in supporting the use of traceability data. Technical solutions can be assessed in terms of different Input/Output Data Matrix categories, and the span and complexity of identification supported. On the other hand, the desired traceability applications can be positioned in the matrix, and their span and complexity determined. Acknowledging the application-specific requirements for information usefulness, this enables assessing the feasibility of different technical solutions.

For example, one important observation that can be made using the framework is that techniques where item-specific information is attached to the item itself (e.g. markings on the items and RFID technologies) support only a limited set of applications. They do support object-to-attribute and object-to-object types of applications when the objects are physically present. However, when attribute-to-object and attribute-to-attribute type of applications are to be used, instant and effortless availability of information is not supported. Another example of the observations that can be made using this framework is that fragmented information systems support the use of traceability data to the extent that the span of identification remains within the information system boundaries. When the span of identification requires combining information from multiple information systems, applications critical to the speed and ease of information availability are not fully supported.

6.3.2 Organisational setting

Prior research and literature

The existing body of knowledge on the impact of organisational settings on the use of traceability data is limited.

Both top-down and bottom-up approaches are advocated as ways of managing the domain of traceability. It is suggested that departmental ownership of traceability data can hinder active utilisation of traceability data (cf. Moulding, 1993). Florence et al. (1993) emphasise the importance of an end-to-end view of traceability and the need for establishing traceability across the supply process. Sohal (1997) emphasises the importance of multidisciplinary teams in the

implementation of traceability. Feigenbaum (1991) exhorts establishment of a systematic program for traceability-related tasks.

On the other hand, according to Wall (1993a) and Williams (1990), establishment of traceability should be driven from the bottom up. They suggest this ensures that the system will work in practice (Wall, 1993a) and be implemented effectively (Williams, 1990).

This study

In this study, the following factors in the organisational setting were found to affect the use of traceability data:

- Ownership structure
- Company policies
- Direct customer requirements and market pressure
- Direct and indirect authority requirements
- Licensee requirements

External authority, customer and licensee requirements play a central role in the use of traceability data in the pharmaceuticals industry and also some role in the food and automobile industries. Mainly, these requirements affect the use of safety-related applications, like error-detection and -prevention, segregation and locating applications.

The ownership structure, i.e. centralised vs. sub-unit (functional or site-specific) ownership of the traceability seems often to affect the scope of traceability applications, and thus the impacts the use of these applications have. The structure is reflected in the scopes of the applications, which are largely aligned with ownership boundaries. In companies where the ownership of traceability is centralised, both cross-functional and functional applications are observed. In companies where traceability is managed on the sub-unit level (functionally or on the site level), the applications in most of the cases support only the sub-unit in question. Cross-functional applications are either not used or their scope is limited to the material flow within the ownership boundaries.

However, traceability data is used for given purposes in multiple functions also, when ownership is fragmented. Nevertheless, the way of using the data is also normally fragmented. This means that traceability data is independently used in each of the sub-units with a distinct application rather than being used in single application that covers the entire material flow in multiple sub-units. For example, in several case study companies with sub-unit ownership, traceability data was used to locate products in the entire material flow, but a distinct locating application was used in each of the sub-units. However, even when fragmented applications with full material flow coverage emerge, with few exceptions, company policies or external requirements appear to play a coordinative role in the use of the data.

Contribution to the prior body of knowledge

This study clarifies the role of the organisational setting in the use of traceability data and highlights the role of external requirements in different industries. Notably, the results of this study suggest that the structure of ownership should be aligned with the desired scope of traceability data usage. If cross-functional applications are considered desirable, cross-functional ownership of traceability should also be established.

The management personnel appraising the appropriate approach for structuring the ownership of traceability in the enterprise should acknowledge that:

- The span of traceability applications can vary from those where traceability data is used at the point of data creation to functional, cross-functional and cross-organisational applications.
- In order not to ignore any opportunities, the structure of ownership should be wide enough to address all desired applications.

6.4 Suggestions for further research

As observed in this research, the existing body of knowledge in the field of traceability is limited. Although this study sheds light on some fundamental questions in this field, many others still remain unanswered providing a wide set of opportunities for researchers.

In this research, the impacts and benefits of employing traceability data were examined from an operations perspective. No efforts were made to quantify the benefits in order to understand the financial importance of traceability, which would be an opportunity for future research.

Moreover, several possibilities for material flow control based on traceability data were acknowledged in this study. However, this subject was not investigated deeply. An academically interesting opportunity for further research could be an investigation of the impacts of controlling products in the material flow increasingly with traceability data as opposed to traditional methods of using product and material codes. Traditionally when products have been identified with a product code, this code has referred to a static set of characteristics, which have differentiated the product in question from the other products. The characteristics referred to by a product code vary in different companies and situations and may, for example, include the design and standard bill of materials of the products. On the other hand, certain other product characteristics, like country of origin or manufacturing date, have seldom been identified with product codes as this information has normally been tied to the serial numbers and lot codes of the products, or identified with product markings. Similar products with different colours or bill-of-materials versions, or physically identical products manufactured by different suppliers have remained in the twilight zone, i.e. they have sometimes been identified using different product codes, and sometimes by tying characteristics information to serial numbers and/or lot codes. In this context, an interesting area of research would

be to study the impact of different approaches to product identification on the effectivity of material flow management. An extreme case could be a situation in which products do not have a product code, but are instead identified with serial numbers referring to a set of characteristics, which together define the product.

Finally, although this study aimed at investigating traceability from a comprehensive perspective, the discussion was largely limited to the use of traceability data within a single organisation. An important extension to the results of this study would be a deep analysis of the use of traceability data in genuinely cross-organisational settings.

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8. APPENDICES

8.1 Appendix 1: Use of traceability data in the case study companies

The following chapter describes the traceability applications observed in the case study companies. The description includes the purpose the data is needed for, the process of data usage, and the impacts and benefits of using the data. In addition to the verbal description, the applications are presented using the ICT-BP model (see Lillrank et al., 1997). The model presents logical paths from application usage through different levels of impacts to the benefits of the application. The benefits are divided into three categories: cost savings, customer-perceived value and business option value. Furthermore, the model indicates the role of information and communication technologies in manipulating and transmitting the data, and thus in supporting the usage of data in the application.

8.1.1 *Company Alpha*

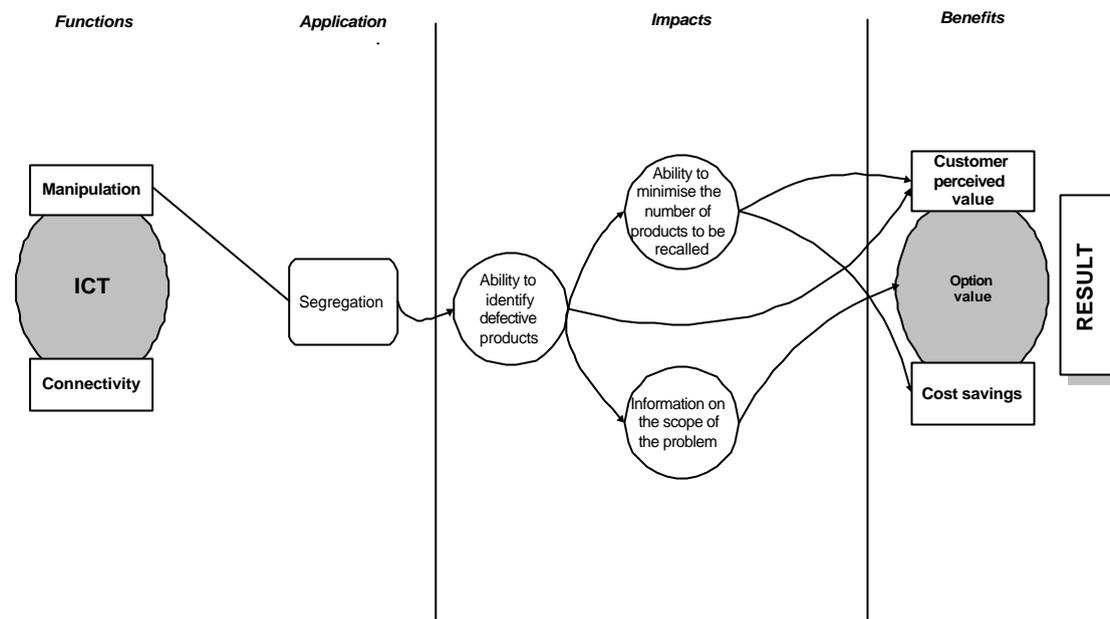
The use of traceability data in quality management had played a central role in the development of Company Alpha. The principal reasons for setting up a traceability system were error prevention in manual assembly and packaging processes, quality improvement and learning through using traceability data, and management of recall situations.

8.1.1.1 *Segregation*

In the event of a quality problem, but depending on the nature of the incident, traceability data was used to identify the affected products and to quantify the problem. According to a consultant participating in the development of traceability systems, the ability to minimise the number of products to be recalled and thus to minimise the costs of recalls was particularly important. The ability to quantify the problem supported the service centres in anticipating the resources needed to tackle the problem. Moreover, traceability data was used to identify the serial numbers of the products being manufactured to order. This information was needed when customers requested order status information or when there was a need to quickly withdraw work in progress from the material flow due to customer order cancellation.

Between 1992 and 1997, there had only been two major quality problems leading to a recall. However, in addition to supporting recall-related activities, segregation had been needed internally in the event of smaller quality problems.

Figure 14: Impacts and benefits of the segregation application at Company Alpha



In the event of a quality problem, segregation was carried out locally using lot and/or serial number data on the components and modules used in the products, and a product-specific bill of materials and software versions.

One or two steps were needed to begin the segregation. If all the data needed in identification was available in the central database, the affected products could be identified with a single query. However, if the data module serial numbers were needed in the identification, the serial numbers of the modules, which were a part of a receiving lot, needed to be first identified in the receiving database. The identified data was either used locally or delivered to an external party to be used, e.g. in the event of recall to the regional party organising the recall.

Before 1997, when the data in the traceability systems was made accessible outside the shop floor, the party needing the data needed to call somebody on the shop floor to retrieve the data. In 1997, a large part of the data was made directly accessible to authorised users through the Internet.

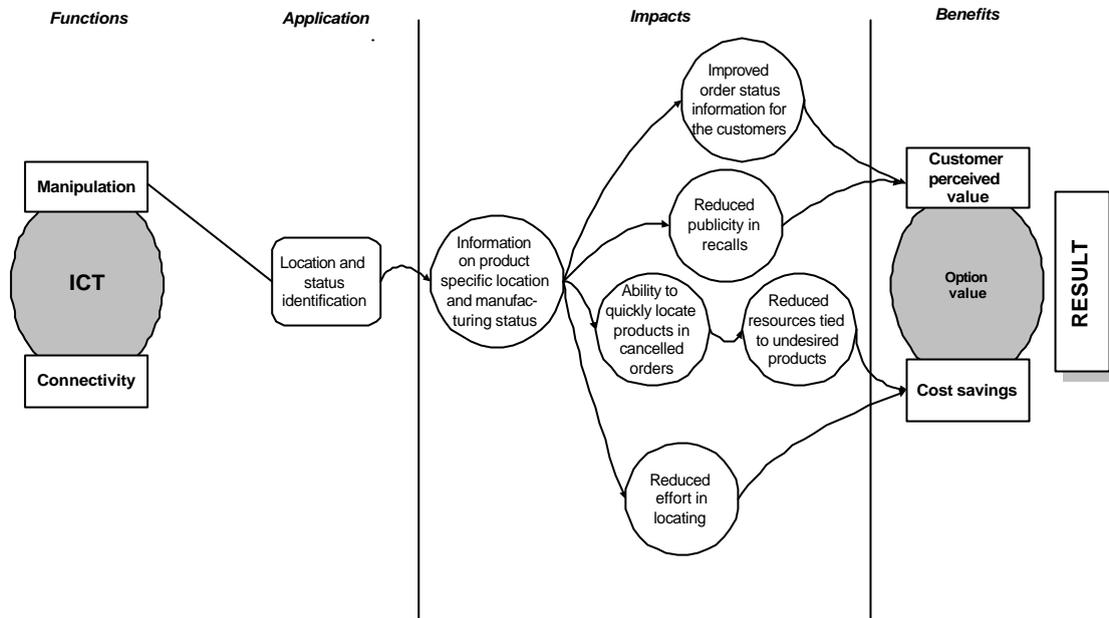
8.1.1.2 Location and status identification

Traceability data was used for location and status identification purposes in three situations:

- In the event of product recall, the data was used to identify the customers to whom the products to be recalled had been delivered. The data was needed to minimise the effort to locate the customers and to reduce the negative publicity caused by the recall.
- In the event of quality problem or customer order cancellation, the data was used to locate affected products in the internal material flow. Quick locating was needed to minimise the resources being tied up in cancelled orders.

- Moreover, traceability data was used by customer service to provide customers with information on the status of the products being manufactured to order.

Figure 15: Impacts and benefits of the location and status identification application at Company Alpha



The data used in internal location and status identification consisted of data on the location of materials, work in progress and finished products. The data was collected in various control points throughout the receiving, manufacturing and delivery processes.

The majority of the data collected at the focus manufacturing site at Company Alpha was available in this site's central traceability database. However, part of the data was maintained in stand-alone databases. Additionally, location data was replicated in the production control system, where it was linked with customer order data. Internal and external shipment destinations could be identified using the shipment data collected on serial number level. In the trading companies, location and destination data was collected in local information systems.

When a customer called Company Alpha's customer service to inquire about an order's status, the data was retrieved from the production control system, in which it was readily available. Providing customers direct access to the data through the Internet was also being considered. A shortcoming in status identification was the inability of Company Alpha's customer service to easily identify the status of products when they were being delivered through trading companies. This was due to the fact that location data in the trading companies was collected in local systems. However, this was not considered to be a problem due to constant lead-times throughout the trading companies.

Before the interface from shop-floor control points to the production control system was established in 1997, the status data was only available in the shop-floor traceability systems. These systems were not accessible from customer service. When a customer inquired order status information, customer service needed to call somebody on the shop floor that had access to the shop-floor systems. Thus, customer inquiries could not be directly answered and additional effort was required of the shop-floor staff. The project manager in charge of manufacturing's traceability systems suggested that at that time, customer service did not always check an order's status. Instead, customers were given an estimate of the status.

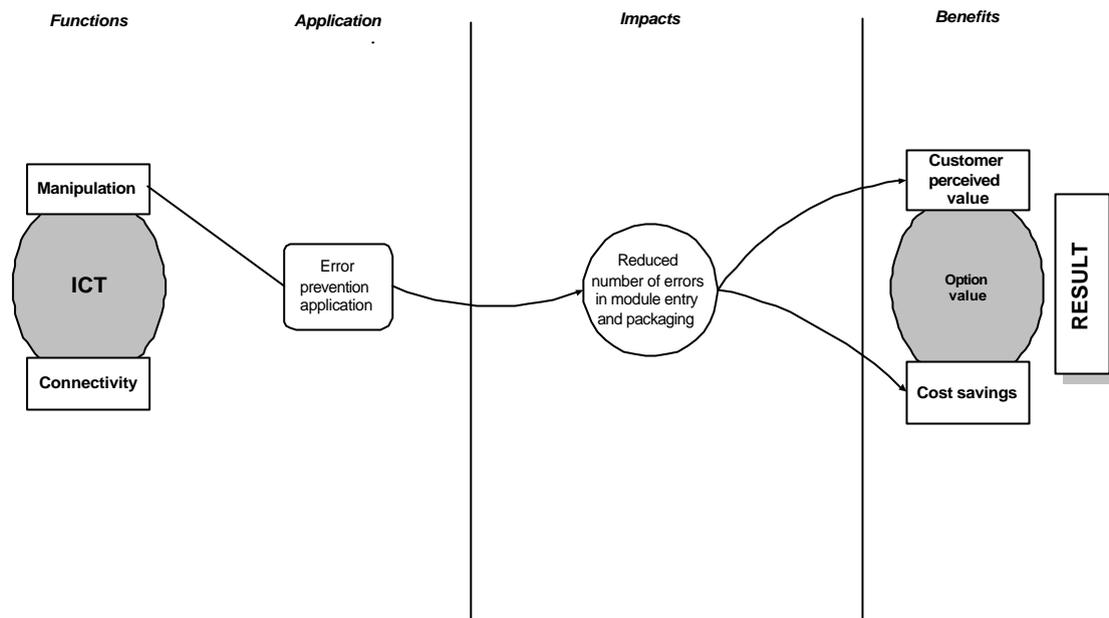
When a customer order was cancelled or there was a quality problem, internal locations could be readily retrieved from the production control system or traceability system at Company Alpha. Similarly, trading companies could readily locate items in the inventory by using local systems. However, in the material flow outside the manufacturing process, item-specific data was normally not used for locating purposes. Instead, the items were located at the product-code level. The use of traceability data was not considered to provide significant benefits, as Company Alpha manufactured products to order and thus the number of products in stock was limited. Nevertheless, when locating was needed, it needed to be separately undertaken in Company Alpha and in the trading companies.

When there was a need to recall products from the customers, distribution centre and trading company shipping registers were used to identify the destinations to which the defective products had been shipped. The data was locally retrieved in each of the units and delivered to the party responsible for recall activities within the European region.

8.1.1.3 Error prevention

Error prevention applications were used in two process phases. In module assembly, the application verified that the modules being used were in conformance with the target bill of materials, and that the version and the manufacturer of each of the modules was approved by the customer who had ordered the product. Moreover, the application verified that all the intended modules were included in the product. In packing, a similar verification was carried out to verify the accessories being put in the sales packages. Before the application was taken into use, the errors were considered to be a problem. The problem was largely eliminated with the introduction of the application.

Figure 16: Impacts and benefits of the error prevention application at Company Alpha



Target data used in the verification consisted of an item-specific bill of materials and data on customer-approved modules and accessory manufacturers. This data was compared with the data on the modules and accessories being used in the assembly of a particular product.

The data from the target bill of materials was entered in the production control system at order entry. When the manufacturing for the order was started, the ID of the target bill of materials was encoded into the product's serial number. The serial number was scanned at the control points carrying out the verifications. Control-point-specific traceability systems obtained the bill of materials structures from the production control system through a systems interface. The structure was needed to translate the ID into child-part item codes. When the modules were being entered in the computer and the accessories in the sales package, their product codes were scanned. The system automatically carried out a real-time verification and noted of any discrepancies.

The project manager in charge of Company Alpha's traceability systems suggested that real-time speed in the verification was important, because delays in the verification would slow down the work and increase lead-times. If the verification results would be received afterwards, the assembly would already be completed and the products delivered to the distribution centre or to the customers. Withdrawing non-conforming products from the distribution chain and disassembling them would not be feasible due to the costs of withdrawal.

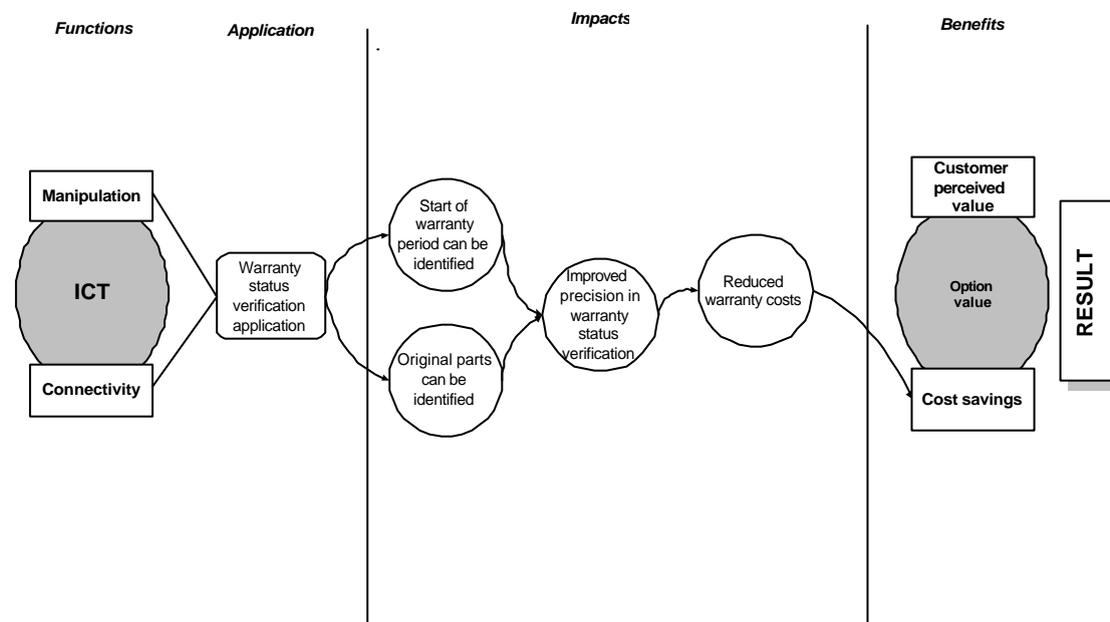
8.1.1.4 Warranty status verification

Traceability data was used in warranty status verification in the service centres in the European region. The dealers selling the products manufactured by Company Alpha were given a warranty, which was valid for three years and two

months starting from the date the product had been shipped from the company to a trade customer. The end-users were given a three-year warranty period, which started from the date of purchase. If the lead-time from Company Alpha through the distribution chain to the end-user exceeded two months, the dealer covered the rest of the warranty period. Furthermore, the warranty covered only original parts of the product that had been included in the product at company Alpha.

The use of traceability data in the verification provided savings in warranty compensations through increased precision of the verification. Moreover, the application brought cost savings through its ability to make a distinction between the modules originally included in the computer, and which were thus covered by warranty, and the modules entered by the customer, which were not.

Figure 17: Impacts and benefits of the warranty status verification application at Company Alpha



When an end-user brought in a product to be repaired, the service centre verified the warranty status and the serial numbers of the modules originally included in the product in question. The data maintained in the traceability system at the focus manufacturing site was used in the verification. This data was accessed with an Internet application that provided nearly instant access to the warranty data. Item-specific data about the shipping date, which was registered at the point of shipping, was used to determine the start of the warranty period. The serial numbers of the modules included in the product at module assembly were used to identify the modules covered by the warranty. The application was used in internal and external service centres throughout the region.

Before Company Alpha's traceability database was made accessible to external parties in 1997, warranty status verification was undertaken by manually contacting somebody working at Company Alpha with access to the traceability system. Due to the effort required, the warranty status was often left unverified.

After the database was made easily accessible to external parties, the frequency of data use increased significantly.

The warranty-status-verification application being used in 1997 covered only the products manufactured by Company Alpha. The other factory in the European region did not have a similar system. The service centres needed to contact this plant to obtain the information.

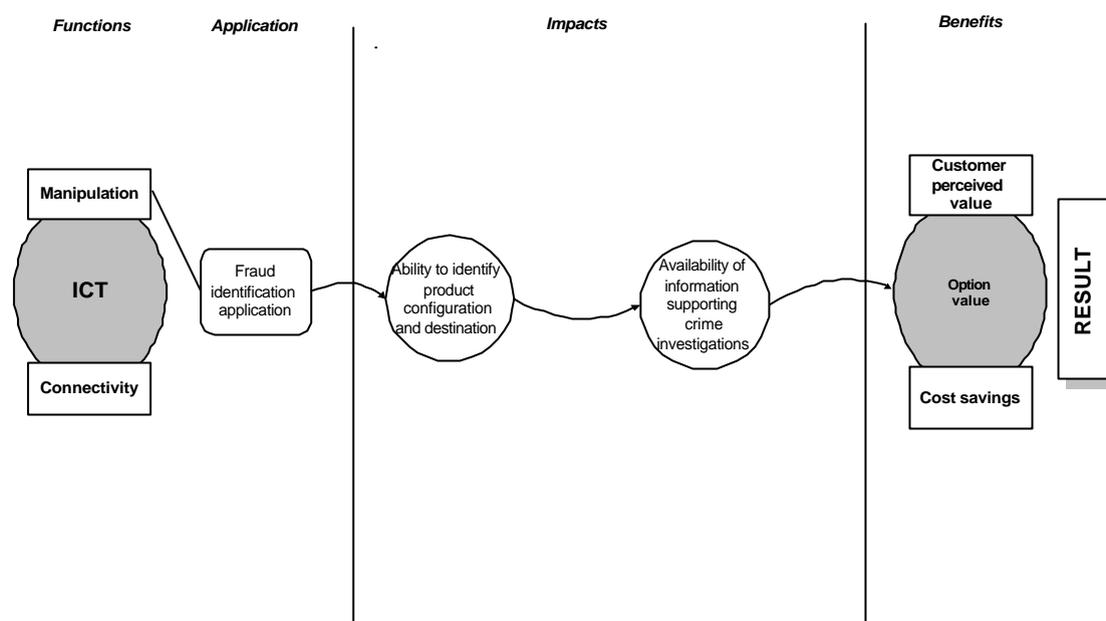
8.1.1.5 Fraud identification

In order to inquire about information on products manufactured by Company Alpha, police authorities occasionally contacted the company during a crime investigation.

The authorities could inquire about to whom a given product had been delivered. Moreover, they were interested in knowing the serial numbers of the modules used in a particular product or, alternatively, the serial number of the product a given module has been included in. The quality manager of Company Alpha demonstrated the usage of the data with the following example:

Police authorities made a house search, as a person was suspected of possessing stolen computers. The suspect had anticipated the search and sunk the stolen items in a lake. However, the event had an eyewitness, who helped the police authorities to find the items. Company Alpha was contacted to study whether it had delivered the modules and to which computer these modules had been included. The serial numbers of the modules were found in the registers, and it was possible to identify the serial number of the computer. Thus, the police authorities were able to show that the modules were taken from a stolen computer.

Figure 18: Impacts and benefits of the fraud identification application at Company Alpha



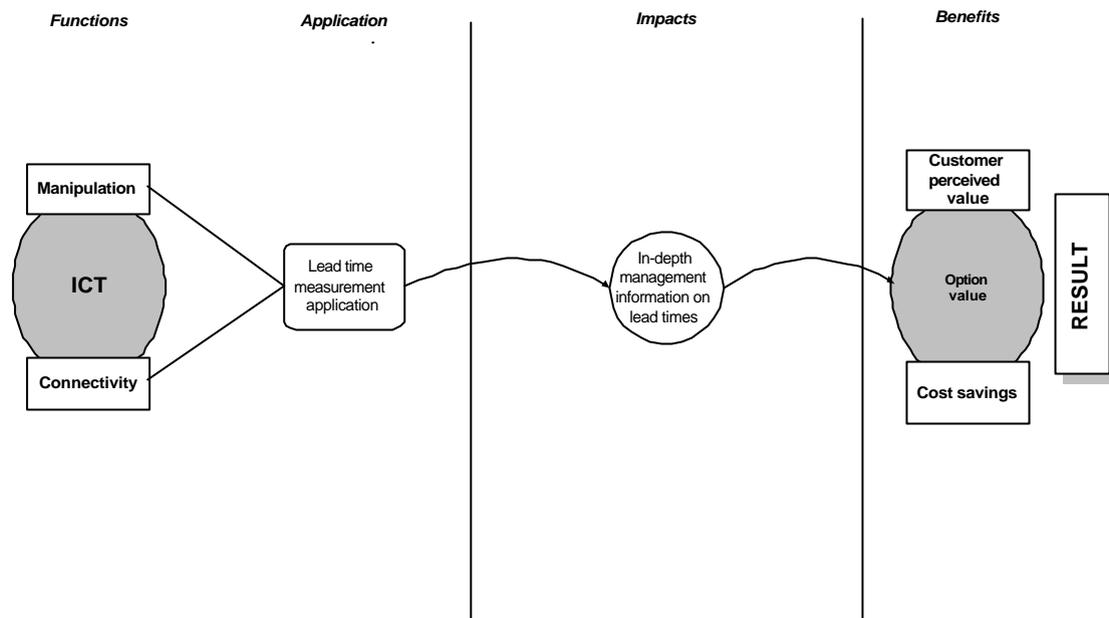
The data used to answer to authorities' inquiries could include shipment destination data recorded at the point of shipping and module serial number data, recorded during the module assembly. The data was maintained and readily available in Company Alpha's central traceability database.

Moreover, the serial numbers of the products delivered in a shipment were recorded. If the receiver claimed that products had been lost in delivery, the serial numbers of the lost products could be identified. The customer could contact Company Alpha with the serial numbers of the received products to compare the serial numbers of the items shipped to those of the items received. The products identified to be lost could be reported to the police authorities.

8.1.1.6 Lead-time measurement

Company Alpha used traceability data in lead-time measurement. Traceability data was used instead of inventory-cycle time information in order to get detailed data on step-by-step lead-times. The project manager in charge of the traceability systems at the focus manufacturing site suggested that the results obtained with alternative methods would not be adequately precise.

Figure 19: Impacts and benefits of the lead-time measurement application at Company Alpha



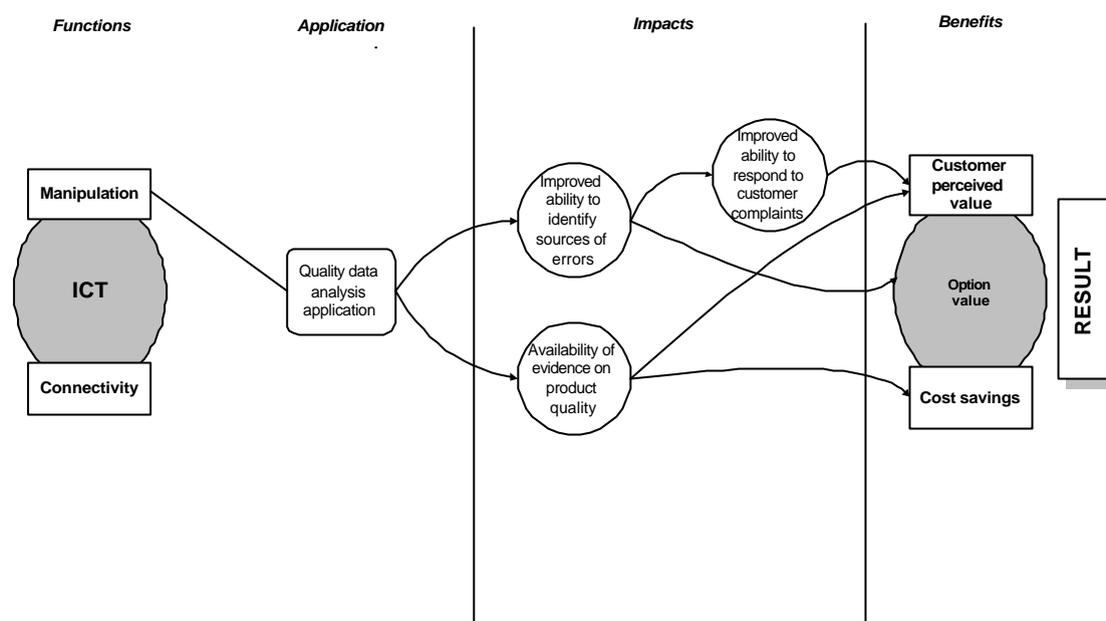
The measurements were carried out by the personnel of the manufacturing site. The data used in the measurements consisted of the time-location data registered for each item at each of the control points throughout the material flow within the manufacturing site. In a similar vein, the scope of the measurements covered the material flow within the manufacturing site and did not extend to the trading companies.

The time-location data was only partially available in the central database. Thus, part of the data needed in the measurements needed to be collected from the control-point-specific databases. Carrying out the measurements could take up to two days for an inexperienced person or few hours for a person who was familiar with the control-point-specific databases. The measurements were undertaken very infrequently, i.e. less than once a year.

8.1.1.7 Quality improvement and proof of quality

Traceability data was used in quality improvement and as a proof of quality. The use of the data could be triggered by a customer complaint, a quality problem observed in an internal quality inspection or feedback obtained from the service centres that indicated a need for in-depth analysis.

Figure 20: Impacts and benefits of the quality-data analysis application at Company Alpha



The quality feedback data was typically cross-referenced with the 'case history of the product' in order to undertake the analysis. The case history used in the analysis could include the lot numbers and suppliers of the components and modules used in the product, data on employees who had participated in the manufacturing process, the faults identified in earlier quality inspections and the repair actions undertaken. Quality feedback data was acquired from the manufacturing quality inspection points, from the service centres, and also directly from the end-users.

On the shop floor, traceability data was applied to give employees in the manual assembly feedback on work quality. The person inspecting the quality of the assembled products could immediately identify the employee who had assembled the product by using the markings on the chassis of the product. Alternatively, the same information could be retrieved from the site's traceability database. When problems were identified, instant feedback could be given to the employees.

Once a month, the ITS summarised the field-failure data collected in the service centres. The summaries were delivered to be analysed by the quality departments in the factories. When a problem requiring in-depth analysis was identified, individual-item failure data could be requested from the ITS. The data was received either in electronic format or on paper reports. It was combined with the traceability data available in the central database of the manufacturing site in order to find statistical relationships between the field failures and manufacturing data. There were no standard reporting tools for the analysis. The queries used in the analysis were custom made.

Traceability data was also used in analysing customer complaints. The consultant participating the project demonstrated the use of the data with the following example:

At one point, Company Alpha started to receive customer complaints regarding problems with hard disks. Traceability records were used to analyse the problem. It was found that no problems had been found in the quality inspection at the receiving point. In further analysis, it appeared that the same employee had always handled the failing items during a later process phase. When the working methods of this employee were observed, it appeared that the employee was handling the hard disks incorrectly, which caused the failure. It was possible to eliminate the problem by showing the employee new working methods.

Moreover, traceability data was used as a proof of quality in the event of customer complaints about missing modules or incorrect configurations. Modules and accessories used in the assembly and packaging of a particular item was used as evidence. Customer service could normally instantly retrieve the data from the site-level traceability database using standard queries. The quality manager demonstrated the usage of the application with the following example:

A customer complained that the ordered amount of random access memory had not been delivered with the computer. The complaint was analysed using the records collected in the module assembly. The records showed that the required amount of memory had been installed in the computer. Moreover, it was discovered that the manufacturers of the memory circuits originally included in the computer and the memory circuits currently in customer's computer differed. Thus, it became obvious that the original memory circuits had been removed and replaced by new ones.

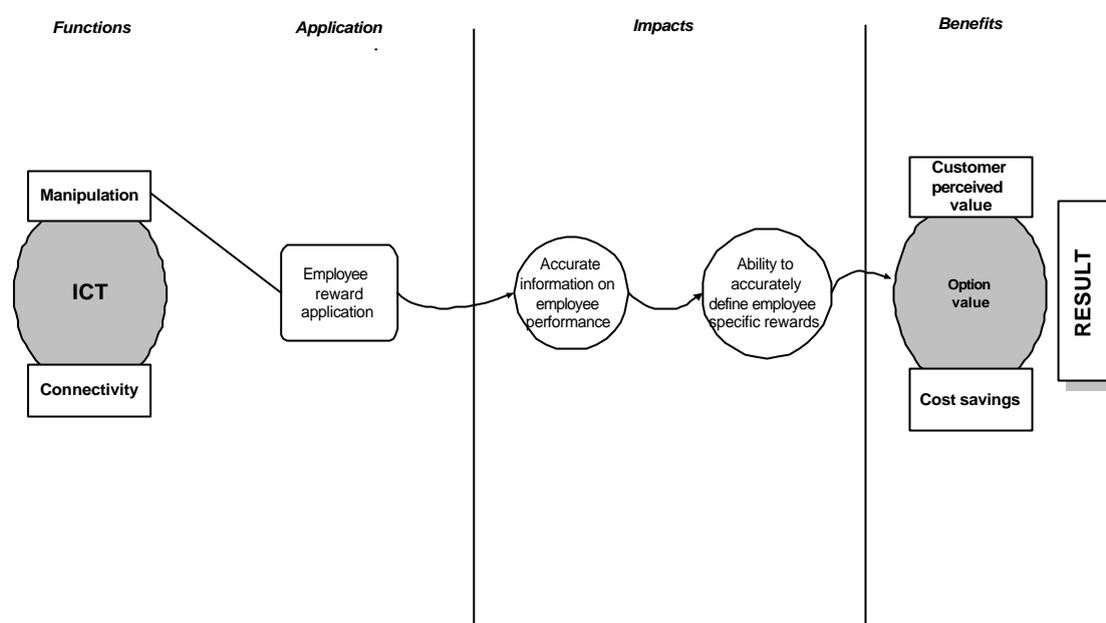
Additionally, traceability data was occasionally used in supplier quality evaluation. The use of the data enabled calculation of supplier-specific field failure rates.

In general, the use of quality data appeared to support pinpointing sources of quality problems, thus supporting quality improvement in internal processes and outsourced materials. Moreover, the use of data seemed to provide evidence needed in showing the fulfilment of contractual requirements. This again was important in maintaining customer confidence and avoiding compensation claims.

8.1.1.8 Employee reward system

Employees in the manufacturing line were given individual rewards, the amount of which varied from two to seventeen per cent of their total wage. The reward percentage was based on individual productivity, quality and employee innovativity. The traceability system was used to measure volumes and quality.

Figure 21: Impacts and benefits of the employee reward system at Company Alpha



Employees in manual assembly registered the serial numbers of the products they had assembled. At the quality inspection point, downstream from the point of assembly, the serial numbers of non-conforming products were registered. The data collected at both of the control points was transmitted to the central traceability database.

The supervisors calculated the reward percentage twice a year. A report was run from the site-level traceability database. Using the serial numbers as the linking factor, the report combined the volume and quality data collected that the points of assembly and quality inspection.

8.1.2 Company Beta

8.1.2.1 Segregation

The use of traceability data in segregating the defective items from the total product population was considered to be one of the most important applications of traceability. The ability to minimise the number of suspect products was needed to minimise the effort and costs of withdrawing the defective items from the internal and external distribution chains, and in reworking the items. The problems resulting from the lack of traceability were demonstrated by the following example:

During a recall at Company Beta, one of the distribution centres needed to open all the packages of certain type to find the flawed products. During this operation, some of the packages were damaged and the products needed to be repackaged. The direct labour costs of this operation were estimated to be

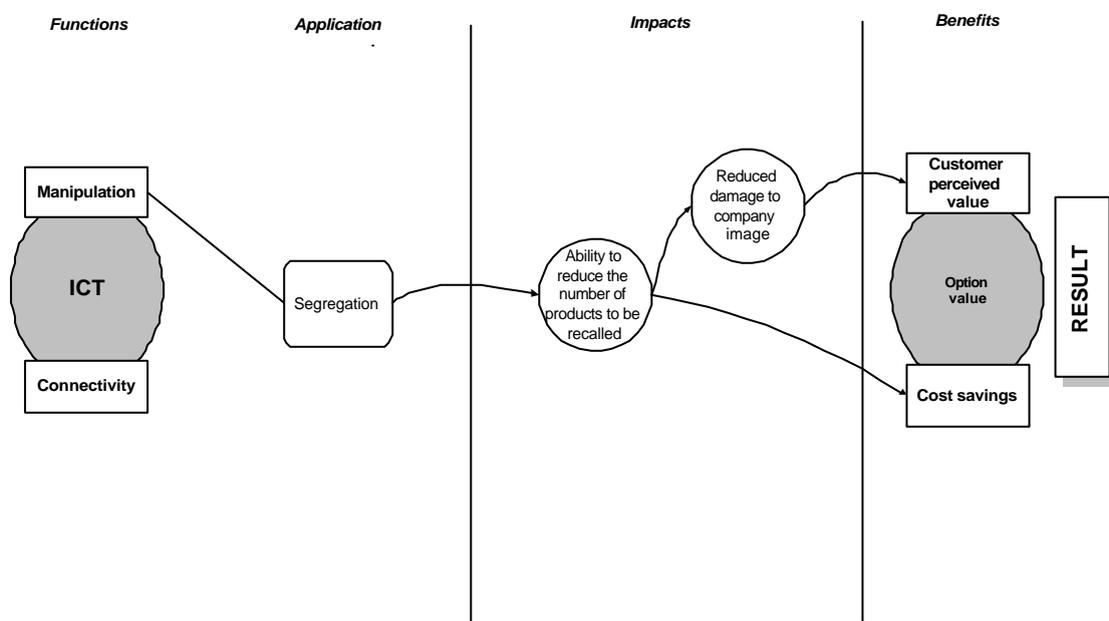
several million FIM. Additional costs accrued as this operation delayed deliveries to the customers.

Moreover, in the event of product recall, the ability to minimise the number of affected products was needed to minimise the damage caused to the company image by the recall. The importance of segregation was underlined by the fact that precise segregation was strongly required by some of the major customers.

In addition to the identification of defective items in the event of a quality problem, segregation was occasionally needed for other purposes. For example, traceability data was used to identify the items with a software version supporting certain functionalities.

The data used in segregation consisted of item-specific date of manufacturing, product version and test result data. Moreover, other data including data on product design changes, purchase invoices and materials usage could be roughly linked with the physical products by means of timestamp records. In the event of failure in purchased materials, suppliers could also be contacted to provide information supporting segregation. Suppliers could use their documentation to identify the affected items and the time period during which they had been delivered to Company Beta.

Figure 22: Impacts and benefits of the segregation application at Company Beta



Item-specific data was created by the manufacturing test system and stored into a large number of manufacturing-line-, product- and time-period-specific files. When there was a need to retrieve data, the retrieval needed to be carried out by the shop-floor personnel that had access to the system and knew how to use it. Thus, in the event of recall for instance, the quality department in charge of organising the recall activities did not retrieve the data itself. Finding the data

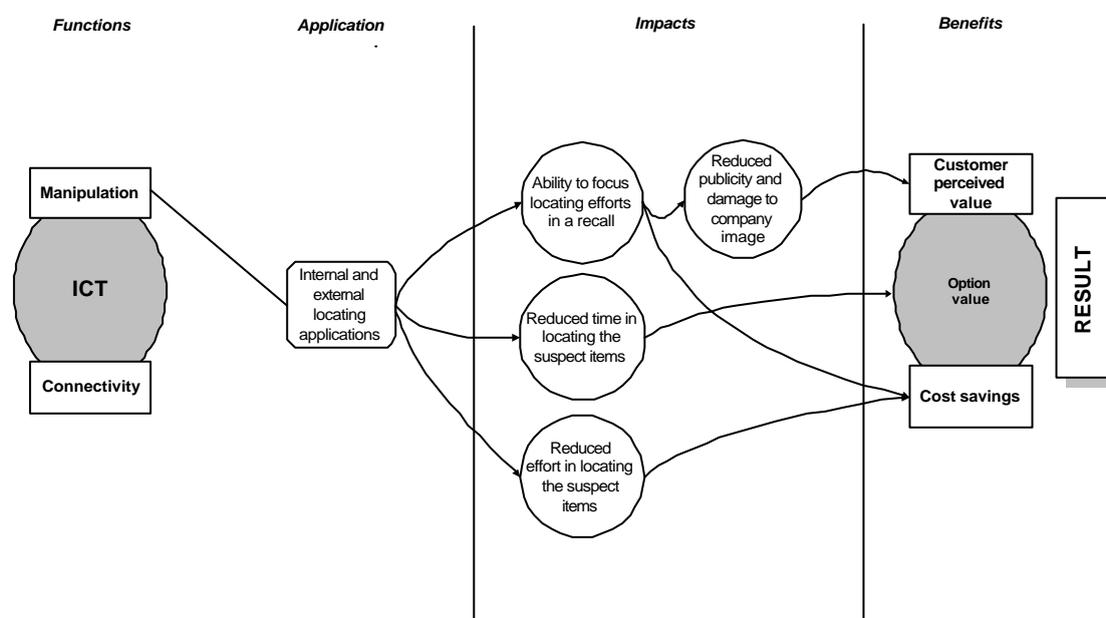
from the file system was relatively laborious due to the effort needed to find the data from distinct files and because there were no proper reporting tools. Carrying out the reporting normally required several hours. However, the effort was not considered to be a major problem due to the infrequent need for segregation. Moreover, as 48 hours was allowed for segregation, instant availability of data was not critical.

8.1.2.2 Location and status identification

Traceability data was used to locate items in the internal material flow and to identify the external destinations to which given items had been shipped. In the service centres, traceability data was used to provide customers information on repair status.

The use of item- and lot-level locating was largely a result of quality problems. The ability to identify the items in stock and the destinations to which these items had been delivered was required by a company-level policy. Depending on the severity of the problem, the delivery of non-conforming items was stopped and items already delivered to the customers recalled. The role of traceability data was to reduce the effort required in searching for the items in internal locations and to focus recall efforts to a limited number of customers and/or countries. In addition to cost savings, the ability to focus recall efforts was considered to help avoid public recalls and the possible damage caused by them to company image.

Figure 23: Impacts and benefits of the locating applications at Company Beta



Item-level data on received, packed and shipped items was used to locate the items in the focus distribution centre and identify shipment destinations. Location and destination data was collected to distribution centre's functional traceability system. A distinct information system - a warehouse management system - was

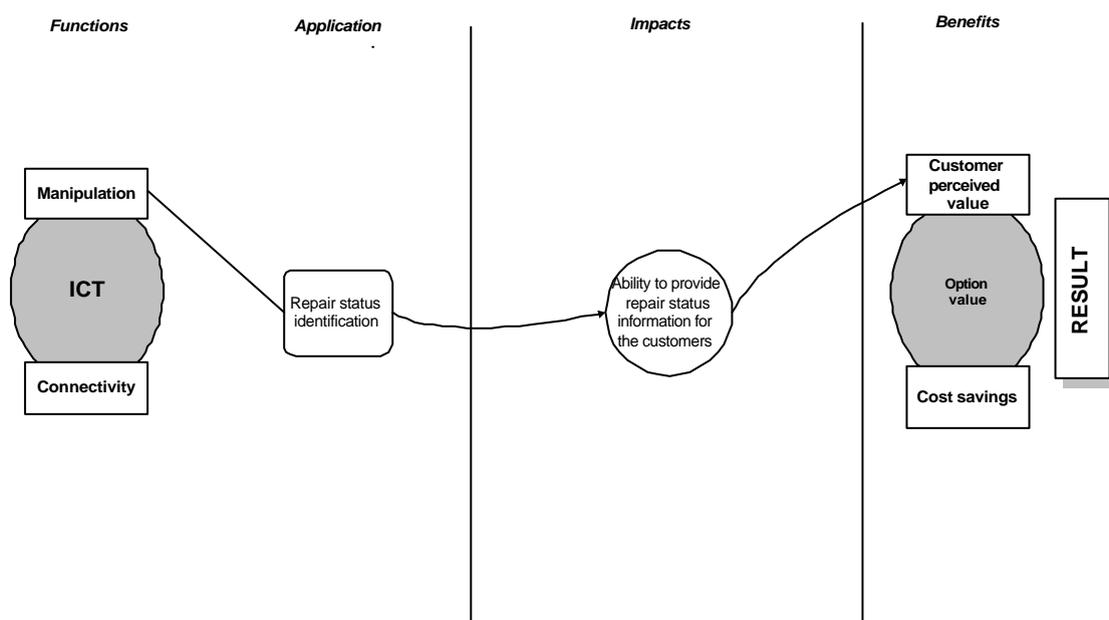
used in the management of material locations in the distribution centre. In this system, the materials were identified by material code. Thus, it did not support traceability.

Using the distribution centre's traceability system, it was possible to identify which of the searched items were in the distribution centre and, more specifically, whether the items were in the unpacked or the packed items inventory.

By manually combining the item-level data in the traceability system with the data in the warehouse management system using time of receiving and packing as a link, it was possible to roughly estimate the storage locations in which the searched items had been placed. However, combining the data was laborious. The person in charge of the distribution centre traceability system claimed that the data in these two systems is combined only when the number of items being searched is limited. On other occasions, the items are withdrawn based on product code.

Identifying the locations of the products in the inventory and the destinations to which products had been shipped was separately carried out in each of the distribution centres. Typically, destination data was manually communicated to the Sales function in charge of locating defective products on the market, or to other functions using the data for ad hoc purposes. In three of the distribution centres, the data in the traceability system could be remotely accessed. However, only a limited number of users was authorised to access the data and in practice, the Information Management organisation retrieved the data in the majority of cases.

Figure 24: Impacts and benefits of the repair status identification application at Company Beta



In the focus service centre, item-level location and status information was used to provide customers information on repair status and estimated time of completion. In approximately ten to fifteen per cent of the cases, the customer who had sent the products to be repaired inquired the service centre's customer service about the repair status and the estimated return time. Inquiries were received on daily basis.

The location and status data used in the application was collected at a limited number of repair process control points. However, receiving and shipping activities, which were carried out by an adjacent distribution centre, were not covered by data collection. Data on received and repaired items and in some situations, data on repair status was stored in the focus service centre's local housekeeping system or to various Excel files. Data on tested items was maintained in a stand-alone test system database.

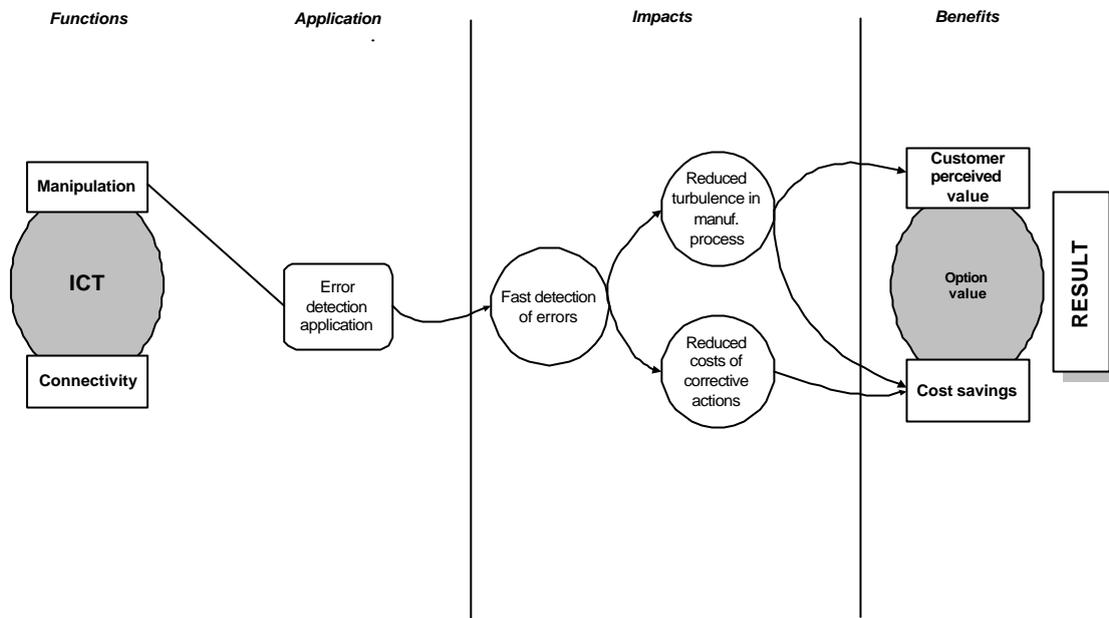
When a customer inquiring about repair status information contacted a service centre's customer service, the data available in the local housekeeping system and in the Excel files was checked. Then the person searching for the data left his or her desk and walked to shop floor to retrieve data from the stand-alone test system and to physically search for the items. The amount of manual work required to obtain the required information was normally one to two hours. However, occasionally, the products could not be easily located, and thus the time required in locating was up to three or four hours. The manager in charge of customer service considered the complexity of locating to be problematic, both the amount of manual work needed to locate the items and particularly, the fact that the customers needed to wait for information. Moreover, the lack of status information from the distribution centre area was also considered a problem. Products could have been received in the distribution centre for example, without the service centre being aware of the arrival.

Answering the customer inquiries was estimated to correspond to 50 per cent of the working time of a full-time employee. Moreover, due to the effort needed in locating, the status information delivered to the customers was not based on identification of the status of all the products in the order, but only on a few samples. Thus, the status information delivered to the customers was not precise.

8.1.2.3 Error detection

The focus manufacturing centre used traceability data to verify that each item had successfully completed each of the required steps in the manufacturing process. Before the application was set up, there were recurring problems with items that skipped process phases. When the problem was observed in the final test, at the end of the manufacturing process, assembly had already been completed. The product needed to be returned to the uncompleted process phase, disassembled and reprocessed. This caused unnecessary effort and disturbances in the manufacturing process. The implementation of the application enabled early detection of errors and thus reduced the magnitude of the problems.

Figure 25: Impacts and benefits of the error detection application at Company Beta



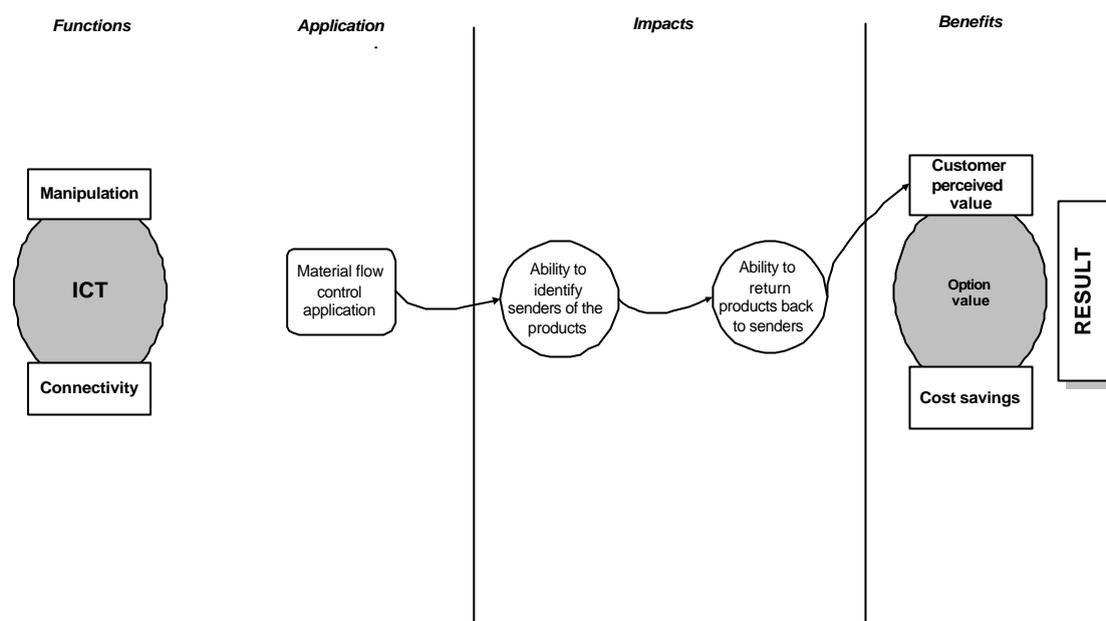
The application was based on item-level data on completed process phases. This data was collected at multiple control points in the manufacturing process. It was stored in the functional manufacturing centre traceability system.

When an item arrived at a control point, it was automatically identified. The system carried out a real-time verification by retrieving item-specific data on completed process phases from the test system and by comparing this data with the target status. The importance of real-time verification was emphasised. Speed was considered particularly important, as the number of verifications carried out each day was dozens of thousands.

8.1.2.4 Material flow control

A fundamental element of the service process at Company Beta's service centres was the ability to return a repaired product back to the party that had sent it to be repaired. Traceability data was used to enable this functionality.

Figure 26: Impacts and benefits of the material flow control application at Company Beta

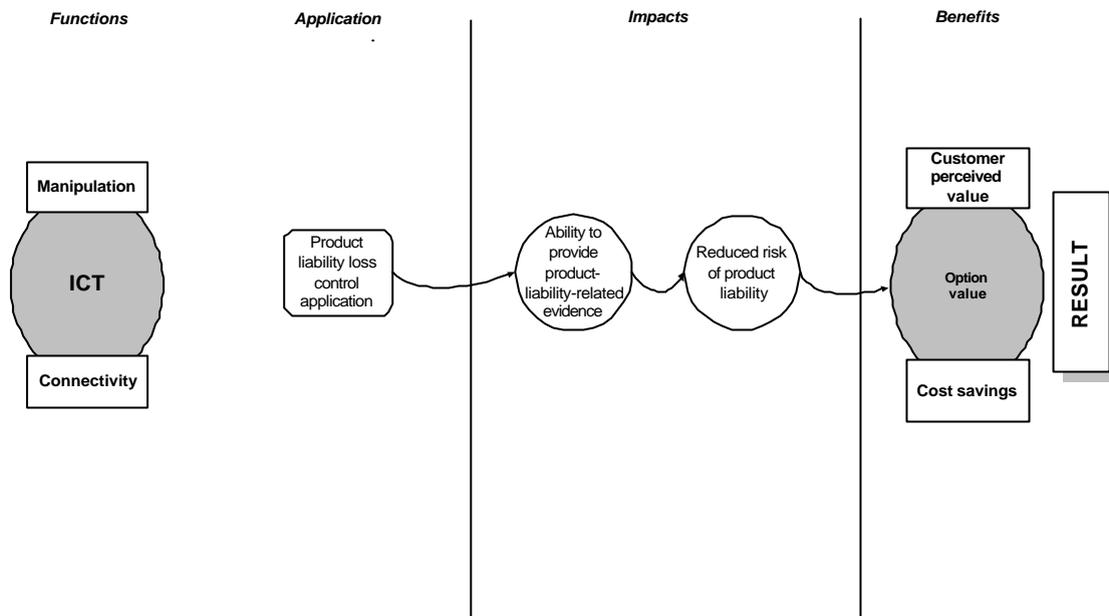


When a product was received to be repaired at the focus service centre, incoming inspection personnel recorded its serial number together with a sender-defined return address. This data was stored in the service centre's local housekeeping system or in various Excel files. Moreover, the product to be repaired was put in an envelope indicating the sender and serial number of the product. The product travelled through the repair process in this envelope. When the repair was completed and the product was to be returned back to its sender, the destination information was identified from the envelope. If the envelope had been lost during the repair process, the sender information needed to be retrieved from the local housekeeping system or searched for in various Excel files. The latter alternative was laborious.

8.1.2.5 Product liability loss control

The set of traceability data, the contents of which were centrally defined in a company policy, was collected to provide evidence for fighting possible product liability claims. The aim was to support minimisation of product-liability-related risks. The importance of product liability risk management was magnified by company Beta's presence on the US consumer market.

Figure 27: Impacts and benefits of the product liability loss control application at Company Beta



Traceability data, which enabled identifying the products manufactured by the company and released to the market, was collected in local information systems in each of the manufacturing and service centres. Data on the products put in circulation and date of delivery was collected in the distribution units.

The responsibility of the management of data retrieval was given to the global quality department. The retrieval of the data, depending on the situation, could include a number of manual steps. Data retrieval was hindered by the fact that the data was scattered among multiple systems in various manufacturing, distribution and service centres. The data was often not maintained in active databases, but archived in off-line storage. Moreover, reporting tools covered only part of the product-liability-related information needs. As a result, obtaining the data was laborious and typically required hours of manual work.

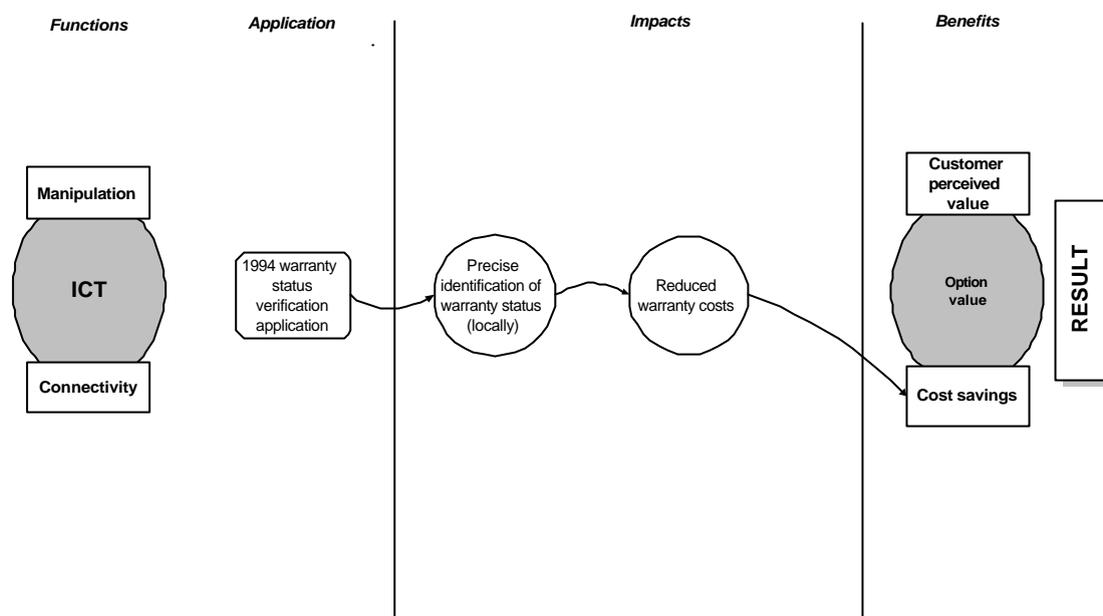
However, the effort required in data retrieval was not considered to be a problem. The data was needed highly infrequently. Moreover, company policy allowed 48 hours for the retrieval, i.e. instant availability of the data was not required.

8.1.2.6 Warranty status verification

Company Beta gave its products a warranty, which was typically valid for twelve months from the date of purchase. However, in most of the cases, the company did not know the actual sales date, since the products were sold by external dealers. Thus, the products were granted a fifteen-month warranty period, which started when the products were shipped from Company Beta to its trade customers. When a product was brought to be repaired, the end-user could show the validity of warranty with the receipt. If the end-user did not have a receipt or there was a reason to suspect its authenticity, the fifteen-month principle was

used. Traceability data, or more specifically, the item-specific date of shipping was used to determine the start of the fifteen-month warranty period. Availability of the shipping data improved precision in warranty status verification and thus, provided savings in warranty compensations.

Figure 28: Impacts and benefits of the 1994 warranty status verification application at Company Beta



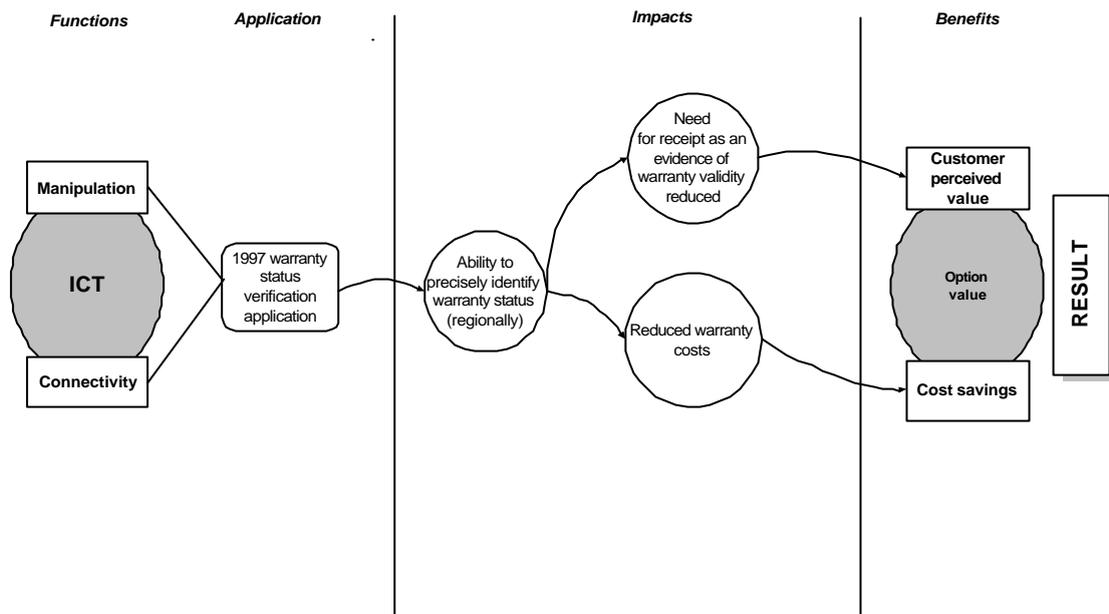
The products were shipped to trade customers from a number of distribution centres and sales companies. The date of shipping was registered for each individual product. Each of the units shipping the products maintained the shipping data in its local traceability information system.

The use of traceability data in warranty status verification was gradually initiated in 1994, when the possibility for using it for this purpose was acknowledged. At that time, the data was only accessible locally in each of the distribution centres and sales companies. When a service centre wanted to verify warranty status, it contacted the distribution unit it suspected to have shipped the product. In the European region alone, the amount of working time needed to answer the warranty inquiries corresponded with the working time of several full-time employees. Moreover, due to the effort needed, warranty status was not systematically verified. Alternative, rough methods were used in warranty status determination. As a result, free repairs were unnecessarily given to end-users.

In 1996, as a result of the requests from the service function, an Intranet-based warranty-status verification application was set up, and in 1997, an Internet-based one was. In the latter application, relevant data from the local distribution unit information systems was transferred to a central database. The authorised internal and external service centres could access this database through the Internet, providing instant availability of data independent of time or location. Furthermore, as all the data was in one place, the user did not need to know the

distribution centre from which the item had been shipped. The introduction of the application notably increased the likelihood of using traceability data in warranty status verification. Moreover, the centralisation and accessibility of warranty data was facilitated the selling of extended warranties for end-users as well as giving the products global warranties in the future. The improved availability of the data also reduced the need for a receipt as evidence of warranty validity, thus having a positive impact on customer satisfaction.

Figure 29: Impacts and benefits of the 1997 warranty status verification application at Company Beta



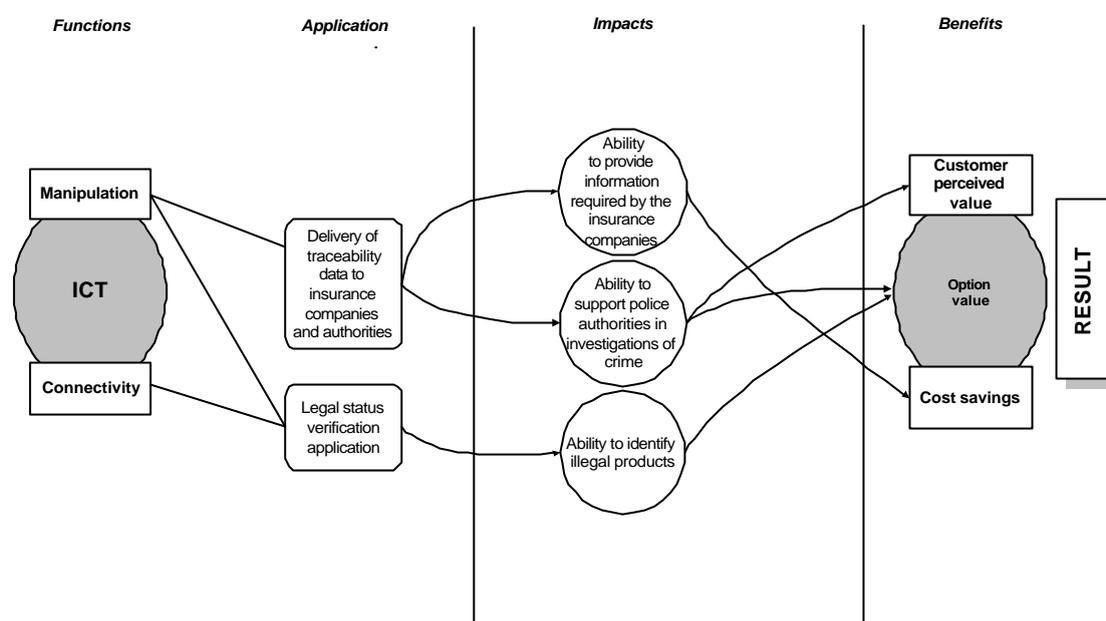
8.1.2.7 Fraud identification

Service centres and other after-market units used traceability data to identify stolen and otherwise illegitimate products. When a product was received in an after-market unit, its legal status was verified together with the warranty status. When a product was identified as illegal, it was not serviced.

Legal status data used in the verification was collected although not systematically, from multiple internal and external sources. Internal sources included manufacturing, distribution and service units. The data was maintained in one company-wide database, which was accessible to the authorised users within the company and in the third-party service centres through remote access. Before 1997, when the central database for illegal products was set up, data was collected in local registers in various countries. The registers were only accessible locally. Thus, the service centres were not able to identify products reported stolen in other countries.

The application was established to ensure that illegal products are not repaired or swapped. It was also in the interest of Company Beta to prevent fraud related to its products. In the long run, the use of the application was considered have the potential to positively affect customer satisfaction and insurance premiums.

Figure 30: Impacts and benefits of the fraud-identification application at Company Beta



Another fraud-identification application related to the legal-status verification application was the identification of the products stolen during transportation. When the number of products received by the customer did not match the number of products shipped by Company Beta, traceability records were used to identify the serial numbers of the missing products. The receiver either used the serial number data delivered with the shipment or contacted Company Beta for the serial numbers needed in the identification of the missing items. In the majority of the occasions, this data was reported to the authorities and to the insurance companies and for use in the above-mentioned legal-status-verification application. Insurance companies required that this information be reported together with the claim for compensation.

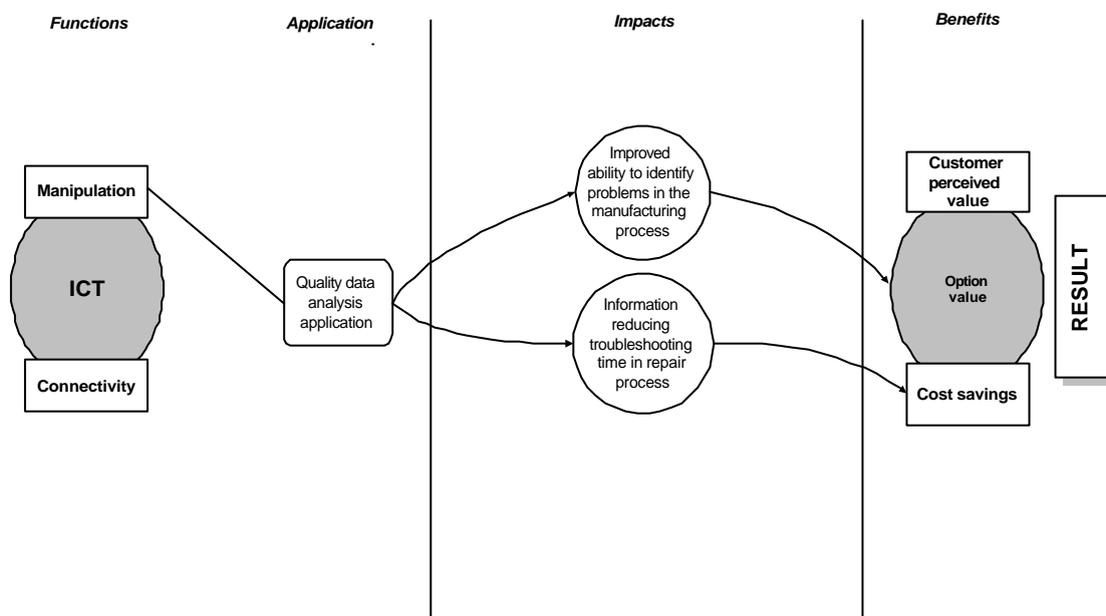
Moreover, traceability data was used to support police authorities in crime investigations. The application had not been taken into account at the time the systems were designed, and thus, the data needed for this purpose was delivered to the authorities to the extent it was available. Typically, authorities requested whether a product had been manufactured by the company, and when and to whom it had been delivered. Delivery of the data to the police authorities was considered to have a positive impact on public relations. Data on the manufactured products was collected in the local traceability system in each of the manufacturing centres. Similarly, shipping destination data was collected in the local traceability systems in each of the distribution centres. When an inquiry was received, the security department normally contacted a manufacturing and/or a distribution centre to retrieve the data. Due to the waiting time, there was typically a delay varying from several hours to several days, before the security department could provide the answer to the authorities. However, the

shipping data in some of the distribution centres was available for the security department through remote access and could be instantly obtained.

8.1.2.8 Quality-data analysis

Traceability data was used in the focus manufacturing centre in quality and process improvement. More specifically, the application was used to identify the need for tuning equipment calibration. The application was suggested to enable timely detection of emerging problems by displaying trends and discrepancies in the measurement values. The manager in charge of the test systems suggested that the implementation of the application enabled accurate tuning of the tuning equipment. As a part of a larger project, this had improved manufacturing yields by several percentage units. The availability of the traceability data was one of the most important factors contributing to the improvement.

Figure 31: Impacts and benefits of the quality-data analysis application at Company Beta



The data used in the application consisted of item-specific measurement values collected in several test phases during the manufacturing process. The data was stored in the local test system. The application automatically and in real-time cross-referenced the test results obtained during intermediate test phases with the test results obtained during the final test. Trends and discrepancies in the equipment tuning were displayed to the users.

The data needed by the application had been available in the test system for several years. However, it had not been used before the reporting application was set up. The manager in charge of the test system suggested that using the data would have been rather laborious without the proper reporting tools. Thus the data was not used at all.

Moreover, repair teams in the focus manufacturing centre used the item-specific test results to identify root causes of the problems in the products that had failed manufacturing tests. The test-result data was readily available in the local test system for the users on the shop floor. Use of the data facilitated troubleshooting and thus reduced the time required to repair the products.

The need for cross-referencing the manufacturing traceability data with the field-failure data in the service centres was perceived. It was considered that the use of the data could support the evaluation of supplier quality and improvement of product design and manufacturing processes. For example, the manager in charge of the reporting field-failure data collected in the service centres for the other functions stated that

It would be interesting to see, for example, whether the field-failure rate of the products that have failed the manufacturing quality tests and been repaired in the manufacturing is higher than the field-failure rate of the products in general.

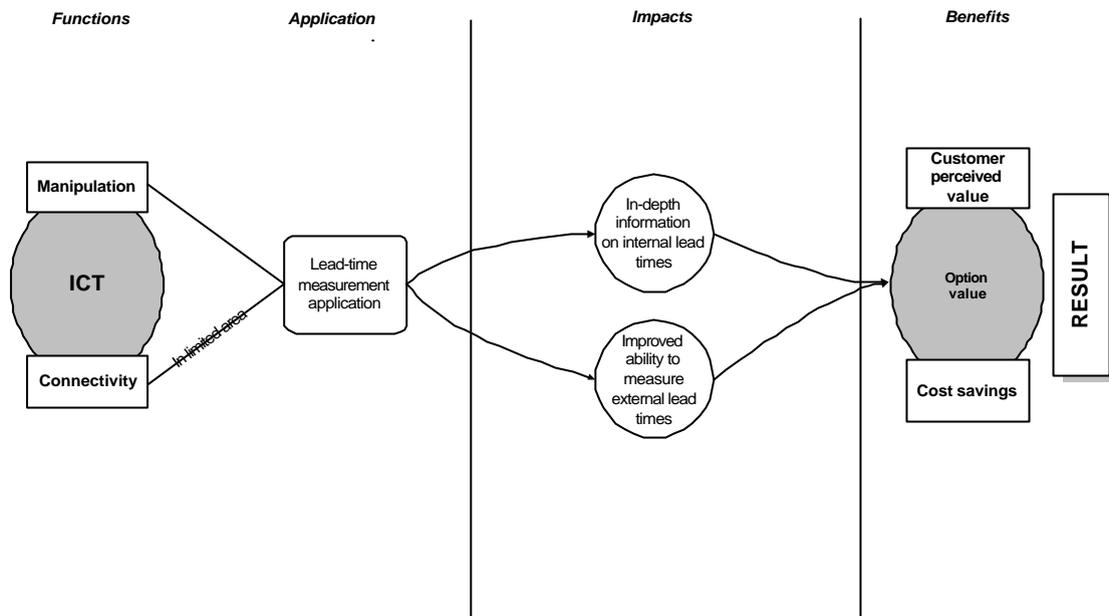
However, at the time when the case study was undertaken, this was not possible, due to shortcomings in data collection and the fact that each of the manufacturing and service centres had distinct information systems.

8.1.2.9 Lead-time measurement

Traceability data was used to measure lead-times from the end of the manufacturing process to the point of shipping and, to a limited extent, from the point of shipping to the point of sales. An important benefit of using traceability data in the lead-time measurements was considered to be the possibility for in-depth analysis. It was possible to calculate lead-times on the material-flow-phase level. The use of traceability data also enabled calculating lead-times for selected item groups. For example, traceability data was used to calculate lead-times for the products being delivered to a specific customer and the lead-times for specific product types. Moreover, traceability data that enabled the calculating of lead-times between the point of shipping from Company Beta to trade customers and end-user purchase through external distribution chain. As suggested by a regional Senior Vice President of Sales, this information was considered to be 'extremely important'.

The data used by the application included time-location data collected in various control points in the manufacturing and distribution centres. Moreover, item-specific data, including the product type, destination customer and destination country, were used in the measurements. The customer-registered date of purchase was used to calculate external lead-times.

Figure 32: Impacts and benefits of the lead-time measurement application at Company Beta



The data collected at the various distribution centre control points was stored in the local traceability system in each of the distribution centres. In a similar vein, data in the manufacturing control points was stored in the local systems in the manufacturing centres. Unlike the other units, the focus manufacturing centre delivered the date-of-manufacturing data to the traceability system of the focus distribution centre through a systems interface. End-user date-of-purchase data was stored in a distinct register dedicated for registering end-user data. There were no standard reporting tools available for lead-time measurement. The data was analysed using spreadsheet and database applications prepared by the users.

Earlier, before the interface between the traceability systems of the focus manufacturing and distribution centres was established, measuring lead-times required collecting data from two traceability systems. This was laborious, particularly because the data in the manufacturing test system was fragmented into a large number of files stored in different locations. Finding the required data was difficult. Measurements were carried out rarely, approximately once a year. After the interface was set up, the amount of manual work dropped from several days to a few hours. In 1997, lead-times were being measured approximately once a week. This was a result of easier availability to and also an increased need for the data.

Measuring lead-times in the other manufacturing centre - distribution centre and distribution centre - distribution centre interfaces required retrieval of data from two or more systems and manual consolidation of data. In most of the distribution and manufacturing centres, the data was not accessible outside the function. Thus, the users of the data needed to request the data separately from each of these units. The data in the various traceability systems was not in a consistent format, and thus, on some occasions, it needed to be reformatted before the

measurements could be undertaken. In these parts of the material flow, lead-time measurement were still infrequent.

Measuring the lead-times from the point of shipping to the point of sales required combining data in the end-user database and distribution centre shipping registers. A relationship-marketing programme, which was in charge of end-user registration activities, had outsourced the registration service. Thus, the end-user database was maintained by the company providing the service. As a result, each time the measurements were undertaken, the data needed to be requested from this company. Normally, this resulted in a one- or two-week delay. When the data was received, it was consolidated with the shipping data from one or several distribution centres, followed by the preparation of custom reports. The amount of manual effort required was several hours. The measurements were undertaken on ad hoc basis, but highly infrequently.

Although the data in the focus distribution centre traceability system was available through remote access in 1997, the IT department still retrieved the data and delivered it to the users - most frequently the global logistics department - carrying out the analysis. Running a large query in the system at the wrong time could slow down the system and thus the operations of the distribution centre. Creating the queries, retrieving the data, reformatting it to the requested format and delivering it to the user took approximately two hours of working time and typically three to four days of calendar time. When the data had been delivered, the requester manually prepared the needed reports, which again took a couple of hours of working time.

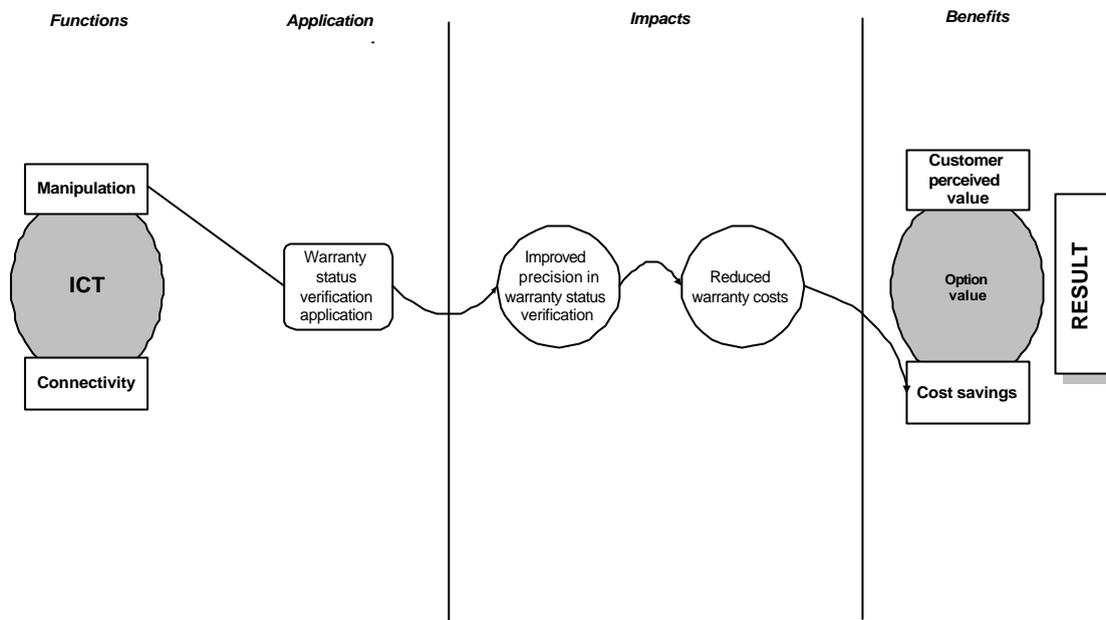
In addition to the work needed in obtaining the data, on certain occasions, the length of time needed to process large amounts of data was a problem. The manager in charge of performance measurements underlined that 'if the processing of the data takes several hours, the user may carry out a couple of analyses. However, due to the time needed, it is likely that the user will not drill down to the details, which would require running additional analysis.'

8.1.3 Company Gamma

8.1.3.1 Warranty status verification

The start of warranty period used in warranty-status verification could be determined by end-user date-of-purchase and Company Gamma's date of shipping to a trade customer. In principle, the end-user date of purchase determined the start of warranty period. Warranty was valid for twelve months from this date. However, because Company Gamma did not have access to end-user date of purchase information, it started calculating the warranty period from the date the product was sold to a trade customer. When the latter method was used in warranty determination, the length of warranty period was increased by three months, from twelve to fifteen months. This was done to allow three months for the delivery from Company Gamma through the external distribution chain to the end-user. If the lead-time exceeded three months, the dealer needed to show the date the product was sold to the end-user.

Figure 33: Impacts and benefits of the warranty status verification application at Company Gamma



Product-specific date-of-shipment data was recorded when the product was shipped. This data was stored in local shipping registers in the distribution centres and sales companies shipping the products. Thus, the shipping data was scattered among a number of systems.

Warranty verification was triggered by a product repaired at an internal repair centre or a claim for warranty compensation from an external repair centre. The verification was carried out by the sales company in the country in question. This sales company used local shipping registers comprising of data on all the products shipped to that country. When the data was available in the local sales company, the warranty status could be readily identified.

If the product in question had been sold by a different sales company, the data needed in warranty verification could not be found from local registers. Other units needed to be contacted to verify warranty validity. First, an inquiry was sent to the unit that had manufactured the product to identify the distribution centre and sales company through which the product had been delivered. When the manufacturing unit had retrieved the information and replied to the question, a second inquiry was sent to the distribution centre or sales company to which the product had been delivered.

When the data needed to be inquired about in different units, the amount of effective working time was approximately an hour and the delay from the first inquiry to the final answer several days. Nevertheless, because the products were normally sold and repaired in the same country, only 1.5 per cent of the repair cases required other shipping units to be contacted. It was suggested that if there would be a common, company-wide information system, warranty status

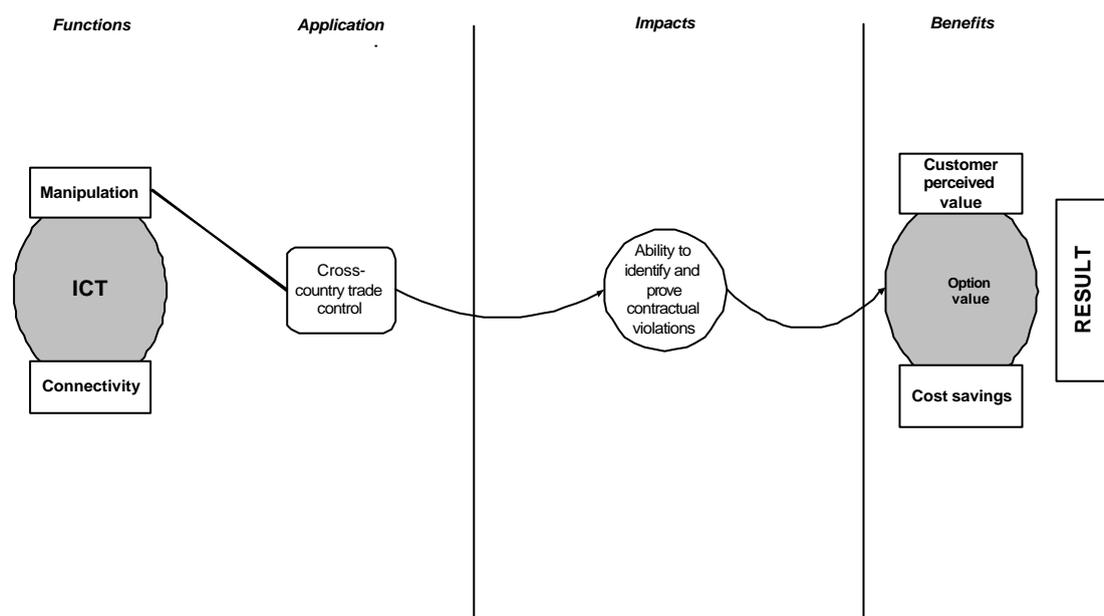
verification would be easier. However, it was estimated that the savings in the effort related to warranty status verification would not alone justify the costs.

8.1.3.2 Cross-country trade control

The prices of the products Company Gamma sold to different countries could vary from country to country, e.g. due to differences in pricing policies and fluctuations in exchange rates.

Trade customers in lower-price countries could occasionally utilise the price differences by forwarding the products with a small margin to be sold in other countries. From Company Gamma's perspective, this kind of cross-country trade was not desirable, as it undermined the company's ability to maintain its pricing policies and affected the competitive situation between the trade customers in different countries. Thus, cross-country trade was, under certain circumstances, prohibited in the agreements made between Company Gamma and its customers.

Figure 34: Impacts and benefits of the cross-country trade control application at Company Gamma



Trade customers suffering from the cross-country trade often triggered analyses of cross-country trade, for instance, by delivering some of the serial numbers of the suspected products to Company Gamma. After receiving the serial numbers, the sales and distribution function at Company Gamma used traceability records to identify the customer and the country to which the product had originally been shipped. When it became apparent that the customer had resold products to other countries, the trade customer was approached with an additional invoice and discussions with the customer were started. The manager of planning and customer service suggested that the company has had positive experiences in fighting cross-country trade using traceability data.

The data used in the application consisted of product-level shipping records collected in local information systems in the distribution centres and sales companies. The identification of the destination customer could include the following steps:

First, the person investigating the issue inquired about the distribution centre that had shipped the product to identify the destination sales company. When the distribution centre had identified the destination sales company and delivered the information to the person in question, he or she contacted the sales company to identify the final destination.

The effective working time needed in the identification was estimated to be one hour, but the actual calendar time, which could be several days, depended on how swiftly the involved units responded to the inquiries.

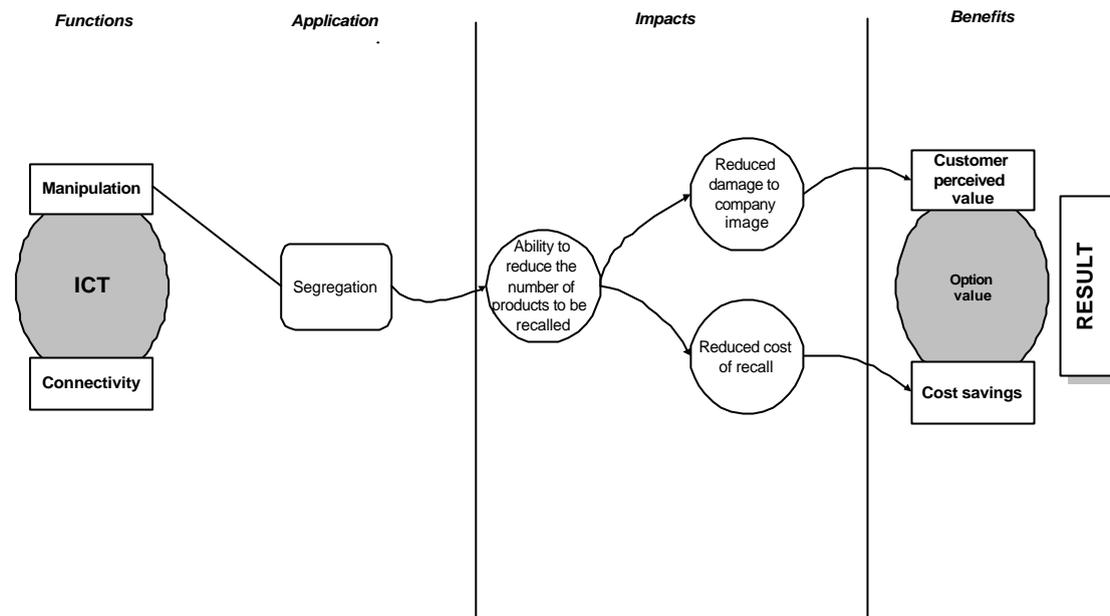
The application was used on ad hoc basis. The importance of cross-country trade prevention was suggested to be declining in the European Union due to EU regulations discouraging these kind of policies.

8.1.3.3 Segregation

On some occasions, traceability data was used in the event of a quality problems to segregate the defective products from total product population. The purpose of the application was to isolate the problem to a minimum number of products. The ability to minimise the scope of the problem was considered to be particularly critical in the event of recall, due to the 'huge' adverse influence recalls had on the company image.

Nevertheless, the reaction to a quality problem depended on the scope and criticality of the problem. If only a few observations of a non-critical quality problem were made, the company did not react. However, if the observed failure rate due to a specific problem reached two to five per cent of the field population, further actions were taken.

Figure 35: Impacts and benefits of the segregation application at Company Gamma



When a quality problem was safety-critical, which had happened only once during the 1990s, the affected products were withdrawn from the internal material flow and recalled from the market. In the event of non-safety-critical quality problems, only the defective products in the internal material flow were withdrawn and reworked. If a product affected by the problem appeared in the service centre, the defect was routinely repaired.

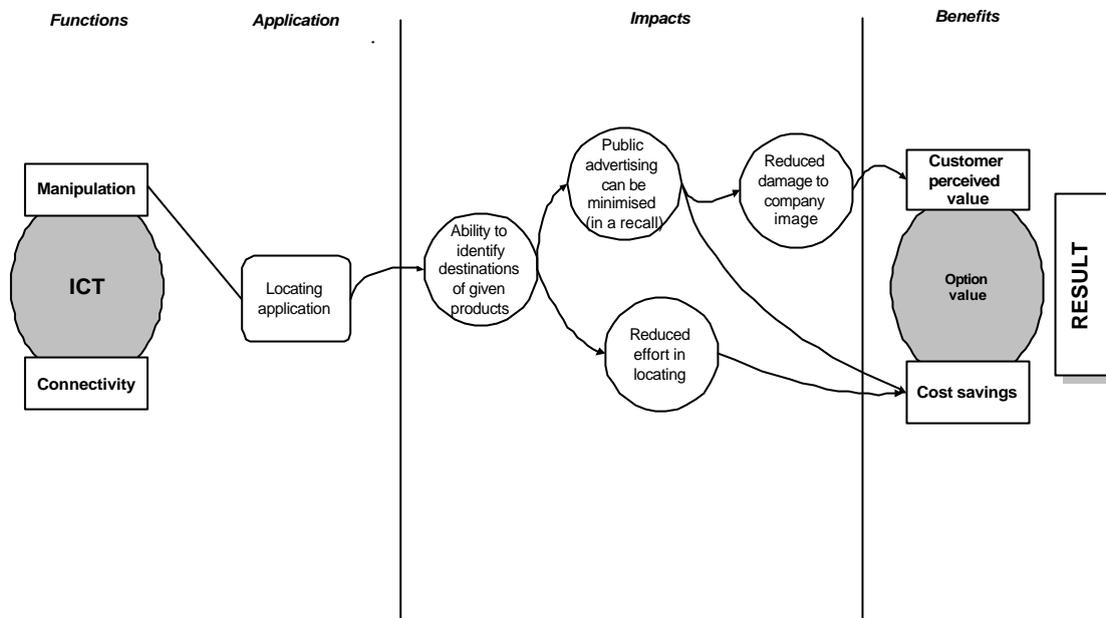
Normally the affected products were identified on the product level and traceability data was not used. However, on some occasions, traceability data was used to identify the serial numbers of the affected products. When traceability data was used, the way of identifying the affected products and the amount of manual work could vary from case to case. If the problem was related to a certain standard bill of materials or software version, the manufacturing units having access to the data could directly retrieve the serial numbers of the affected items from the MRP system. However, if the problem was caused by another factor, e.g. by a component lot or process change, the time period during which the problem had existed was estimated using various data sources. Then the serial numbers of the products manufactured during this period were identified and the data delivered to the party in charge of recall operations at the company level. However, a lack of data (e.g. component usage and change management data) was considered to be a problem in the identification. The speed with which the identification was carried out depended on the criticality and scope of the problem.

8.1.3.4 Locating

In the event of a quality problem requiring corrective actions, traceability data was used to identify the destinations to which the defective products had been shipped. The ability to identify product destinations was considered to be

important in order to reduce the damage to public image caused by a recall. For instance, public advertising carried out in the newspapers could possibly be limited to certain countries.

Figure 36: Impacts and benefits of the locating application at Company Gamma



The data used in identifying the product destinations consisted of data recorded in local registers in the distribution centres and sales companies. Identification of the destination followed a similar process as in the cross-country trade application described earlier, i.e. the shipment destinations were separately identified in the distribution centres and then in the sales companies. However, the scope of the effort was or could be significantly larger, as the destinations would potentially need to be identified in multiple distribution units for a large number of products.

Traceability data was not used to locate affected products in stock, because received items were not recorded at the serial-number level. Thus, a distribution unit could not easily identify which individual products it had in the inventory. When there was a need to locate certain items within a distribution unit, locating was carried out on the product-code level, i.e. a 100 per cent check was made. A system that would enable internal locating was considered to be expensive in comparison to the benefits it would provide.

The lack of end-user data was considered to be a problem in locating given products on the market, which resulted in the need to carry out the product recall using public advertising.

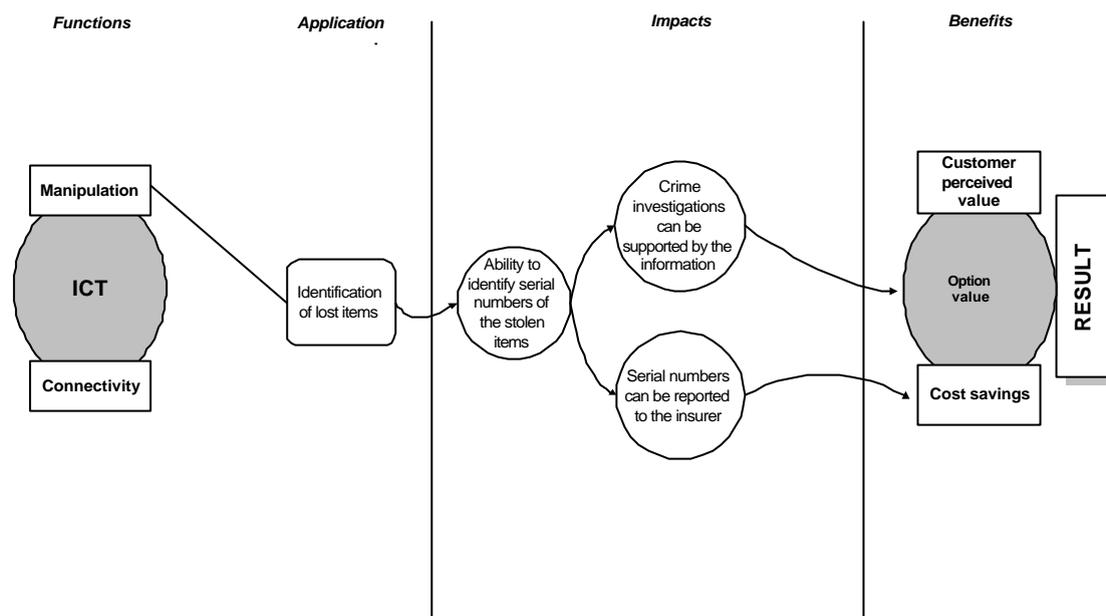
8.1.3.5 Identification of lost items

In the event that products were observed to be missing in internal transit between a distribution centre and a sales company or between company Gamma and its

customer, traceability records were used to identify the serial numbers of the lost items.

The ability to identify the serial numbers of the products enabled reporting the serial number information to the police authorities to support investigations and discouragement of crime. Moreover, the serial number information was required by the insurance companies as a prerequisite for insurance compensation.

Figure 37: Impacts and benefits of the application identifying the lost items at Company Gamma



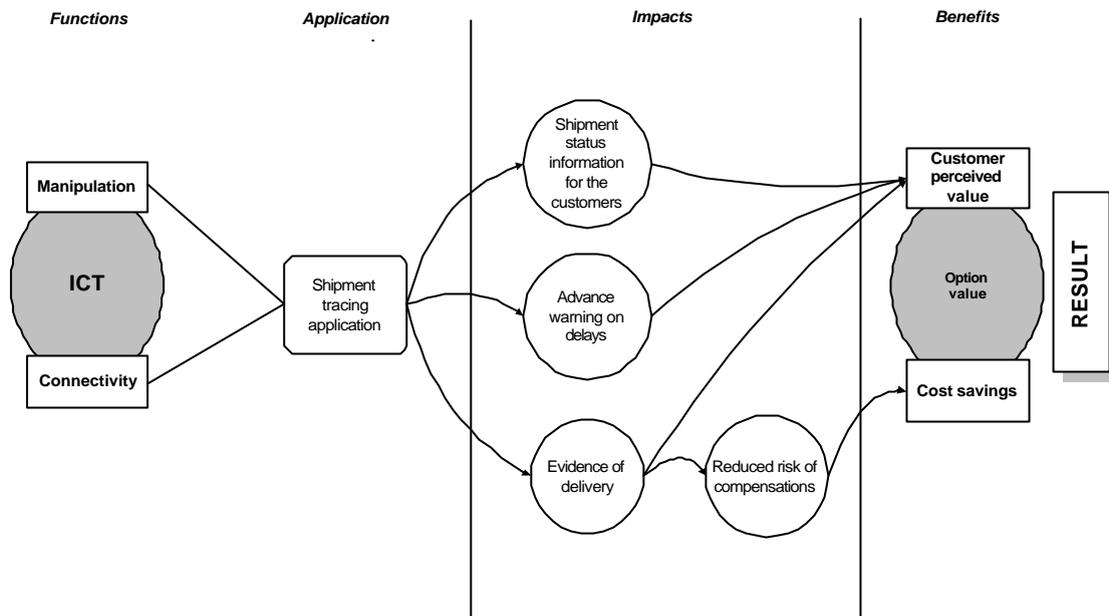
The data used in the application consisted of the serial numbers of the products delivered in a shipment. The unit that had shipped the products could identify the serial numbers of the lost products by using the serial numbers of the remaining products. Some manual work was, however, needed to identify the products.

8.1.4 Company Delta

8.1.4.1 Shipment status monitoring and verification of delivery

One of the applications at Company Delta was shipment status monitoring. The application enabled the company's personnel and its customers to monitor shipments throughout the shipping processes. The information provided by the application indicated the location of the shipment, the route via which it had been delivered, whether the shipment had been delivered to destination, and to whom the shipment had been handed over at the destination. Moreover, the application provided information on possible delays in the delivery of the shipment.

Figure 38: Impacts and benefits of the shipment tracing application at Company Delta



The main impact of the application was improved customer service - the application was suggested to be a market standard required by the customers. Many of the customers wanted to know the status of the shipment and whether it had arrived at its destination. The availability of this information was suggested to be particularly important, when timely arrival of the item being shipped was critical for the sender. This could be the case when a shipment contained, for example, 'a bid for a business contract, which needed to arrive on time to be taken into account or a letter of credit from a bank that would lose interest if not delivered on time'. Some customers also had a lack of confidence in the carrier, due to earlier bad experiences for instance, and thus wanted to trace all the shipments, irrespective of their value. Additionally, it was suggested that items traced based on general curiosity. It was underlined that although only one to five per cent of shipments were being traced, most of the main competitors of the company were providing a similar service for their customers. Altogether, the application was viewed as a market standard that must be available to keep from losing business.

Moreover, traceability data was also used as evidence indicating whether the shipment had been delivered to destination and whether the delivery had taken place on time. For instance, in the USA, it was a common practice to give a 'money-back guarantee'. If the item was not delivered on time, the customer did not need to pay for the shipment. A modification of this contractual clause, although rare, was to give a money-back guarantee in case the shipping information, i.e. the traceability data, could not be delivered. The use of the application was suggested to provide cost savings and improve customer confidence in Company Delta.

The data used in these applications consisted of time-location data that was collected at different control points throughout the material flow from the point of

receiving to the point of delivery. Additionally, data on possible delays and the name of the person to whom the shipment was handed over could be used. This data was transmitted to the global databases used in the monitoring. The customer's as well as the company's personnel could access the data using Web browsers on the Internet. By entering the shipment identification number, the system instantly indicated the shipment status information. Customers could also call Company Delta's customer service to request status information. Legally valid documents with customer signatures were maintained in the field offices that had delivered the shipments. These documents could be manually searched for in the archives or the imaging systems when they were needed.

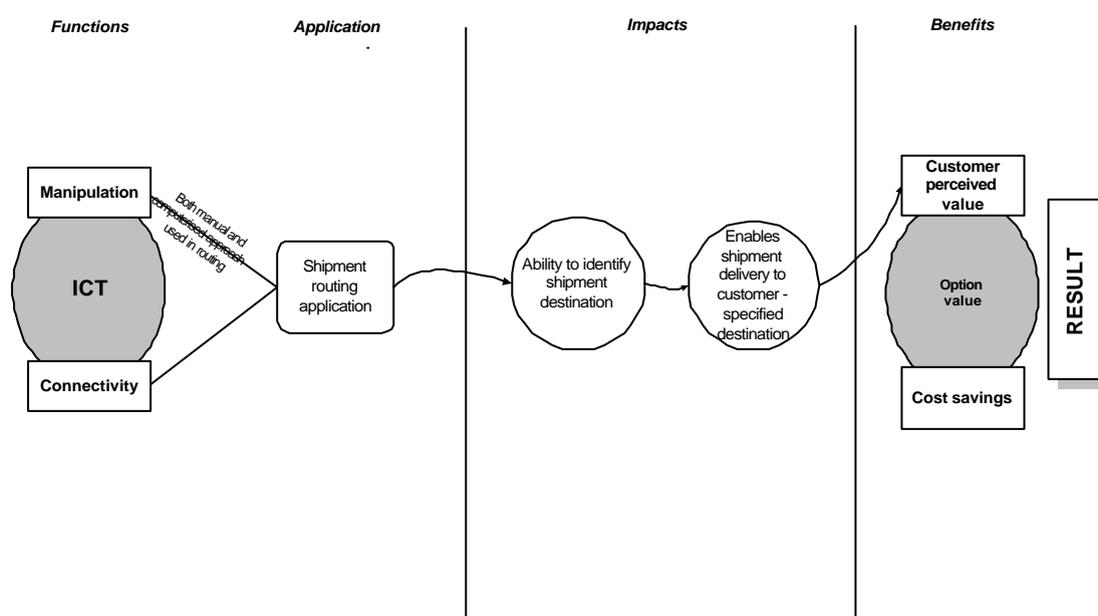
Despite the easy availability of the status information on the Internet, the frequency of application usage had not changed significantly after the Internet application was introduced. However, the ability of the users to retrieve the data without contacting Company Delta's customer service notably reduced the pressure on the customer service. Ninety per cent of the inquiries were carried out using the Internet.

At the time of the interview, the status monitoring application was being developed to enable proactive traceability. If the shipment was delayed, e.g. due to delays in customs clearance, the customer could be automatically notified about the delay. This would give the customer the chance to react to the problem in advance.

8.1.4.2 Shipment routing

The shipment destination data that was manifested by the customer was used to route the shipments to their destinations. The availability of the address data enabled shipment delivery to the customer-specified destination.

Figure 39: Impacts and benefits of the shipment routing application at Company Delta



Customers provided shipment destination data to Company Delta by writing it on the shipment label. Alternatively or in parallel, the customers had the chance to connect to Company Delta's information system and enter the shipment data in the system. This saved customer's time and money in shipment preparation and to reduced manual data entry at Company Delta.

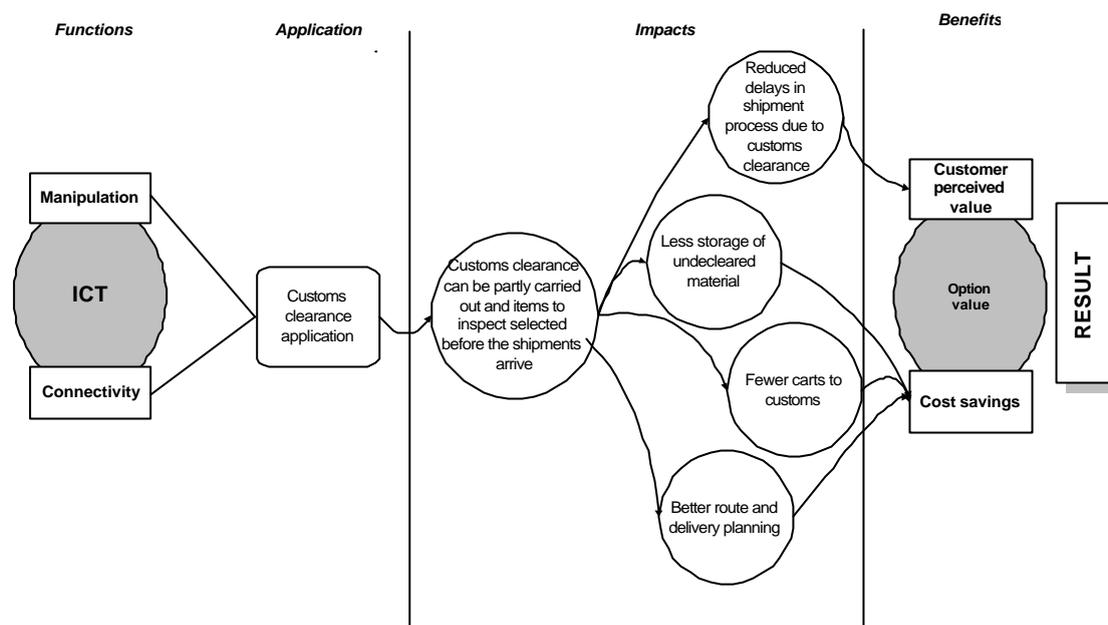
During the delivery process, shipment destination data was observed to be used in two ways in routing. First, the destination could be read from the shipment label and the shipment could be manually routed accordingly. Secondly, the destination could be identified using a shipment-specific identification number. Among other shipment-specific data, the destination of the shipment, manifested by the customer sending the shipment, was stored in the global traceability information system. The identification number could then be scanned in the automated and manual process phases and the shipment could be automatically routed correspondingly. With both methods, the destination data was readily available to be used throughout the distribution chain. Moreover, in both cases, incorrectly entered data and illegible, hand-written data caused problems in routing.

When the shipments were routed based on the shipment identification number, shipment data, including the destination of the shipment, did not need to be visually identifiable. This improved security in the delivery process, as the possible value of the package contents could not be determined on the basis of the label.

8.1.4.3 Customs clearance

When shipments crossed national boundaries, they were in many cases subject to customs clearance and/or spot checks. To minimise the delay caused to the shipment process by the customs clearance, Company Delta delivered shipment-specific documentation to the customs authorities at the destination country to enable authorities to carry out the paperwork related to the customs clearance before the arrival of the shipments.

Figure 40: Impacts and benefits of the customs clearance application at Company Delta



Data on the sender, destination and contents of each shipment was used in the application and delivered to the customs authorities. This data, which was consolidated in the global traceability database, was automatically delivered through a systems interface to the authority information system in the destination countries. Using this information, the authorities could then carry out the customs clearance and select the items to be inspected without delaying the majority of the shipments. Moreover, this reduced the need to handle and store undeclared materials and supported better route and delivery planning.

8.1.4.4 Error prevention

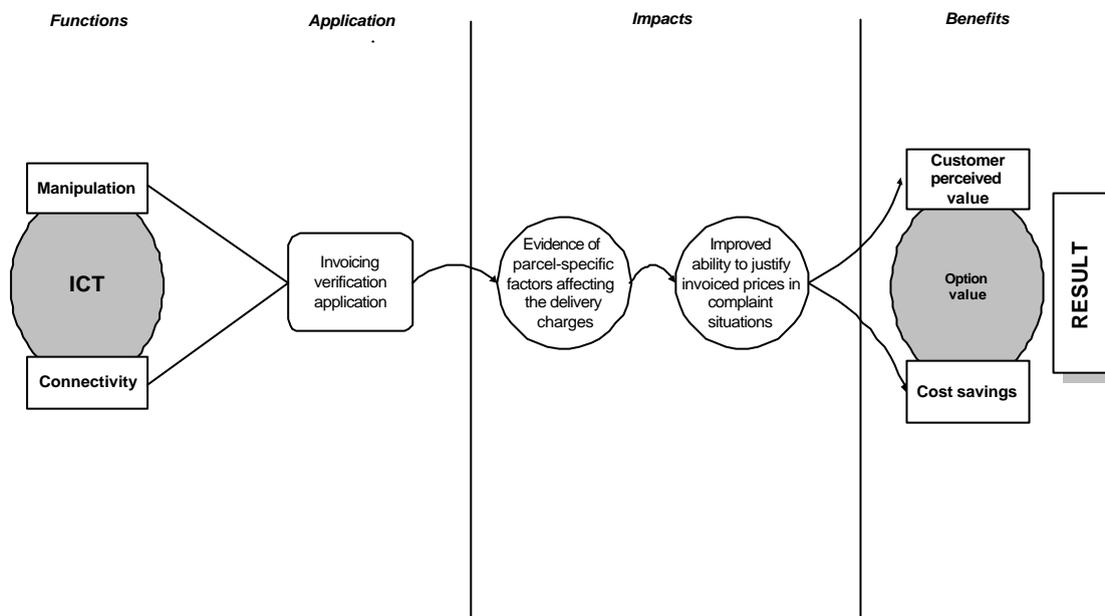
A shipment could consist of one or multiple items. When a shipment comprised multiple items, there was a need to keep the items together throughout the distribution process so that they could be delivered to the destination at the same time. The use of the application was considered to improve customer satisfaction as the parcels could be delivered to the destination at the same time. Moreover, the elimination of multiple delivery attempts provided cost savings.

Joint delivery of the items was ensured using traceability data. Data on the items within a shipment was recorded in the global traceability system. At specified control points throughout the distribution chain, an application was used that prevented items from proceeding before all the items in the shipment had arrived. When an item was identified, item- and shipment-specific data was retrieved from the global traceability database and a real-time verification was carried out. Thus, the use of the application did not cause notable delays in the material flow.

8.1.4.5 Invoicing verification

Shipment weight and volume determined the delivery charges. Shipment-specific weight and dimensions were measured in the first sorting centre receiving the parcels to be delivered. This information was used as the basis for invoicing. The data was also recorded in the global traceability system. In addition to the measured weight and dimensions, the database contained the weight and dimension data originally manifested by the customer and also possibly commentary information on special events that took place during the delivery.

Figure 41: Impacts and benefits of the invoicing verification application at Company Delta



In the event of a customer complaint regarding the invoiced price, shipment details could be retrieved to be used as evidence of correct invoicing. The use of traceability data for this purpose was demonstrated by a sorting centre operations supervisor with the following example:

A customer reclamation on incorrect invoicing was received. The customer had shipped a 100-gram circuit board. However, the price charged from the customer exceeded the tariff for 100-gram items with the dimensions of the circuit board. Using the traceability system, it was identified that the circuit board had been inadequately packaged by the customer. After the board had been repacked in the sorting centre, its weight and dimensions had grown, affecting the price to be invoiced. Thus, it was possible to justify the increase in price.

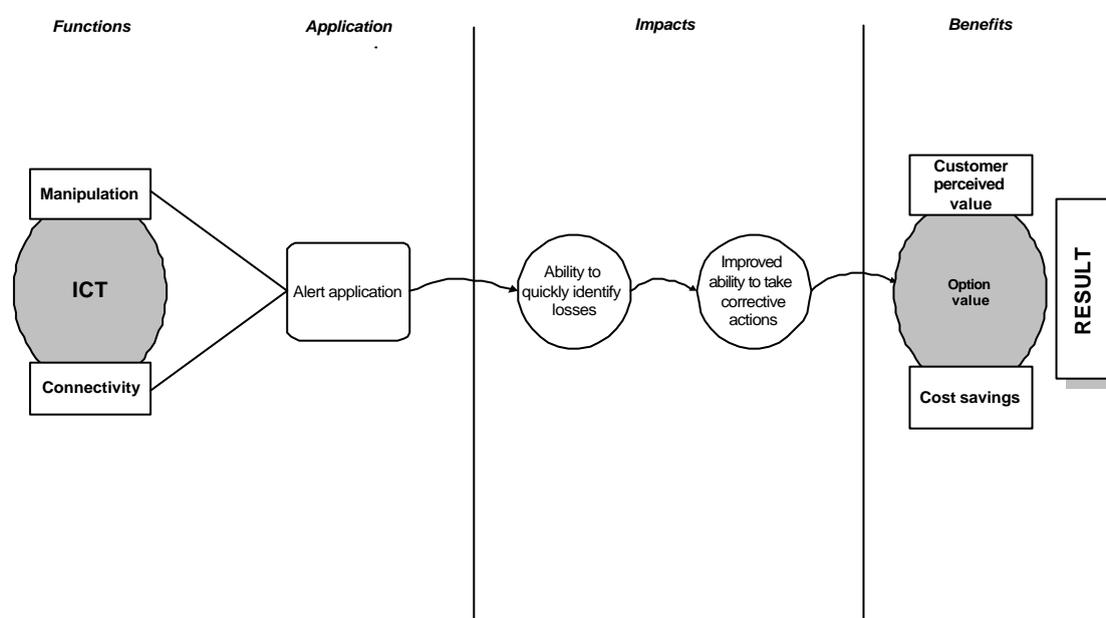
8.1.4.6 Alerts

Company Delta's sorting centres applied traceability data to detect lost items as demonstrated by the following description:

Shipments were delivered through a sorting centre twice a day. The parcels received to be shipped arrived at the sorting centre in the evening. Shipments were sorted and forwarded to domestic and foreign destinations. In the morning, shipments from other countries were received to be delivered to domestic destinations. As all received parcels were forwarded during the shift, there were no parcels in the sorting centre when the shift was over.

During the shift, received and forwarded parcels were identified. This data was stored in the local traceability database. At the end of the shift, before the shipments were released to be forwarded, a report was run indicating those items which were registered to be received but not forwarded.

Figure 42: Impacts and benefits of the alert application at Company Delta



The use of the application gave the company the opportunity to rapidly identify losses and to take timely measures to study and rectify the problems. Indirectly, this application was considered to improve material flow security and customer satisfaction and confidence through improved delivery reliability. The real-time functionality of the application appeared to be critical in order not to delay deliveries.

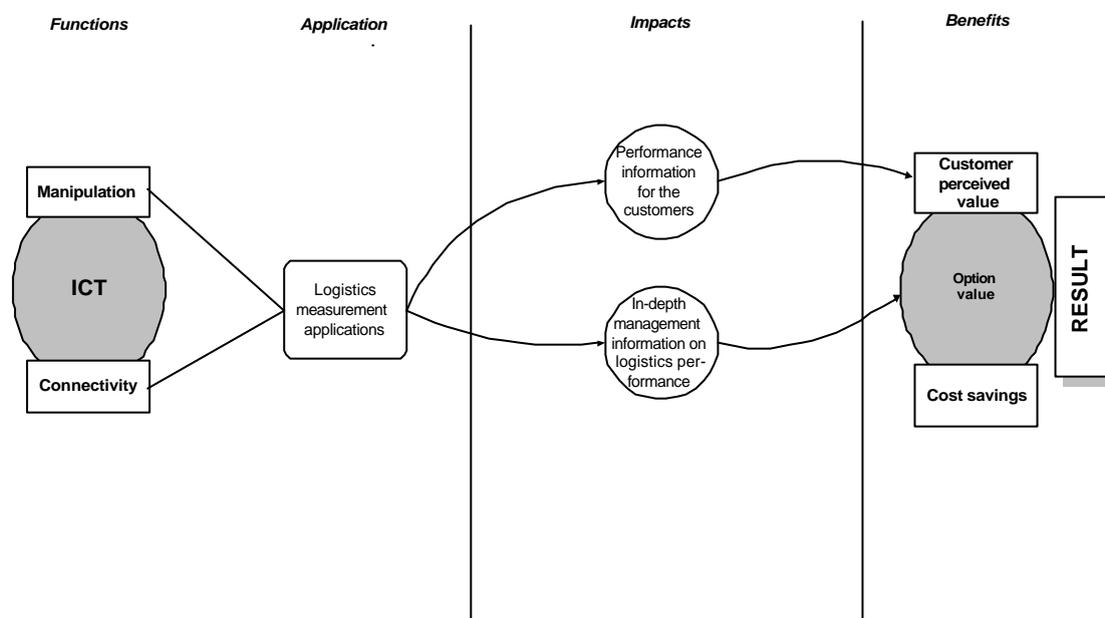
8.1.4.7 Logistics measurements and analysis

Company Delta employed traceability data in a number of ways in logistics related measurements and analysis. These included on-time delivery rate, lead-times and delivery pattern measurements. The measurements were complemented by analysing the factors underlying the deviations in the measured values.

The use of traceability data enabled 'microanalysis of the process'. For example, it was possible to study the performance of different routes in different countries. Logistics measurements and analysis provided management with information, that supported internal development, competitive analysis and marketing. Moreover, the availability of the information provided the means to answer customer reclamations on company performance in general.

The same system could also be used to provide customers with data for their performance measurement. When the system was interfaced with a customer's traceability systems, the customer could extend measurements beyond company boundaries. Customers could use the data, for example to measure actual order-to-delivery lead-times instead of order-to-shipping lead-times.

Figure 43: Impacts and benefits of the logistics measurement applications at Company Delta



In on-time delivery rate measurements and analysis, the item-specific time of receiving and time of delivery were used to identify whether a shipment was delivered on time. In delivery pattern measurements, the same data was used to analyse the patterns in pick-up and delivery times. It was considered better when the items could be collected from the senders later in the evening and delivered to their destinations earlier in the morning. In both of these measurements, exception data and environmental factors were used to study the reasons for failures in on-time. Analysis could also be made to identify possibilities for improvement. As an example of the usage, it was suggested that the data could be used to analyse the impact of changing the mode of transportation on a given route from propeller to jet aeroplane on delivery performance. Lead-times were measured using the time-location data collected when an item passed through various control points on its route from the sender to the receiver.

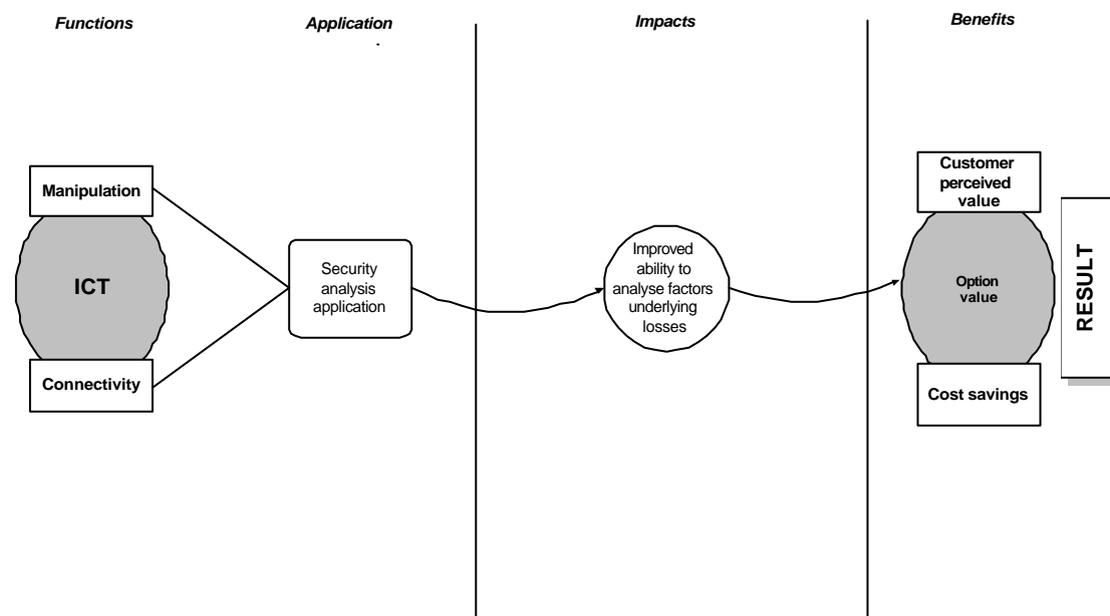
The measurements were carried out either using standard reports or by customising a report for a specific purpose. When standard reports were used, the measurement could be quickly and effortlessly undertaken. The reporting tools used either data in local or global databases, depending on the measurement scope and the party carrying out the measurements. Local databases were used in the field units when sub-process performance - for instance lead-times within a local sorting centre - was being analysed at a detailed level. Global databases, which did not contain all of the details maintained in the local databases, were used in analysing process-wide performance. Reporting was carried out periodically.

8.1.4.8 Security analysis

Company Delta applied traceability data in security-related analysis. Traceability records were used to identify the points of the material flow where the losses were taking place and the circumstances - including who was responsible - that prevailed at the time of the loss. The use of the application supported security improvement in general, and in individual cases, identification of the factors underlying the losses.

All of the data needed in the analysis, including persons on shift and time-location data, was collected to and retrieved from the company-wide traceability system. The data could be readily retrieved from the system.

Figure 44: Impacts and benefits of the security analysis application at Company Delta



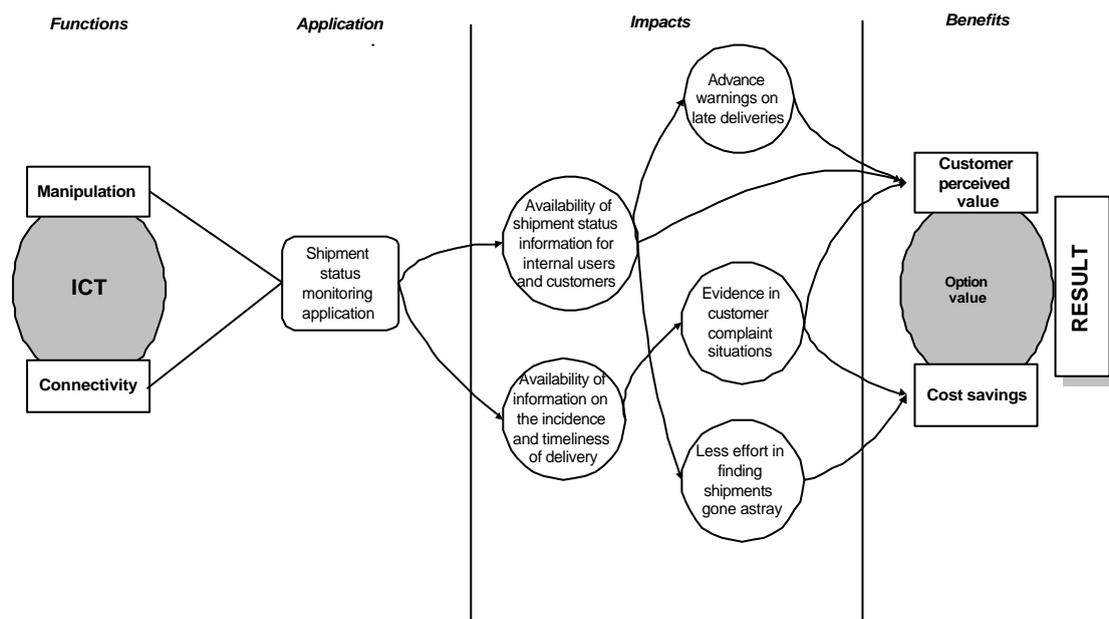
8.1.5 Company Epsilon

8.1.5.1 Shipment status monitoring and proof of quality

A shipment status monitoring application, which was established in 1997 to respond to market pressure, aimed at providing easy availability of shipment status and other shipment related data to the customers. Availability of this data was considered to improve customer satisfaction. The following example demonstrated the importance of the application:

A frequent source of customer questions were undelivered shipments. Frequently, when these cases were analysed, it was found that the shipment had been delivered to its destination, but it had not reached the receiver within the destination organisation. The ability to trace shipment status from the traceability information system was likely to reduce the amount of work on these kinds of occasions.

Figure 45: Impacts and benefits of the shipment status monitoring application at Company Epsilon



Customers were also considered to be generally interested in being able to identify shipment statuses. The need for the service was magnified by the fact that all the major competitors of the company were providing a similar service to their customers.

Shipment data was also used to identify and to provide evidence showing whether the company had fulfilled its commitments by delivering the shipment to its destination and carried out the delivery on time. Traceability data could be used to identify when the customer had brought the shipment in to be delivered. For example, if Company Epsilon had promised that shipments it has received by 6:00 p.m. will be delivered to the destination during the following working day,

the system could be used to identify the time when the shipment was received to be delivered and the time when it was delivered to the destination. If an express shipment was not delivered to destination on time, the company compensated the sender. Thus, the use of the data enabled the company to obtain savings in unnecessary compensations. Moreover, the ability to provide the information was considered to be important for maintaining customer confidence.

Data used in the application consisted of time-location data collected at a varying number of control points during the delivery and status data indicating a delay.

A customer could identify shipment status by calling the customer service centre at Company Epsilon. Major customers had also direct, computerised access to the data. Shipment data was maintained in the central database, from which it could be readily retrieved. The application enabled the customer to identify through which delivery process control points the shipment had already traversed and whether the shipment had already been delivered to its destination. When there was a deviation from normal course of delivery, e.g. misrouting, breakage or other factor, delay information could be displayed or delivered to the customer.

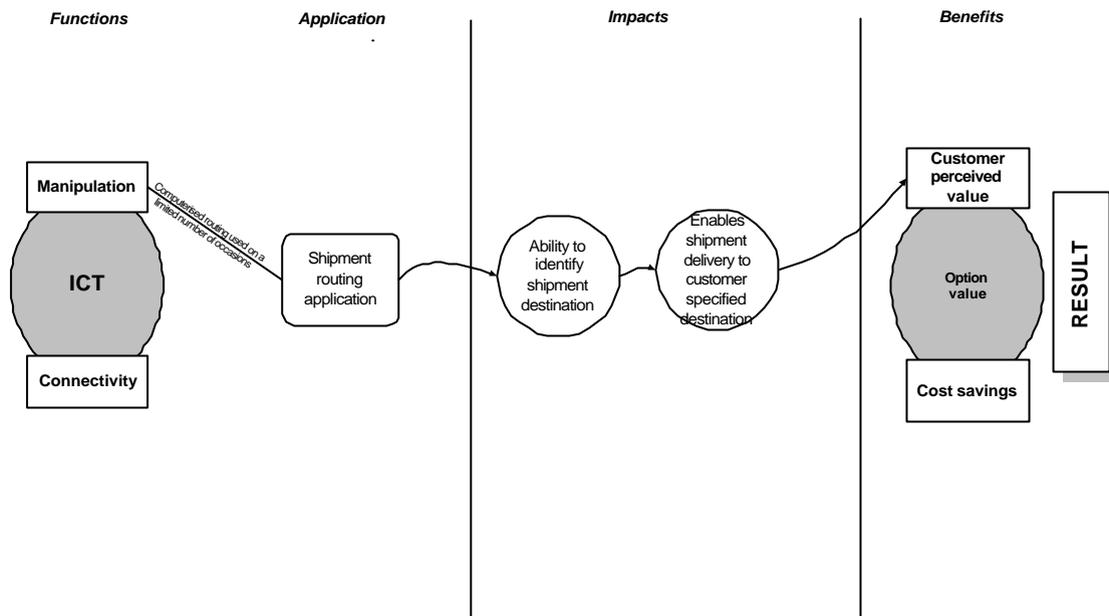
If a shipment had been misrouted to a wrong destination, it was possible to identify the error before the time the shipment was delivered to the destination. The receiver could be informed about the problem and the cause of the problem could be explained.

Before the computerised traceability system was set up in 1997, traceability data collected on paper documents and maintained in the field units was used to provide the evidence needed in showing whether the shipment had been delivered to destination and whether the delivery had taken place on time. The branch office which had delivered the shipment to the destination was contacted to retrieve the delivery document. Often, the branch office which should have delivered the shipment was not exactly known and several offices needed to be contacted to search for the document. Searching for the documents required significant amounts of working time, which was considered to be a problem. The problem was aggravated by the large number of inquiries. Despite the introduction of a computerised traceability system, paper documents with receiver signatures were still used as legally binding evidence.

8.1.5.2 Shipment routing

The shipment-specific address data presented in address labels was used to route the shipments from the sender throughout the distribution chain to the destination. The availability of the address data enabled shipment delivery to the customer-specified destination.

Figure 46: Impacts and benefits of the shipment routing application at Company Epsilon



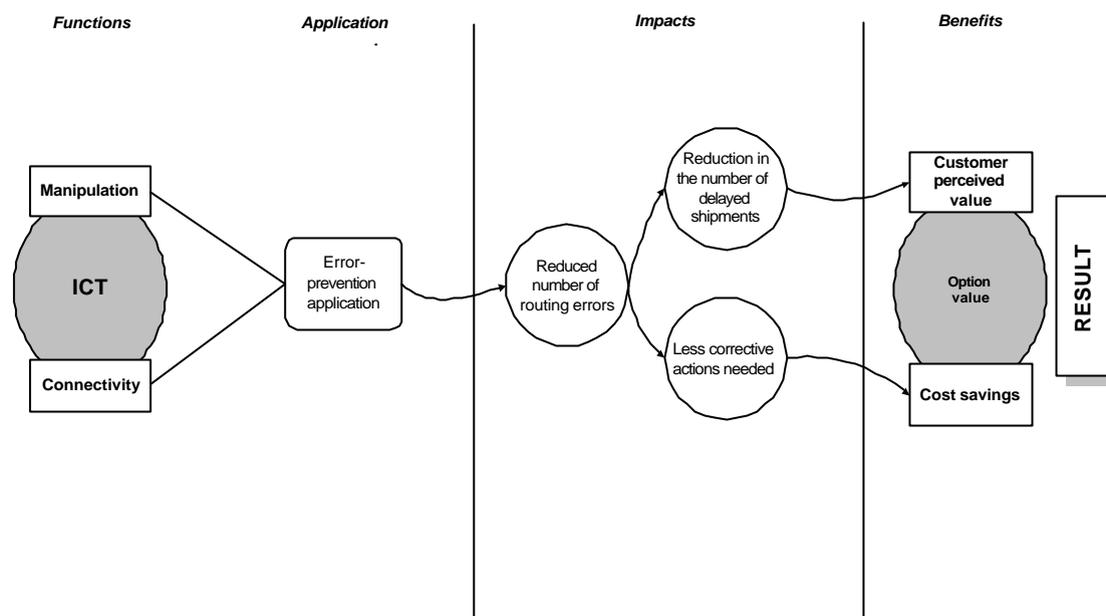
When the address was not hand-written, shipment destination data could be read in Company Epsilon's major sorting centres from the address label using optical character recognition. Shipments could be automatically routed correspondingly. Shipment destination data was also manually read from the address labels. Shipments were then either sorted manually using manual methods or automatically by using a sorting system in which the user entered the destination data. However, in both of the cases, the destination data was readily available to be used.

Problems in routing were caused by hand-written data, which could not always be correctly interpreted.

8.1.5.3 Error prevention

Traceability data was employed to prevent handling unit routing errors and thus, to improve accuracy in the delivery processes. Improved accuracy was considered to affect customer satisfaction and provide cost savings. Errors in the delivery process were likely to lead to decreased customer satisfaction, due to inability to fulfil the promised service level. In certain cases, customers also needed to be compensated for failures to deliver on time. Moreover, misrouting prevented shipments from being delivered to the destination through an optimal route. Carrying out the corrective actions and duplicate work was considered costly. As a result of undertaking the verifications, unintentional misroutings were considered to be very unlikely.

Figure 47: Impacts and benefits of the error-prevention application at Company Epsilon



The data used in the error prevention application consisted of the destination and route of each individual handling unit and the destinations of the vehicles delivering the handling units.

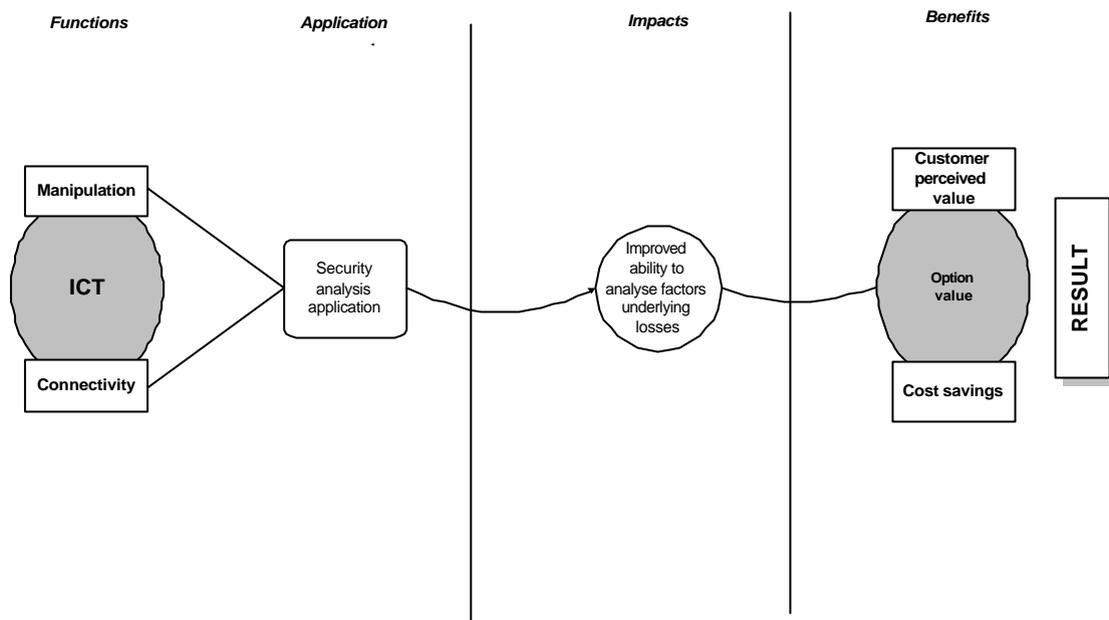
The verification was carried out using off-line scanners. The vehicle destination was transferred to the scanner from the vehicle routing system through an off-line interface. The scanner identified the handling unit destination from the handling unit serial number in which it was encoded and carried out a verification. If the scanner observed that the handling unit and vehicle destinations conflicted, a notification was given. The verification was fully automated and carried out in real time, which was considered to be important in order not to delay deliveries.

The handling unit destination was embedded in the serial number of the handling unit, although it could have been retrieved from the central traceability database. However, the response time in data retrieval from the central database would have been several seconds, which was considered too long. Moreover, on-line scanners would have been needed in the verification.

8.1.5.4 Security analysis

In the event a shipment was lost in the distribution network, traceability data was used to investigate the problem. The information obtained using the data supported the efforts to find the lost shipments and to identify the possibilities for security improvement in the distribution network.

Figure 48: Impacts and benefits of the security-analysis application at Company Epsilon



Time-location data collected in various control points in the distribution network and data on the persons responsible for the shipments in each process phase was used to study the losses. The traceability data needed in the analysis was readily available in the central traceability system.

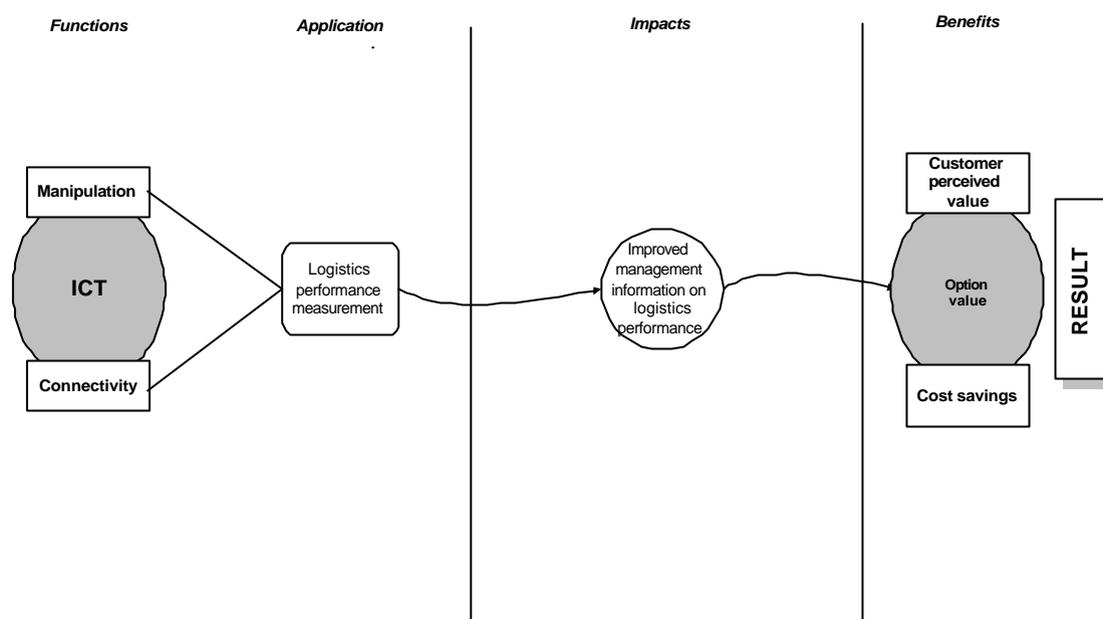
Before the computerised traceability system was set up in 1997, paper records scattered among the various units throughout the distribution network were used to identify the place of loss. Tracing the shipment was started from the point at which the shipment had been received to be delivered. The shipment's route was traced step-by-step using paper documentation in each unit along shipment route. Tracing the shipments required a significant amount of work and time.

8.1.5.5 Logistics measurements and analysis

Traceability data was used to support different types of measurement and analysis needs in the field of logistics. The reporting, which was carried out periodically, included lead-time and on-time delivery rate measurements.

Traceability data was also used on a daily basis in individual item-level analysis regarding the reasons for misroutings and deviations in process performance. The analysis could be carried out at the process-phase or responsibility-area level. Furthermore, traceability data was used to analyse the movements of the handling units. The analysis could include when, from where and to where handling units had travelled in the distribution network. The use of traceability data provided detailed management information supporting logistics performance improvement.

Figure 49: Impacts and benefits of the logistics performance measurement applications at Company Epsilon



The data used in the analysis consisted of time-location data on handling unit destinations and shipment status data indicating the cause of delay. This data was collected at various control points throughout the delivery chain. Measurements and analysis were limited by the fact that the detail of the data related to other shipments than express and insured shipments, and to handling units was limited.

The analyses were carried out by selecting a standard report, which provided effortless availability to the required information. In addition to running standard reports, the users were able to create custom queries. The availability of custom queries was considered to be of particular importance in providing flexibility to the analysis. The reports were run in the information database dedicated for analysis purposes.

Before the computerised traceability system was set up in 1997, measurements were carried out using sampling. Experimental arrangements were used to collect the data needed in the analysis. Because carrying out the measurements was laborious, the measurements were infrequently carried out. Frequent availability of up-to-date information was considered to be one of the most important benefits provided by the new system.

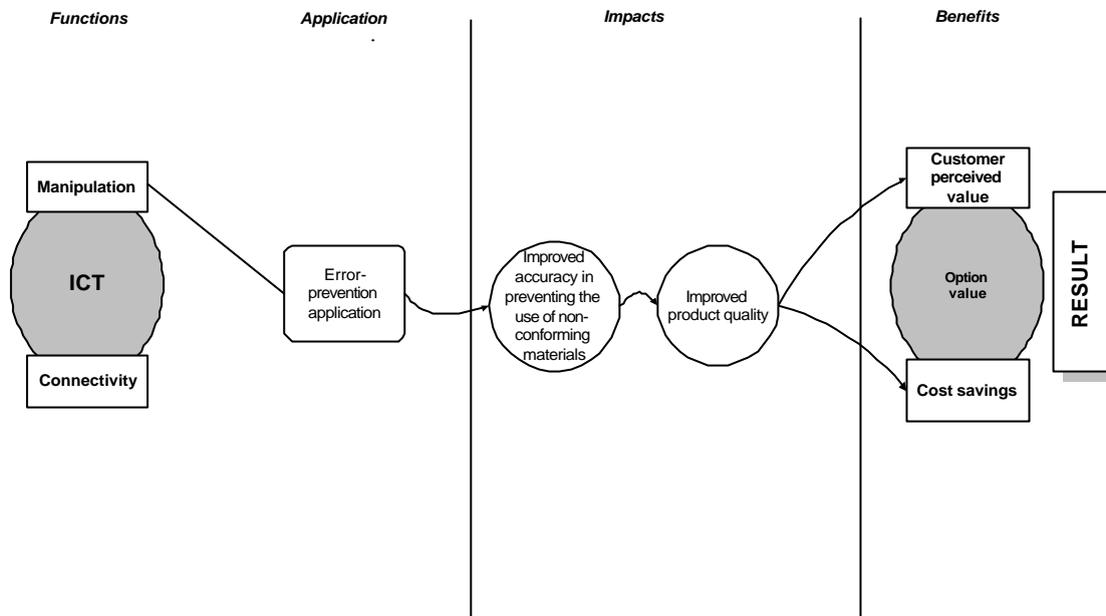
8.1.6 Company Kappa

8.1.6.1 Error prevention

Traceability data was employed in error-prevention applications, preventing the use and delivery of non-conforming lots. The application controlled lots that were expired, rejected or unapproved. The use of the application was considered to

prevent the damage caused by the use of non-conforming materials and by the delivery of non-conforming materials to the customers.

Figure 50: Impacts and benefits of the error-prevention application at Company Kappa



The data used in error prevention consisted of lot-specific best-before date data and quality status data. Best-before-date data was obtained from the raw material suppliers and from the manufacturing process, and quality status data originated from the quality inspections. The indication of the best-before-date information was also required by the authorities. The above-mentioned data was stored in the logistics information system that was being used in the manufacturing area.

Verifications were used on specified occasions when raw materials, semifinished products or end-products were being issued to be used in a production order or to be transferred to another location. Given the lot number of the materials or finished products in question, the logistics information system automatically and instantly verified the quality status and noted deviations.

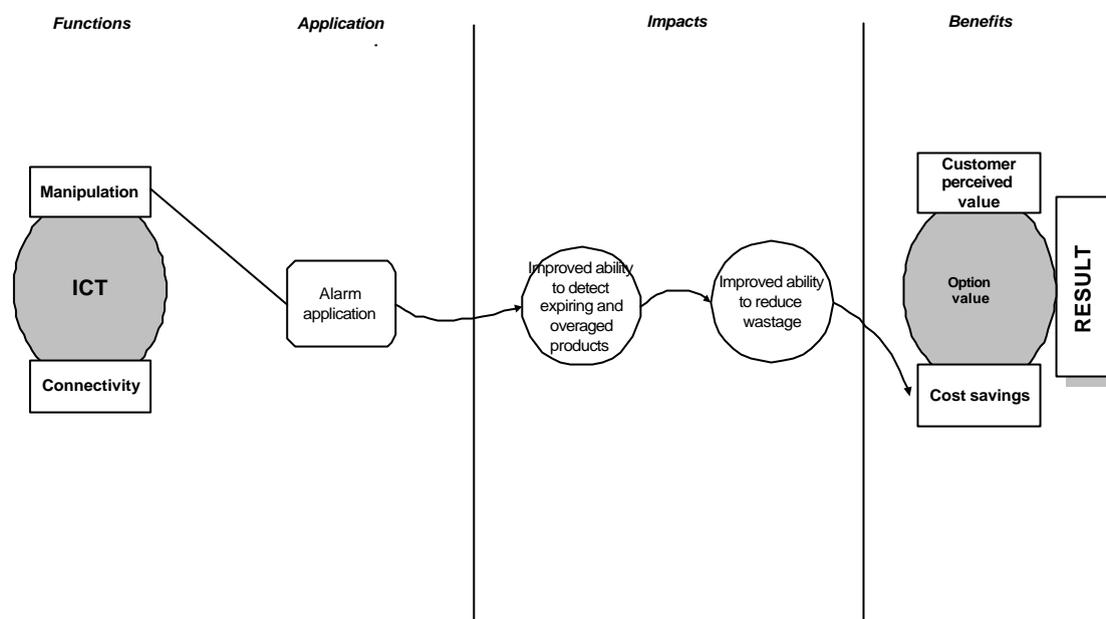
In baby food manufacturing, the quality status was verified in each process phase. Unapproved lots could not proceed in the material flow. On the other hand, in the confection manufacturing, quality approvals were given and verifications carried out for the end-products only. Confections were considered to be less critical to consumer safety than baby food and thus, to require less controlling.

8.1.6.2 Alarm

Traceability data was employed to identify raw-material and end-product lots the age of which was about to exceed the minimum allowed time to expiration or the storage time of which was about to exceed the maximum allowed time in a

storage location. The application aimed at reducing waste in the form of expired raw materials and finished products.

Figure 51: Impacts and benefits of the alarm application at Company Kappa



In addition to prespecified time limits, lot-specific expiration date data - the providing of which was required by the authorities - and the time a lot had arrived at a storage location were used in the application. Raw-material expiration-date data originated from the suppliers, and the end-product-specific data came from Company Kappa's manufacturing process. The data used in the manufacturing area was maintained in the logistics information system.

The application was used by periodically running reports in the logistics information system. The reports pointed out expired lots by inventory location. Reporting was fully automated and thus did not require any manual effort.

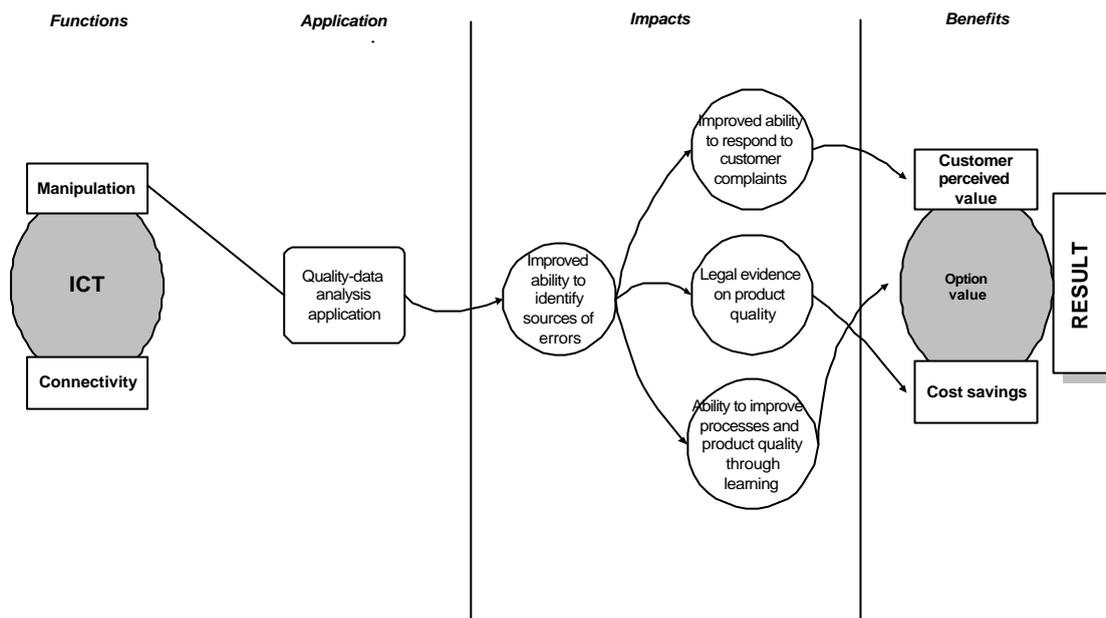
In addition to the usage at the manufacturing area, a distinct age alarm application was being used at the distribution area. It was based on the finished products' expiration-date data originating from the manufacturing process.

8.1.6.3 Quality-data analysis and proof of quality

In the event of a customer complaint, customer service at the manufacturing site used traceability data to support identification of the root cause of the problem and to provide evidence showing whether the acknowledged problems originated from the company. The ability to respond to customer complaints was considered to be important in maintaining the company image. The use of traceability data to provide evidence was also considered to enable the company to reduce the risk of compensations.

Moreover, traceability data was used internally in quality and process improvement. By using the data, the company had successfully been able to identify and eliminate the sources of errors, optimise processes and improve working methods and instructions. The use of traceability data was considered to be an important factor in employee training, as suggested by the factory quality manager: 'The personnel can learn how their actions affect the subsequent process phases and end-product quality.'

Figure 52: Impacts and benefits of the quality-data analysis application at Company Kappa



Quality-data analysis were based on feedback data received from the customers and internal quality inspections, and traceability data collected during the manufacturing and packaging processes.

When feedback related to a specific lot was received, root problem analysis was started by analysing the manufacturing samples and the possible samples sent by the customer. Then, if needed, analysis was continued by studying what traceability data was available for the particular lot in question. The available data was retrieved from the logistics information system. The data in the stand-alone systems and paper records was obtained by having somebody 'walk through the process and retrieve the data from end-products to intermediate products and further to raw materials'. It could, for example, be studied what the product had been like, when it was manufactured, which process parameters had been used, what kind of analysis had been made for the raw materials and when the raw materials had been received at the company. The suppliers could also be contacted to continue the analysis.

When the data was available, it was analysed whether something abnormal had taken place or been observed during the manufacturing process and during other related processes. Moreover, the analysis aimed at identifying whether the

problem was one of a kind or it affected a larger group of products. The usage of traceability data in managing quality problems was demonstrated by the following examples:

A recurring quality problem in the granularity of the foodstuff was detected. Using the traceability records, it was identified that the occurrence of the problem was independent of the raw materials used. Thus, it was concluded that the problem was caused by a factor in the manufacturing process. As a results, internal examinations were started. It was possible to identify the department from which the problem originated. Transillumination equipment was acquired in the department, with which it was possible to identify the exact source of the problem.

Customer reclamations were received on product quality. Samples were analysed and it was detected that there were pea blossoms in the food. As the company had a number of pea suppliers, the manufacturing history of the non-conforming products was studied. It was identified that peas from certain supplier had been used in all of the cases where pea blossoms were found. After studying the problem with this supplier, shortcomings in supplier's storing methods were identified.

Thus, the use of traceability data also supported supplier quality evaluation. Moreover, traceability data was also used in process improvement, as demonstrated by the following example:

Traceability data was used to optimise candy-wrapping-machine rotation speed. Lot-specific rotation speed was cross-referenced with lot-level quality feedback. Thus, it was possible to identify the impact of different rotation speeds on product quality and optimise the rotation speed.

Normally the time needed in going through the traceability records was approximately one hour. However, this time could vary greatly and in some occasions, much more time was needed. Still, the amount of time and effort needed in the analysis was not considered a problem due to the infrequent need for analysis. For instance, in the BSE crisis, identifying the sources of raw materials was a minor task in comparison to the amount of work required in answering customer questions.

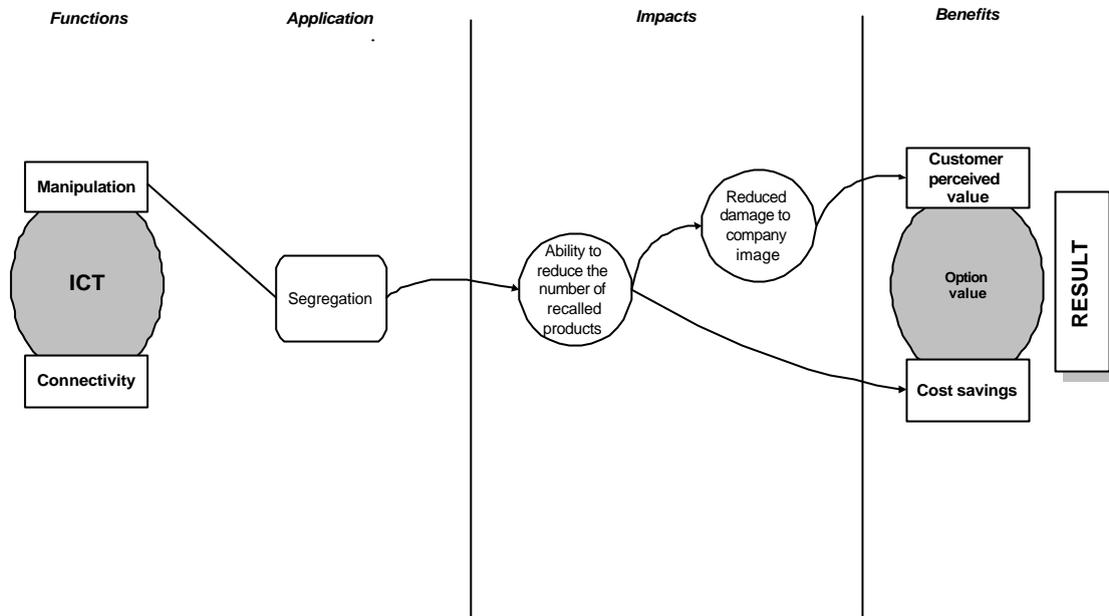
Analyses were complicated by shortcomings in data collection in confection manufacturing. Process changes and problems in the processes could only roughly be connected to the affected lots, because the date and time of change implementations were not registered.

8.1.6.4 Segregation

In the event of quality problems, traceability data was used to identify the manufacturing and/or packaging lots that had been affected by the problem. The

aim of the application was to enable minimising the number of products to be withdrawn from the distribution chain and from the market.

Figure 53: Impacts and benefits of the segregation application at Company Kappa



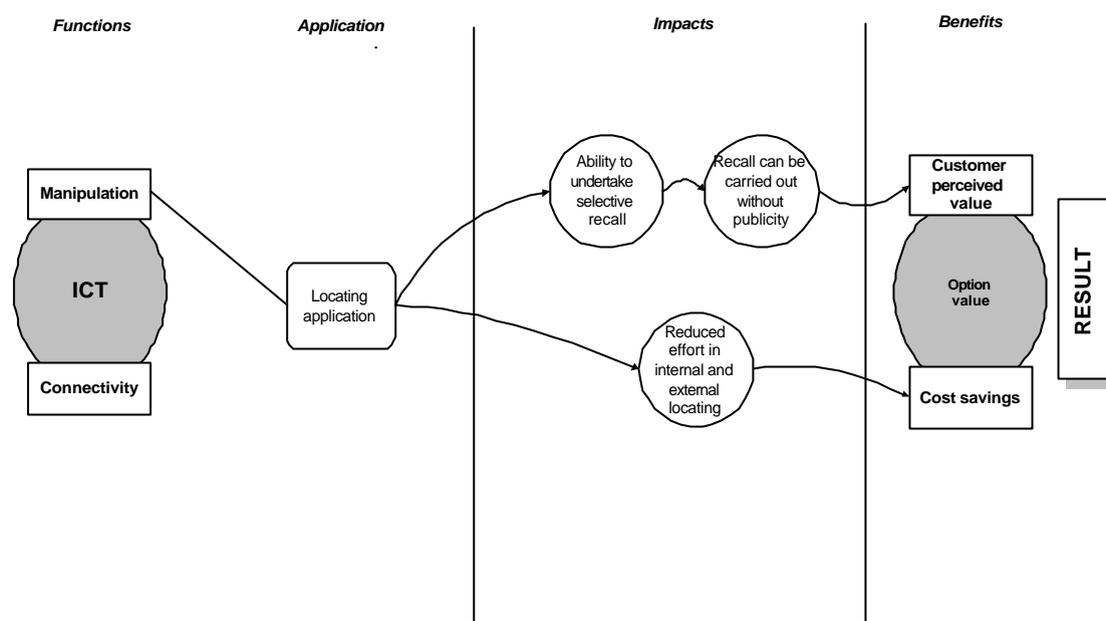
Manufacturing's quality department organised the segregation. When the root cause of the problem was known, traceability records were used to identify the manufacturing or packaging lots affected by the factor causing the problem. For example, the end-product lots in which a given raw material lot had been used could be investigated. Like in the quality-data analysis, basically any of the materials-usage and manufacturing-process-related traceability data items could be needed in the segregation.

Logistics information system, stand-alone systems and paper documentation could be used in the segregation. No standard reporting tools were available for this purpose. The amount of manual work needed in segregation was approximately one hour. Due to the limitations in confection traceability data, the affected products could on some occasions only be roughly identified.

8.1.6.5 Locating

In the event of a quality problem, traceability data could be used to identify the locations of non-conforming products and raw materials within the company and the destinations to which these products and materials had been delivered. The availability of precise location data enabled the company to reduce the effort needed in locating materials internally and destination data, minimising the publicity caused by possible recall.

Figure 54: Impacts and benefits of the locating application at Company Kappa



The data used in internal locating consisted of the lot-specific location data collected at the control points along the material flow. This location data was collected in the logistics information system in the manufacturing area and in the local information system in Corporation Kappa's distribution centre. Given a lot number, it was possible to readily identify the inventory and line locations in which the products or materials could be found. Locating needed to be separately carried out in the manufacturing and distribution units.

Lot-level shipment destination data was used to locate the defective products on the market. However, this data was only recorded when the pallet being shipped was fully loaded. Thus, it was not possible to identify shipment destinations for all items.

In the event of a safety-critical quality problem, public advertising, together with traceability-based locating, was always used to support the recall. When the quality problem was non-critical, e.g. when there were cosmetic flaws in the confections, the objective was to recall the majority of the non-conforming products from the market without public advertising. Thus, the withdrawal enabled the company to minimise the damage caused by the quality problem to the company or brand image and simultaneously to maintain the recall costs at a reasonable level.

The personnel in the distribution centre could readily retrieve the shipment destination data maintained in the distribution centre registers. Problems requiring a recall were estimated to take place approximately once a year. Normally, these problems were non-critical and did not require a public recall.

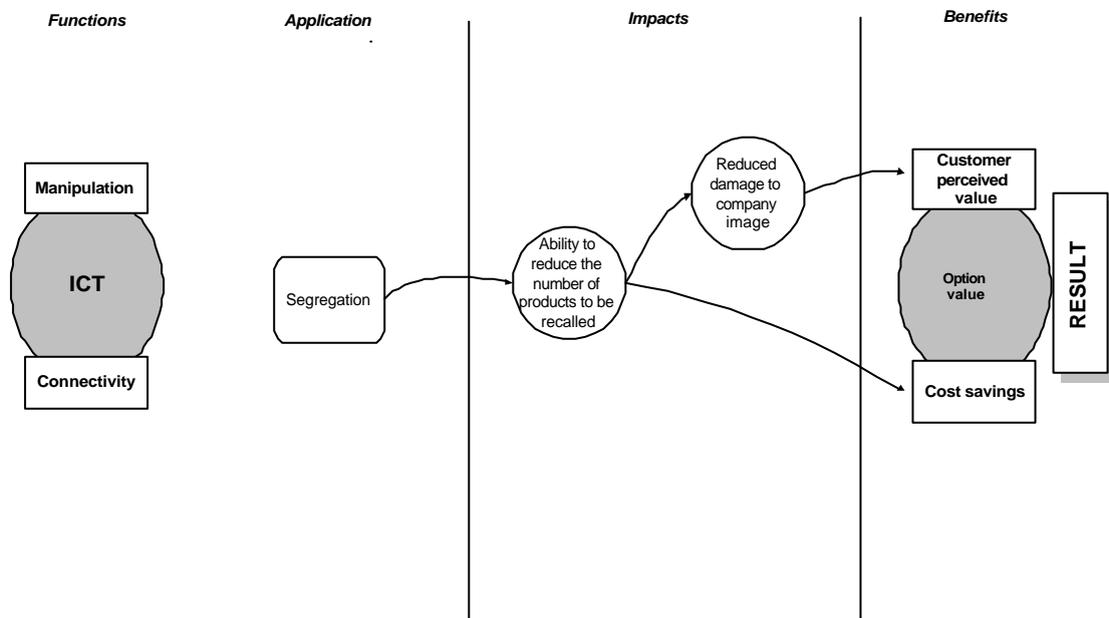
8.1.7 Company Lambda

8.1.7.1 Segregation

On some occasions, traceability data was used to identify manufacturing and packaging lots affected by quality problems. However, in general, the role of traceability data in the identification of non-conforming lots was small. It was stated that before a finished product lot is released on the market, its quality is carefully assessed, minimising problems in this respect. If problems are after all experienced, they are normally limited to one lot and thus, identification is not needed. Moreover, samples of prior and subsequent manufacturing lots may be analysed to identify if the same problem recurs. The factory manager interviewed acknowledged only one case where traceability records were needed in segregation:

The supplier of a purchased raw material discovered that the composition of a raw material lot did not conform with the requirements set for the material. The supplier approached Company Lambda with a suggestion to recall the affected end-product lots from the market. Company Lambda used the traceability records to identify the manufacturing lots in which this raw material lot was used and carried out the recall.

Figure 55: Impacts and benefits of the segregation application at Company Lambda



A wide range of data could possibly have been used in segregation, depending on the source of the problem. If segregation would have been needed, local users could have retrieved the data from the PPCS and/or paper-based batch records. Moreover, data could have been received from the suppliers. Manufacturing and packaging lots where a particular raw material lot had been used could have been readily identified using PPCS. However, if the problem

would have been related to the manufacturing or packaging process, lot-specific, paper-based records would have been needed. Data maintained in the paper-based batch records would have been needed to be manually retrieved, which would have been laborious.

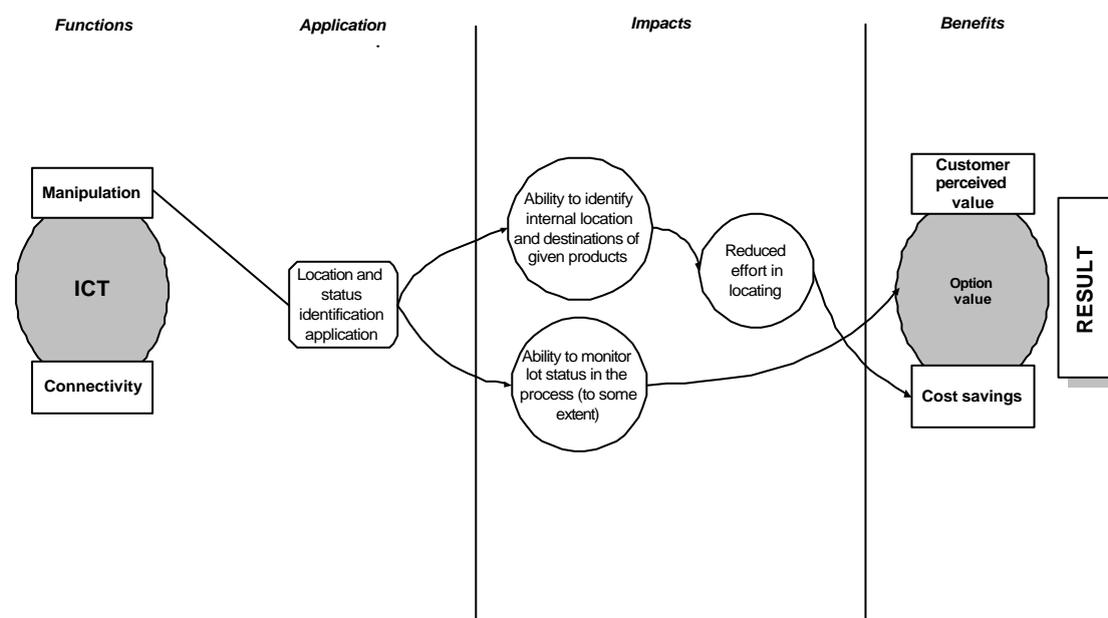
Segregation activities were co-ordinated by and the retrieved data was delivered to the person responsible for recall activities on the company level. This was also required by the Good Manufacturing Practice.

8.1.7.2 Location and status identification

Lot-level identification of raw materials and finished products was needed in the event of a quality problem in order to reduce locating efforts. Moreover, locating was needed to provide lot-specific manufacturing-status data, providing management in the operations visibility to the manufacturing process and supporting production control.

Locating was based on lot-specific location data and data on shipment destinations. At the manufacturing site, this data was collected in the PPCS. Trading companies maintained locally collected location data in their warehouse management systems. Monitoring of the lot status in the manufacturing process, was based, in addition to the location data, on data on completed process phases and quality approvals given to the work in progress. A small part of this data was maintained in the PPCS, as the majority of the data was maintained on paper documentation.

Figure 56: Impacts and benefits of the location and status identification application at Company Lambda



Given the lot number, PPCS enabled instant identification of raw-material and end-product locations in storage and lot status in the manufacturing process. A lot location in storage could be precisely located. Nevertheless, because part of

the status data was maintained on paper documentation, manual steps were needed to retrieve this data from the paper-based batch records. The new production control system being designed was being planned to solve the problem by enabling more detailed, computerised status monitoring.

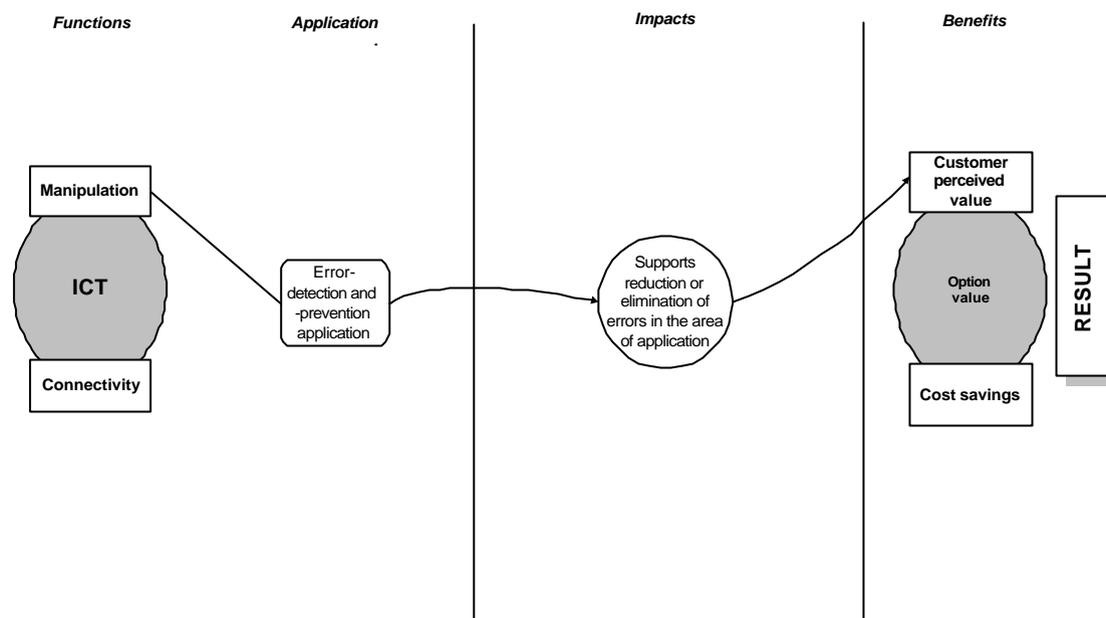
If a lot which had already been delivered to a trading company needed to be located, two steps were taken. First, the shipment destination, i.e. the trading company in question, was identified using PPCS. Secondly, the trading company in question was contacted to locate the items using its local information system.

As lot-level shipment destination data was not recorded in the trading companies, only the trading company from which a particular lot had been delivered (and implicitly the country to which the products had been delivered) was known. In the event of recall, the sales personnel at Lambda Distribution was made to contact the pharmacies to which the products could have been delivered to halt the sales and return the lots. Because the entire sales personnel could be organised to contact the pharmacies, it was suggested that sales could be halted within three hours. Lot-level shipment destination identification was not considered essential, as this was not required by the authorities and as the number of potential destination pharmacies was limited.

8.1.7.3 Error detection and prevention

Company Lambda applied traceability data in error detection and prevention to automatically prevent the use and delivery of unapproved and expiring raw material and end-product lots. Moreover, traceability data was used to prevent the sale and supply of finished product lots, which did not conform with the authority requirements set for production and other factors relevant to product quality.

Figure 57: Impacts and benefits of the error-detection and -prevention application at Company Lambda



The data used to identify unapproved lots consisted of lot-specific quality status data. This data was stored in the PPCS during the quality inspections. When a lot was to be issued to be used or to be delivered, it was identified and a real-time verification was carried out in the PPCS to ensure the quality of the lot. The functionality of the application was demonstrated with the following example:

When a raw material lot was being weighed in order to issue it to be used in the manufacturing process, the identity of the lot was entered to the system. If the lot did not have a quality approval, the system did not allow the user to weigh it.

In a similar vein, the lot-specific expiration date was verified at Company Lambda to prevent issue and delivery of expired materials. This verification was carried out using the expiration-date data obtained from the suppliers in the form of product markings and internally from the manufacturing process within the PPCS.

Before a finished product lot could be released for delivery, the finished product assessment was carried out. This assessment was based on data on production conditions, in-process test results and other manufacturing data that was recorded in the lot-specific records. The quality of the finished products was judged in the finished product assessment by manually going through the data in the lot-specific records. Thus, some manual work and time was required. If the lot did not conform with the requirements, its quality status was not updated to 'approved', and as a result, it was not possible to release the lot for sale or supply. It was stated that as a result of this verification, it is basically impossible for a failure in the manufacturing routines to go unnoticed and non-conforming products to be delivered to customers.

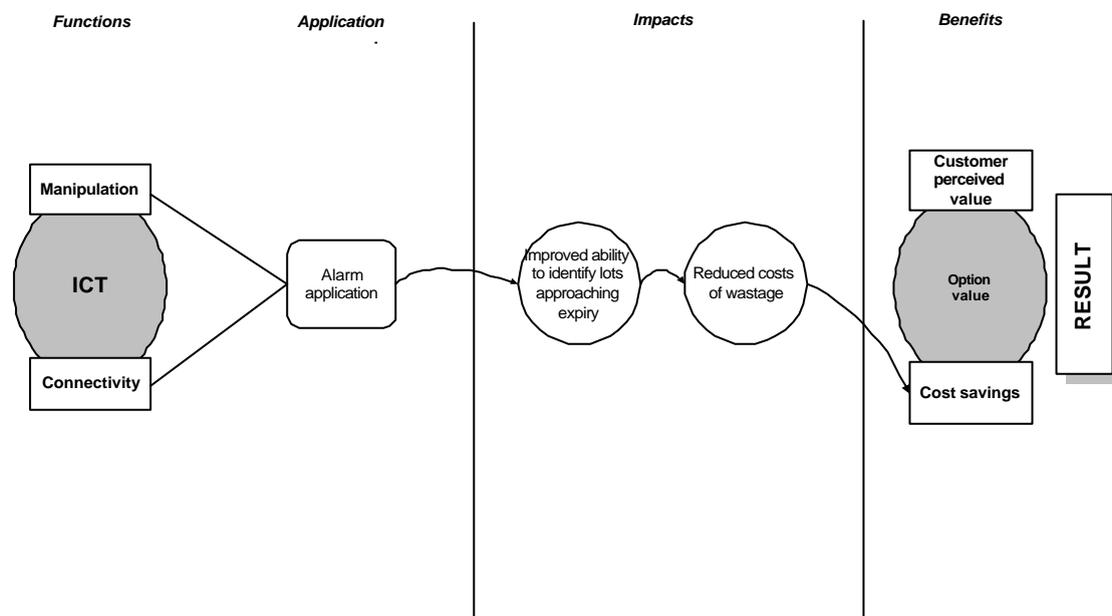
Authority requirements played a central role in these applications. The finished product assessment and quality status verification were directly required by the authorities. Age verification again was affected by the authority requirements for best-before markings.

8.1.7.4 Alarms

Traceability data was used to monitor the age of the raw material and end-product lots in the inventories and to set off alarms on expiring lots. The application aimed at reducing materials waste.

The focus manufacturing site at Company Lambda runs a report once a month to identify expiring lots by storage location. The report indicated the lots the age of which exceeded the minimum time to expiration. This application was based on lot-specific expiration-date and location data, which were maintained in the PPCS. Standard reporting tools, which retrieved the data from the PPCS and automatically prepared the reports were used. The raw-material expiration-date data used in the application originated from the suppliers, and the finished product data came from the manufacturing process.

Figure 58: Impacts and benefits of the alarm application at Company Lambda



A distinct alarm application based on expiration-date data originating from Company Lambda was used at Lambda Distribution to identify lots approaching expiration. The local warehouse management system at Lambda Distribution received the lot-specific age data used in alarms from Company Lambda's PPCS through an EDI connection.

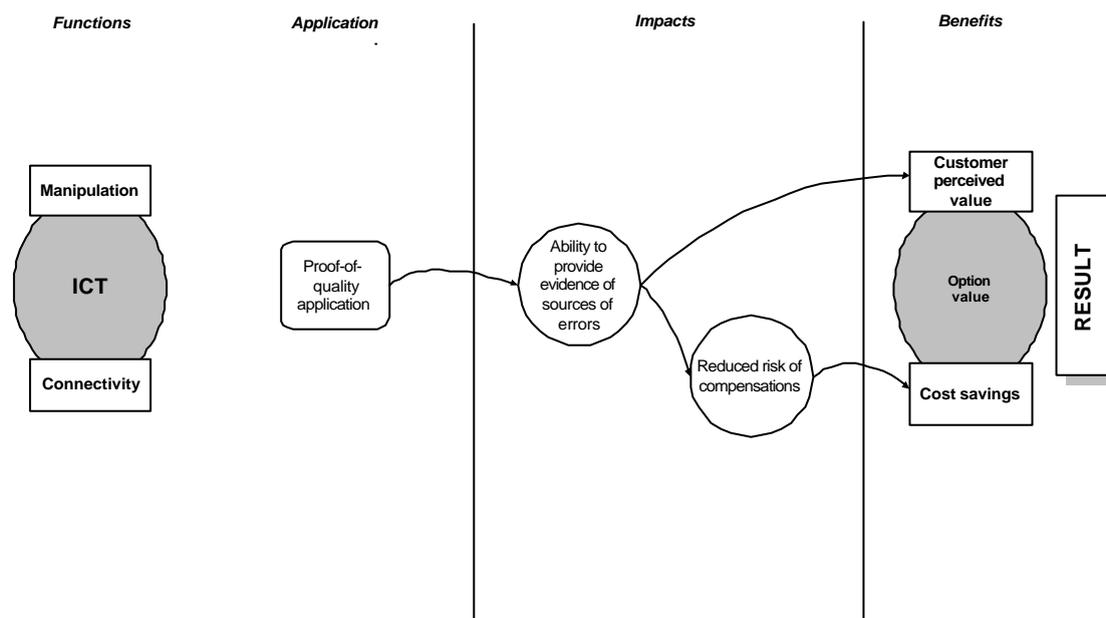
8.1.7.5 Proof of quality

In the event of customer complaints about product quality, traceability data could be used in complaint analysis. Traceability data could be used to analyse

whether the problem had originated before or after the product had left the company and what had caused the problem. Such analysis were also required by the GMP. The nature of the analysis was demonstrated by the following example:

The most common source of customer complaints was that incorrect tablets had been mixed up with the right contents of the package. When this kind of complaint was received, it was first analysed whether the company had manufactured the incorrect tablets. If this was the case, it was then analysed whether the tablets had been manufactured in the same factory. If they had been manufactured in the same factory, it was finally analysed whether the tablets had been manufactured in two consecutive production runs or whether a particular employee had been involved with the manufacturing of both of these lots. If the tablets did not have anything in common, it became evident that the problem had not originated from Company Lambda and the company was not responsible for the problem.

Figure 59: Impacts and benefits of the proof-of-quality application at Company Lambda



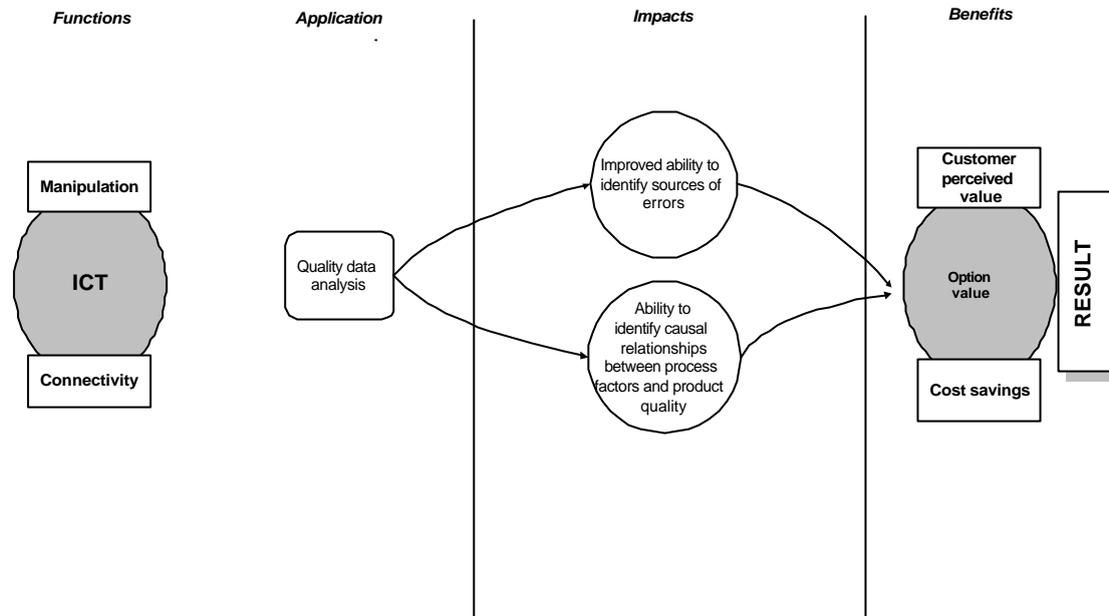
The data used in the analysis varied from case to case. However, the analyses were based on lot-specific manufacturing history maintained in the paper-based batch records. The data was locally retrieved. The analyses were manually carried out. Thus, several hours of manual work could be needed to carry out the analysis and to obtain the proof of quality. The obtained data was delivered to internal and/or external users.

8.1.7.6 Quality-data analysis

The data collected during the manufacturing process was applied in process and quality improvement. The data was used in order to identify correlations between

process parameters and product quality, and to identify trends within the quality data. For example, the use of the data provided information on the impacts of process changes on product quality. Thus, the information supported the company in optimising processes and product quality.

Figure 60: Impacts and benefits of the quality-data analysis application at Company Lambda



The data used in the analysis was maintained in lot-specific records. Because the documentation was paper-based, it needed to be manually retrieved. This was suggested to be laborious. The factory manager illustrated the issue as follows: *'When an analysis is undertaken, the required data is collected piece by piece.'* The amount of time and effort needed in the analysis varied depending on the depth of the problem.

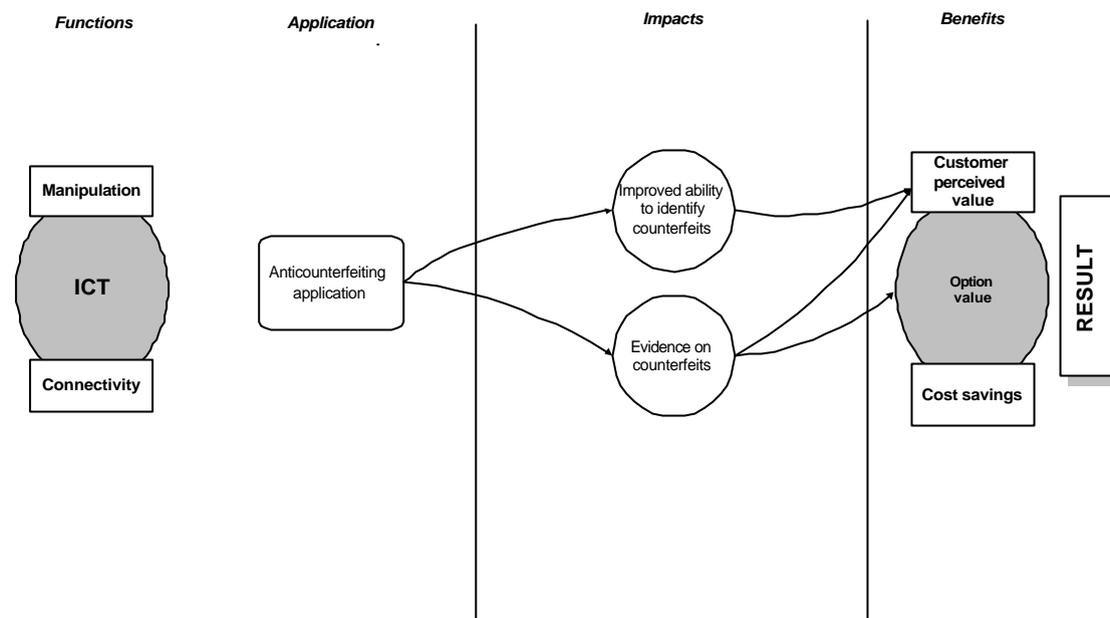
According to the factory manager, as a result of the effort needed, there needs to be a major reason before the analyses are initiated. He estimated that many of the small problems may go unnoticed, because traceability data is not routinely used in quality and process improvement. However, on some level, traceability data was used on a daily basis for quality purposes.

The new production planning and control system was going to improve the usability of the data. The increased availability of the data in electronic format was predicted to facilitate quality-data analysis.

8.1.7.7 Anticounterfeiting

Company Lambda had the capability to use traceability data to support identification of counterfeit products, although it had never been needed. This capability was suggested to be critical, as even an assumption of piracy could require sales to be halted.

Figure 61: Impacts and benefits of the anticounterfeiting application at Company Lambda



It was suggested that counterfeit products are normally not a major problem, because the distribution channels in the industrialised countries are tightly controlled and the material flow cannot be easily penetrated by external parties. However, in developing countries, counterfeit products were considered a problem.

If a product would be suspected of being a counterfeit, among other things, its appearance, chemical contents and traceability markings could be used to verify its authenticity.

Lot-specific, paper-based records would be used to identify that the packaging and manufacturing lot numbers marked on the suspect product are not in conflict with each other.

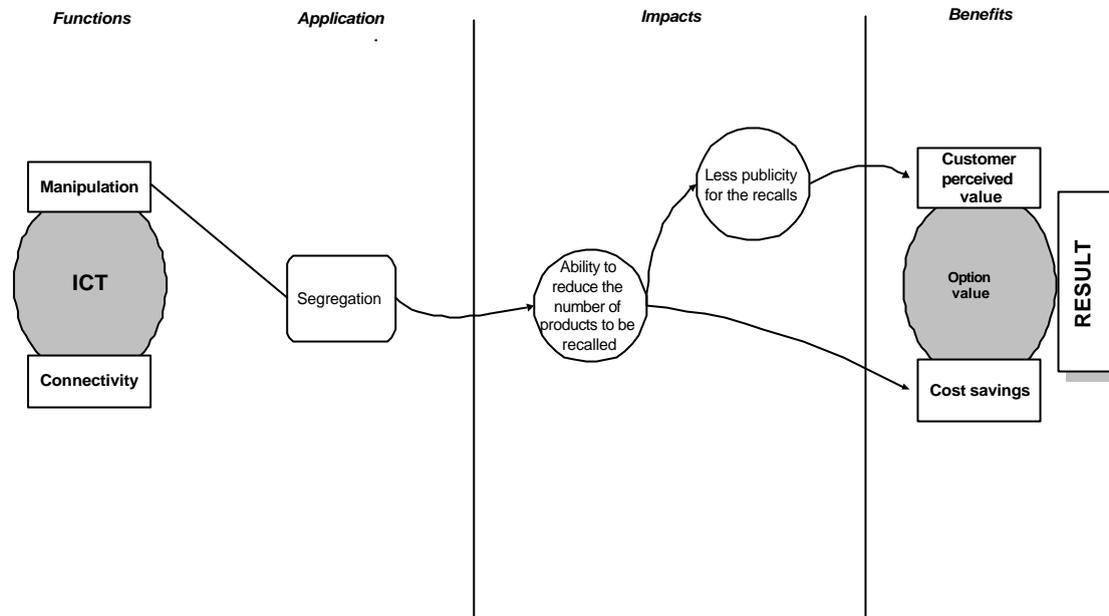
8.1.8 Company Sigma

8.1.8.1 Segregation

The costs of recalls had constantly been high during the 1990s. At the highest, in 1991, the direct costs of recalls alone were approximately FIMM 700. The main purpose of traceability was considered to be facilitating and reducing the cost of recalls by improving resolution, i.e. by improving the ability to segregate defective products from non-defective ones. The reason why the 1996 project to improve traceability was started was that in the recent recalls only ten per cent of the recalled automobiles had actually been defective. The major share of these costs could have been avoided with a functioning traceability system. Secondly, recalls were considered to have high publicity value and a significant impact on

company reputation. If an adequate traceability system would be available, the adverse effects of recalls could be minimised.

Figure 62: Impacts and benefits of the segregation application at Company Sigma



Recall activities in which segregation was used were co-ordinated at the company level, although the data was locally retrieved. The data used in identifying the defective products consisted of the lot and serial numbers of the parts and components used in the manufacturing process. The process of identifying the affected products required a notable amount of manual work, because the data was scattered among multiple systems and locations and because part of the data was maintained on paper records. The steps required to identify the defective products was demonstrated by the following example:

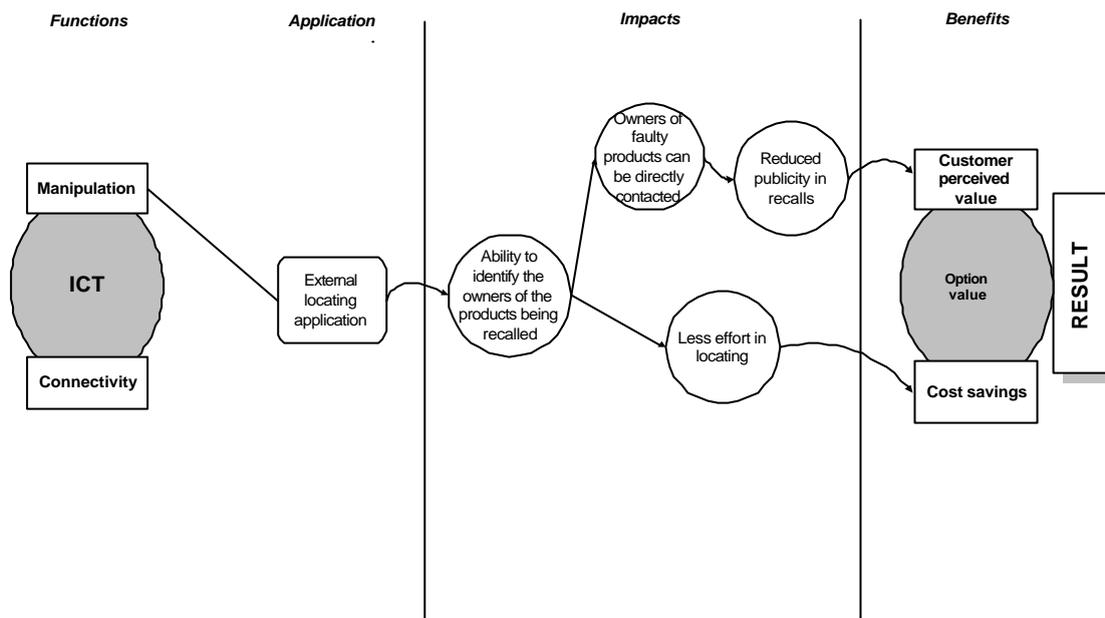
When a critical quality problem in a component used in motor manufacturing was identified, the motors affected by the problem were first identified. The lot codes of the defective components were first identified by the component supplier. Then the paper records in the motor factory were investigated to identify the affected products. The serial numbers of the affected motors were then delivered to the automobile assembly plant. When the assembly plant had received the serial numbers of the motors, the serial numbers of the corresponding automobiles were retrieved using local records. Finally, the data was delivered to the sales and after-sales units, who could then locate and recall the products or routinely repair them when they were brought in for service.

The introduction of TSS was going to reduce the amount of manual work in data retrieval due to the storage of information in electronic format.

8.1.8.2 Locating

In the event of recall, end-user records were used to identify the owners of the affected vehicles. Using this data, it was possible to carry out a recall by directly contacting the car owners instead of recalling the automobiles using public advertising. In addition to saving effort, the ability to directly contact the owners of the defective cars was seen to be particularly important in minimising the negative impacts of recalls on company reputation.

Figure 63: Impacts and benefits of the locating application at Company Sigma



The data needed by the application consisted of customer contact information collected at the point of sale. The car owners were identified using the sales information systems in different countries.

8.1.8.3 Material flow analysis

In addition to the original targets set for the traceability system, positive impacts had been obtained through simplification in the material flows, as demonstrated by the following example:

The traceability information system had been implemented earlier in one axle factory. Immediately after the system was taken into use, the complexity of the material flows - a problem until then - decreased. The reason for the improvement was not known for sure, but it was believed that the transparency of the material flows given by traceability had helped in pointing out the problems in the process.

Nevertheless, simplification of the material flows was not an objective for setting up the traceability system in this factory, nor was it an objective for the 1996 traceability improvement project.

8.1.9 Company Tau

8.1.9.1 Segregation

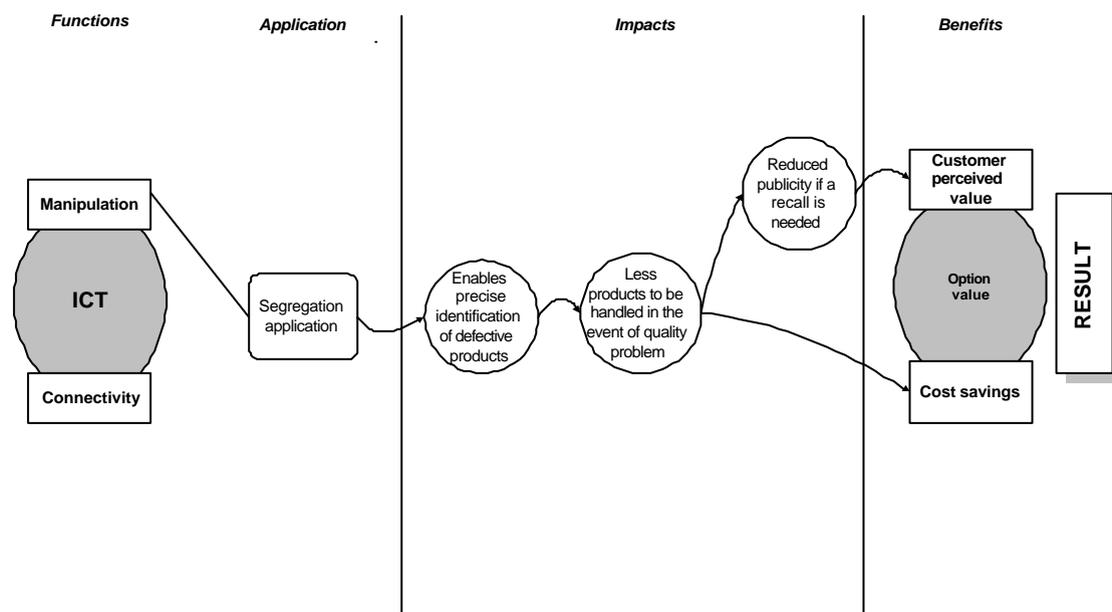
In the event of quality problem, Company Sigma used traceability data to segregate defective products from the total product population. Segregation capability was needed to minimise the costs of these quality problems. For example, in the event of a recall, segregation capability would enable precise identification of defective products and minimising the number of products to be recalled.

Segregation could be used in the event of both critical and non-critical quality problems. If the quality problem were critical, the affected products would be recalled. In less severe situations (e.g. in the event of a quality problem in car painting), the products would be withdrawn from the internal material flow and reworked. The service units would be informed about the problem and asked to carry out the corrective actions when the defective products would be brought to service.

The ability to precisely segregate the defective products was suggested to be an absolute customer requirement. The customers required that the company must be able to identify and report the serial numbers of the defective products within 48 hours of the request. The ability to fulfil this requirement was estimated to be a prerequisite for partnership with the OEM customers.

Segregation activities were co-ordinated by the quality department, whose responsibility was to request the required data from the suppliers and co-ordinate data retrieval within the manufacturing site.

Figure 64: Impacts and benefits of the segregation application at Company Tau



In the event of material defect, the data used in segregation could consist of the time period during which and the process phase in which the defective material lot(s) had been used. This data could be retrieved from the materials management system. The data could then be linked to the data on vehicles that had passed the control point in question during this time period. Vehicle-specific data could be retrieved from the production control system. Retrieving the data from two systems was said to require approximately ten to fifteen minutes. Before the new materials management system was taken into use, the data retrieval time had been two to three hours. In the event the problem was supplier related, the suppliers would be required to provide the information on defective lots within 24 hours.

In the event of problem caused by changes in the manufacturing process, the process of segregation would be similar. The production control system could be used to identify the time when the process change causing the problem had started and ended. Then the production control system could further be used to identify the products which had been manufactured during this time period.

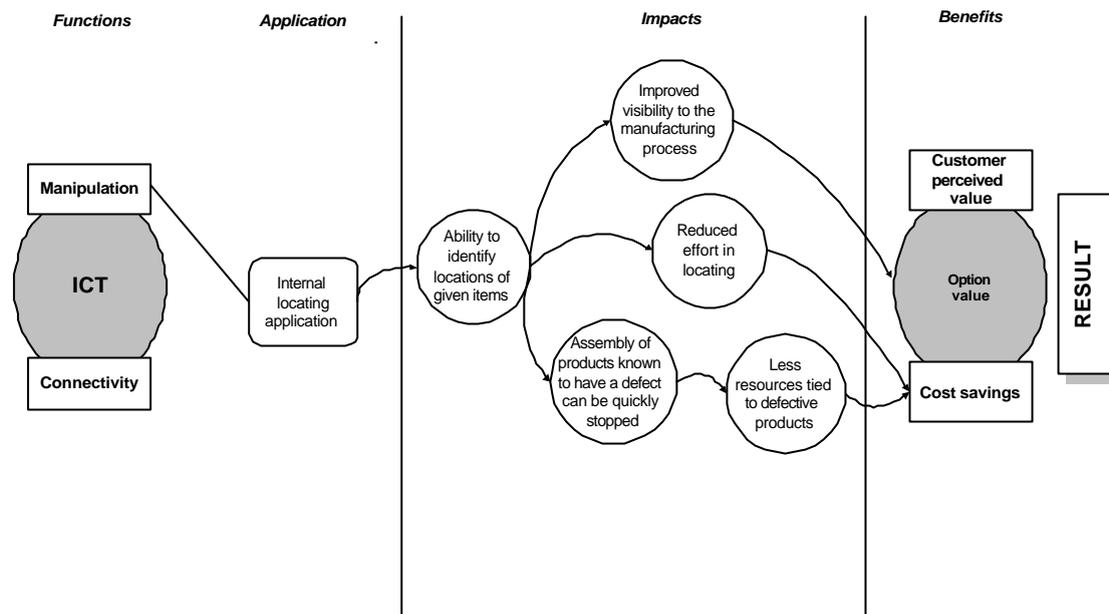
Due to detailed data collection, the application enabled the company to precisely segregate defective products. The affected products could be identified from among the total product population with in a margin of one to two per cent.

8.1.9.2 Locating

Traceability data was employed to locate materials and work in progress in the internal material flow within Company Tau. The use of traceability data in locating was related to quality problems where non-conforming products and materials needed to be located and withdrawn from the material flow. The availability of the location data aimed at reducing the effort needed in locating. Moreover, it supported quick withdrawal of defective products from the manufacturing line, thus reducing further damage.

Moreover, traceability data was used to monitor the status of work in progress in the material flow. The ability to exactly identify the location of a given item in the material flow was suggested to play a critical role in process control.

Figure 65: Impacts and benefits of the locating application at Company Tau



Materials were located using lot- and/or serial-number-level data on received, stored and issued materials. This data was stored in and could be readily retrieved from the materials management system.

Vehicle time-location data collected at the manufacturing process control points was used to locate the work in progress from the start of the manufacturing line to the point where the products were handed over to the customer³⁰. This data was maintained in the production control system, from which it could be readily retrieved. Quick locating was considered to be particularly important when withdrawing defective products from the manufacturing line.

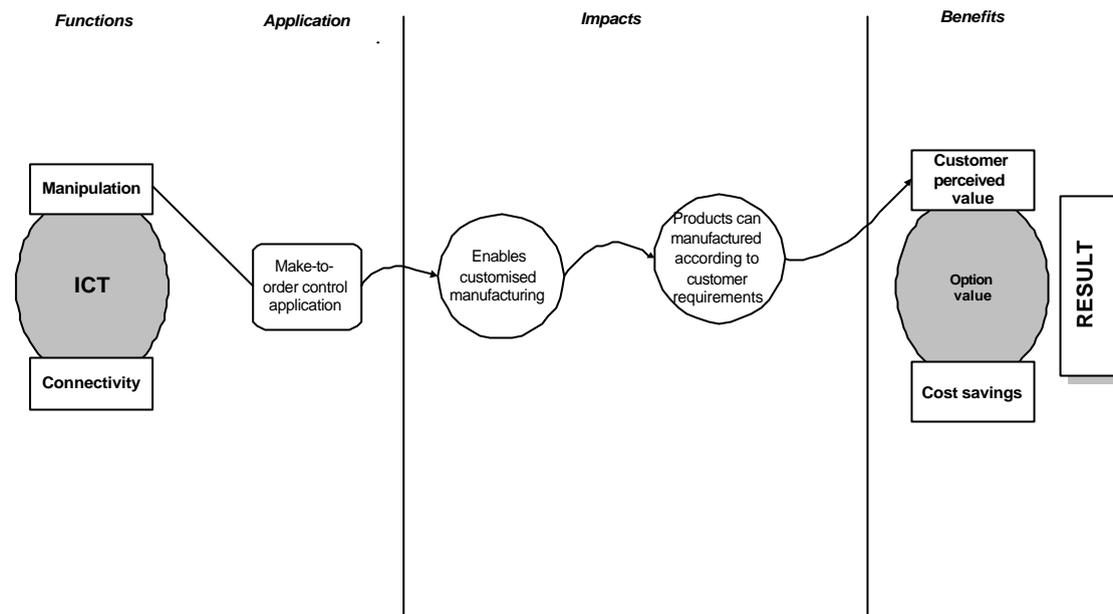
Efforts to locate finished products did not extend beyond the manufacturing site, as the locating was carried out by Company Tau's OEM customers. In the event of recall, OEM customers would be able to directly contact the owners of the products using their traceability records.

8.1.9.3 Make-to-order control

Company Tau manufactured products to order. Each automobile was customised based on customer requirements. For example, motor and gearbox type and paint colour could be selected by the customer. Traceability data and systems were used to communicate automobile-specific instructions or target data for the manufacturing process. The use of traceability data enabled customised manufacturing, providing the customer-perceived value.

³⁰ After the manufacturing had been completed, the vehicles were delivered to a customer-controlled storage area.

Figure 66: Impacts and benefits of the make-to-order control application at Company Tau



When a customer order was received, the options selected by the customer were entered in the production control system. On some occasions, the customised parts were ordered from the suppliers.

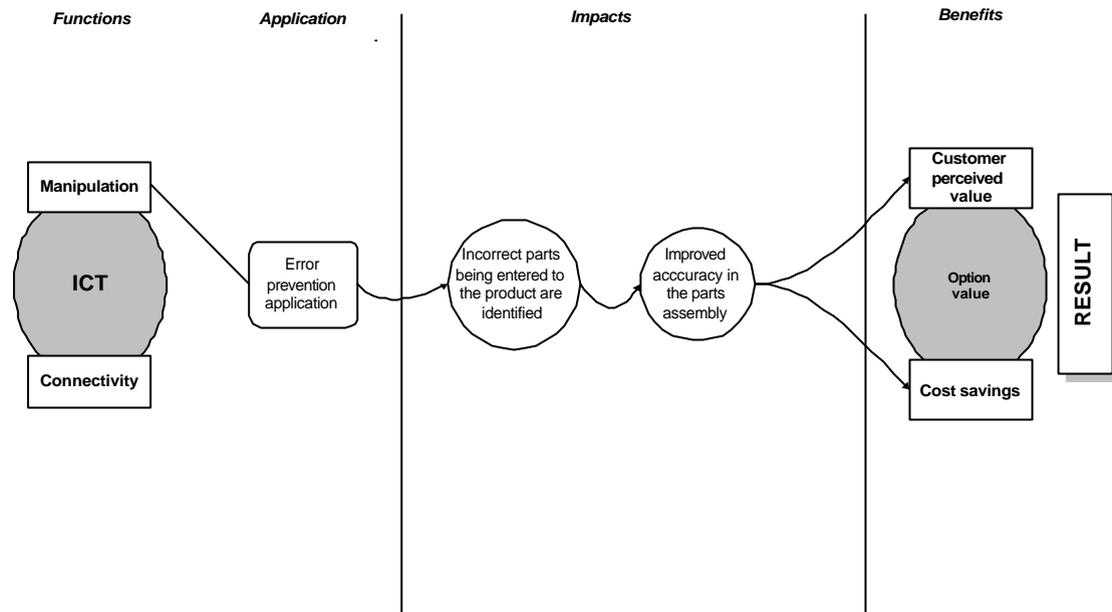
Then, a car body was assigned to the order and the manufacturing was started. The body was automatically identified at a number of control points in the fully automated manufacturing process phases, and the body was processed according to the individual item-specific instructions retrieved from the production control system. In the manual process phases, individual vehicle-specific instructions were made available for the employees on paper documentation, which travelled with the car through the manual process phases.

Both when the data was retrieved from the production control system and when it was available on paper documentation travelling with the vehicle, it could be readily obtained.

8.1.9.4 Error prevention

In the parts assembly, traceability data was employed to prevent incorrect parts from being entered in the automobiles during the manufacturing process. The use of the application aimed at preventing errors and improving accuracy in parts assembly.

Figure 67: Impacts and benefits of the error prevention application at Company Tau



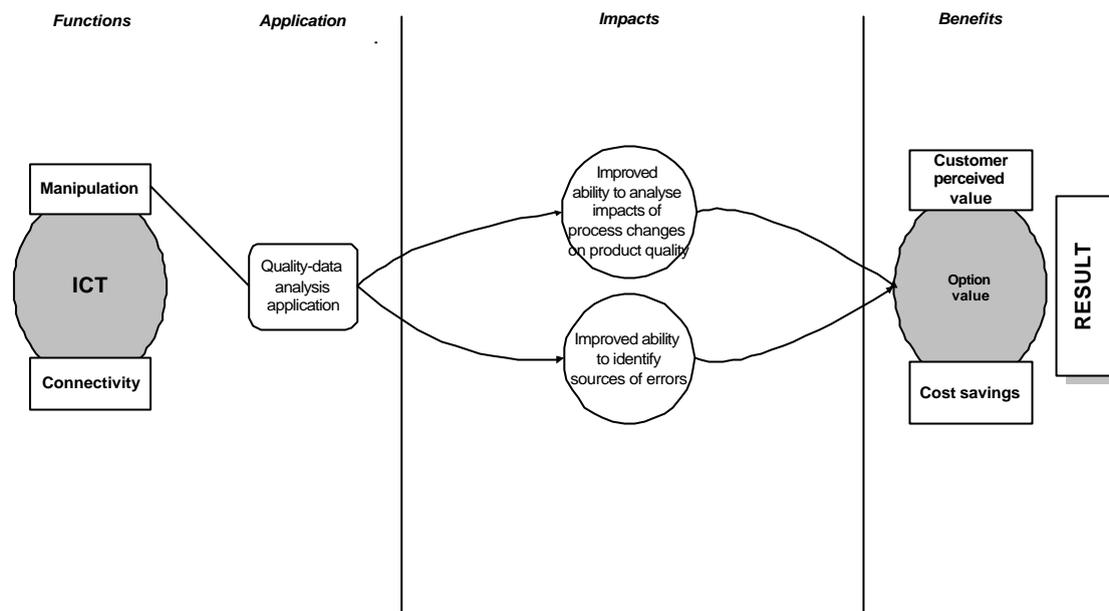
The application was based on a vehicle-specific bill of materials, which was generated as a result of customer requirements stored in the production control system at order entry. In the control points where the verification was carried out, the part being included in the vehicle was identified and verified against the target bill of materials. This real-time verification was carried out using the production control system. If deviations from the target were detected, the system generated a notification.

8.1.9.5 Quality-data analysis

Traceability data was applied in root problem identification and in analysing the impacts of process changes on product quality. The use of the application provided the company with information supporting quality and process improvement and minimising the damage caused by quality failures.

The analyses carried out by the quality department were based on the data collected during the manufacturing process and the feedback received from internal and external sources. Informal feedback was received from the OEM customers when problems arose. Moreover, one of the OEM customers maintained a database in which individual-vehicle-level data on warranty repairs carried out in the field service units was collected. The OEM customer in question analysed the data. When it was suspected that a problem had originated in the manufacturing process at Company Tau, Company Tau was contacted. Company Tau, which had access to the database, could then further analyse the problem. Internally, feedback was received from quality inspection points located on the shop floor.

Figure 68: Impacts and benefits of the quality-data analysis application at Company Tau



Feedback received was cross-referenced with the data collected during the manufacturing process.

When feedback on a failure in an individual vehicle was received, a vehicle-specific vehicle card maintained on microfilm could first be investigated to identify the scope of the problem. Information on the card was reviewed to identify whether all the required inspections had been carried out, whether the vehicle has been repaired during the manufacturing process and whether parts had been changed during the repair process or whether there are remarks in the documentation that explain the problem. The microfilm could be retrieved relatively quickly, and the analysis required less than 15 minutes of time altogether.

If the problem could not be explained by the vehicle-specific data on the microfilm cards or if the problem had appeared in several vehicles, other sources of manufacturing data were used. The production control system could be used to identify when the automobile had been manufactured and what process changes had taken place around the time of manufacturing. The materials management system again could be used to study the material lots used in manufacturing the failing vehicles. The employees on shift could also be identified using a payroll computation system.

In a similar fashion, the manufacturing and feedback data could be used to analyse the impact of changes on the manufacturing process on product failure rates.

The analyses based on traceability data were carried out a few times a month. Although the time and the amount of manual work required to carry out the

analysis depended on the scope of the analysis, in general, the time required for an analysis was less than one hour.

On some occasions, the speed of identifying the factor causing the quality failures was considered to be critical. The ability to take timely corrective actions and to eliminate the source of error were stressed to be important in order to eliminate the source of error and to stop further damage. If the problem was component related, the factories of the OEM customer in question using the same component were also informed about the problem.

The way the manufacturing process was organised reduced the need for using traceability data in the field of quality management. Together, the use of just-in-time philosophy, lack of alternative routes in the manufacturing process and inspections carried out in the work cells enabled providing instant feedback to the employees without using traceability data.

8.2 Appendix 2: Framework of interview questions

Company and organisational setting:

- Company, its structure and products.
- Structure of the material flow, suppliers and customers.
- Management and ownership of traceability.
- Internal and external requirements affecting the development of traceability.

History of traceability and traceability information systems

- Why products are traced (the most important reasons in the order of importance).
- How traceability and traceability systems have evolved over time and what impulses have triggered the development efforts.

Implementation

- Is traceability based on item- or lot-level identification of the traced items?
- What traceability data is collected and in which process phases?
- How is the data stored?
- In addition to data collection, what other methods are used to support traceability?
- What information systems are used to manage traceability data?

Applications

- How traceability data is applied?
- What is the functionality of each application: data and information systems used, automated and manual steps needed, application speed and the amount of manual work required?
- What factors are critical for application functionality?
- How frequently is the application used?
- Who are the users of the applications?
- What are the impacts and benefits of the application?

Problems

- What problems in the field of traceability are identified.

Future

- How traceability is predicted to evolve in the near future.

8.3 Appendix 3: European Union Council Directive 85/374/EC

In the following, extracts of the European Union Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products are introduced and commented on to the extent they are relevant to product traceability.

According to Article 1, the producer shall be liable for damage caused by a defect in his product.

Article 6 states that a product is defective when it does not provide the safety which a person is entitled to expect, taking all circumstances into account, including:

- (a) the presentation of the product;
- (b) the use to which it could reasonably be expected that the product would be put;
- (c) the time when the product was put into circulation.

Article 7 declares that the producer shall not be liable as a result of the Directive if he proves:

- (a) that he did not put the product into circulation; or
- (b) that, having regard to the circumstances, it is probable that the defect which caused the damage did not exist at the time when the product was put into circulation by him or that this defect came into being afterwards; or
- (c) that the product was neither manufactured by him for sale or any form of distribution for economic purpose nor manufactured or distributed by him in the course of his business; or
- (d) that the defect is due to compliance of the product with mandatory regulations issued by the public authorities; or
- (e) that the state of scientific and technical knowledge at the time when he put the product into circulation was not such as to enable the existence of the defect to be discovered; or
- (f) in the case of a manufacturer of a component, it will be a defence that the defect is attributable to the design of the product in which the component has been fitted or to the instructions given by the manufacturer of the product.

Due to Article 11, Member States shall provide in their legislation that the rights conferred upon the injured person pursuant to this Directive shall be extinguished upon the expiry of a period of ten years from the date on which the producer put into circulation the actual product which caused the damage, unless the injured person has in the meantime instituted proceedings against the producer.

Case (c) in Article 6 and cases (a), (b), (c), (d) and (f) in Article 7 appear to have implications on collection and use of traceability data as Article 11 is likely to affect the storage time of the data. Wilhelmsson (1991, pp. 132 - 133) argues

that in case (b) in Article 7, it is often difficult to provide exhaustive evidence. In some events, information on manufacturing process, product or defect that is not directly related to this particular product unit, can be used as evidence. (Wilhelmsson, 1991, pp. 132 - 133).

8.4 Appendix 4: EN ISO 9001:1994 - Section 4.8

European standard EN ISO 9001:1994, Quality systems - Model for quality assurance in design, development, production, installation and servicing (ISO 9001:1994) - Section 4.8, Product identification and traceability:

'Where appropriate, the supplier shall establish and maintain documented procedures for identifying the product by suitable means from receipt and during all stages of production, delivery and installation.

Where and to the extent that traceability is a specified requirement, the supplier shall establish and maintain documented procedures for unique identification of individual product or batches. This identification shall be recorded.'