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Information and Communication Technology Enabling Reverse Logistics

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16.1 Introduction

In this chapter, we examine how Information and Communication Technologies (ICT) are being used to support reverse logistics; ICT is the term widely used in a European context instead of IT, which is commonly used in American publications. Focusing on the ICT infrastructure, this chapter does not follow a quantitative approach as does the rest of the book. Nonetheless, the topics covered in this section outline how ICT systems enable and support the quantitative approaches presented in other chapters of this book. Furthermore, this chapter provides a roadmap to the reader about what aspects of reverse logistics are implemented and what remains to be addressed in the future.

Most ICT systems for reverse logistics have been developed to address needs in a specific sector (i.e. decision-making on different recovery options of returns, designing a product for optimal end of use recovery, etc.) or to cover the reverse logistics requirements of a particular company. Thus, in our attempt to present this area systematically we need to develop a framework of reference first.

For that reason, we go back to the essentials of reverse logistics where the recurring theme regarding reverse logistics is that they include *processes* related to the recovery of *products* with the objective to facilitate reintroduction of returns into a *market*.

Based on these three keywords, we have identified that ICT systems for reverse logistics have indeed attempted to address one or more of the issues related to

1) product data, that is, data regarding the condition and configuration of the returns;

2) process facilitation, and more specifically supporting operations of reverse logistics; and
3) redistribution to the market, in particular attempts to consolidate the fragmented marketplaces.

Product data are essential for efficient handling of returns. However, returns are plagued by a high degree of uncertainty regarding some of their important attributes (i.e. place of origin, timing and quality standards). Since product data of returns are rarely available, ICT systems have been developed to trace the required information through the systems that were used in the original production phase of each return or to retrieve these critical data through monitoring and, in some cases, reverse engineering methods.

ICT systems developed for the control and coordination of reverse logistics processes assist in the decision-making for the recovery options of returns (reuse, remanufacturing, recycling) and support administrative tasks related to returns handling that contribute to more efficient returns management.

Upon completion of the required recovery operations, used parts and products need to be forwarded to the market. Interestingly, markets for such parts or products are highly fragmented. In recent years, with the expansion of e-commerce applications, several attempts have been made to consolidate markets for returns through the creation of specialized e-marketplaces.

In view of these three main underlying themes, we develop a three-dimensional space (Figure 16.1) with axes of reference *Products*, *Processes*, and *Marketplaces*, with the aim to systematically analyze how ICT systems process information flows related to these aspects. First, we identify the constraints imposed upon these information flows. Namely, we discuss the impact of uncertainty about products, processes, and marketplaces and demonstrate with a concrete example the value of information with respect to control and planning of reverse logistics. Finally, using this three-dimensional space as a roadmap, we examine each ICT system shown in Figure 16.1 in detail.

This chapter is structured as follows. Section 16.2 examines uncertainty issues and Section 16.3 outlines, through an example, the value of information in reverse logistics. Section 16.4 presents the ICT systems that mainly address collection and update product data throughout the product's life cycle. Section 16.5 presents the ICT systems that support processes in reverse logistics and Section 16.6 presents the ICT systems that enable the formation of marketplaces in reverse logistics. In the following three sections, we examine systems that address a combination of two out of the three prime issues. In Section 16.7, we present ICT systems that support product data and reverse logistics processes, in Section 16.8, we present those that support reverse logistics processes and marketplaces, and in Section 16.9 we describe systems that enable both product data collection and marketplaces for reverse logistics. We conclude this chapter by identifying some issues for possible further development in Section 16.10.

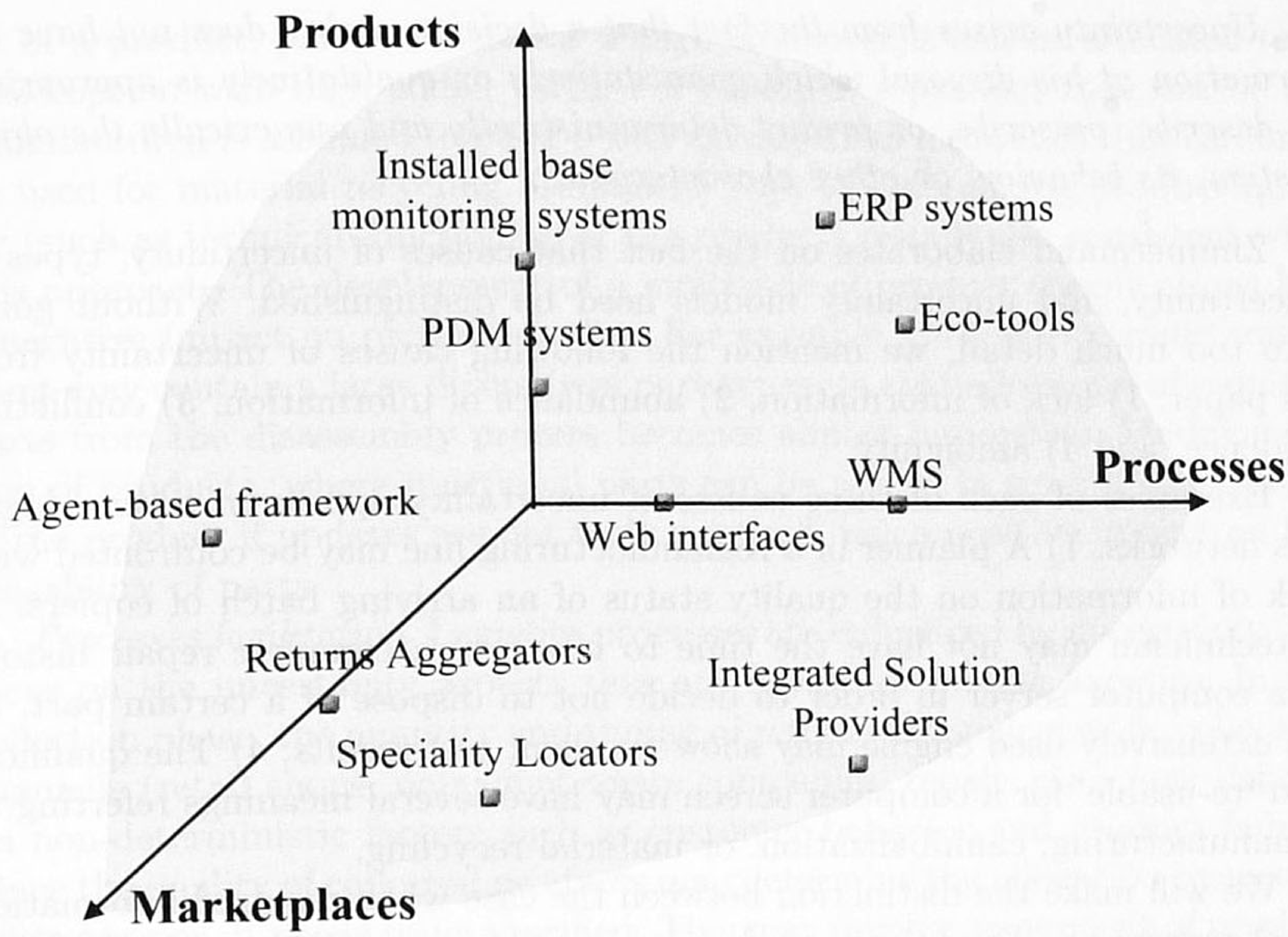

Fig. 16.1. A classification for ICT systems in reverse logistics

16.2 Uncertainty Issues

In this section, we discuss the notion of uncertainty and show how it arises in reverse logistics networks using the proposed framework in Section 16.1.

Planning of reverse logistics operations requires information on the (future) values of quantities such as processing times, arrival times, end-of-life product returns, customer demand, product quality, etc. In the scientific literature, the problem of 'uncertainty' attached to such quantities in reverse logistics processes has been addressed extensively (see, for example, Thierry et al. (1995); Fleischmann et al. (1997)). It is the aim of this section to clarify sources of uncertainty in reverse logistics networks.

Reverse logistics networks are merely part of demand and supply networks and are generally put in contrast to the classical forward supply chain (for an extensive discussion, see Chapter 2 on the Framework for reverse logistics). In the discussion below, we focus on reverse logistics flows, although it should be clear that not all sources of uncertainty are unique to such flows.

In many contributions to Operations Research, uncertainty has been described using concepts from probability theory. We shall adopt a description of uncertainty by Zimmerman (2000) as a situational property. A decision maker uses a model to perceive the information he actually receives from the object system. The following working definition of uncertainty is proposed.

Uncertainty arises from the fact that a decision-maker does not have information at his disposal which quantitatively or qualitatively is appropriate to describe, prescribe, or predict deterministically and numerically the object system, its behavior, or other characteristics.

Zimmermann elaborates on the fact that causes of uncertainty, types of uncertainty, and uncertainty models need be distinguished. Without going into too much detail, we mention the following causes of uncertainty from his paper. 1) lack of information, 2) abundance of information, 3) conflicting evidence, and 4) ambiguity.

Examples of each of these causes of uncertainty appear in reverse logistics networks. 1) A planner of a remanufacturing line may be confronted with lack of information on the quality status of an arriving batch of copiers. 2) A technician may not have the time to interpret a complete repair history of a computer server in order to decide not to dispose of a certain part. 3) An extensively used engine may show excellent test results. 4) The qualification 're-usable' for a computer screen may have several meanings referring to remanufacturing, cannibalization, or material recycling.

We will make the distinction between the case when required information is not present at all and the case when it is simply not available to the decision-maker. For example, the fraction of hazardous material that can be retrieved from a batch of refrigerators by means of a particular separation process may not be known in advance, since the process of extracting the material need not be deterministic. This is bound to be the case when the extraction process is destructive. On the other hand, the quality status of a part within a product may be fixed but only accessible after disassembly.

It is conceivable that uncertainty arises from a specific lack of information, namely a proper understanding of the mechanisms that determine certain outcomes. Forecasting methods that employ probabilistic methods can be used to relate product demand and return patterns; see Toktay (2001) or Chapter 3 in this book. An issue there is whether the forecasting models provide, on an aggregated level, a satisfying description of the outcome of immensely complicated processes or not.

Uncertainty, as described in this chapter, confronts the decision-maker with various ways of dealing with it. The decision-maker may invest in information systems, say, to get more or better information, he may adjust his model (e.g. by incorporating uncertainty in probabilistic terms) to achieve a better understanding of the information he receives from the object system, or he may try to manipulate the object system.

We give a concise overview of sources of uncertainty in reverse networks, discuss their impact qualitatively, and mention some possible measures a decision-maker may take. We use the three dimensions discussed in the introduction.

Product Data. Product design influences uncertainty in product quality. Here we define product quality from an instrumental point of view. The quality of a product, part, or material is high whenever it can be allocated to a reuse option with high added value. For example, a product that can be remanufactured is assumed to be of better quality than a product that can only be used for material recycling. Canonical ways of determining product quality (such as technical functioning of the product) usually are consistent with this approach. The development of a multitude of product specifications has a negative impact on product quality. For example, certain electronic equipment may contain a large diversity of part types, so that allocation of required parts from the disassembly process becomes almost impossible. Modular design of products, where functional parts can be reused in several generations of the product if updates are not truly required, has a positive impact on the reusability of parts.

Processes facilitation. Logistics processes are influenced by uncertainty. We focus on the uncertainty aspects that are typical of reverse logistics. In the collection phase, the quantity and timing of returns through specific collection channels (retail shops, municipal waste companies, repair, etc.) may depend on non-deterministic factors such as customer behavior and product failure. Since the quality of collected products may determine the allocation to specific reuse options, it needs to be specified. This may involve assessment of product data (usage or repair history, product type specifications) or physical tests. Recovery processes such as disassembly, separation, extraction, and repair involving materials, parts, and products may be non-deterministic in released quantities and quality due to the nature of the physical processes. In most of these cases, product design and systematic collection of product data seem appropriate measures to deal with these uncertainty issues.

Marketplace consolidation. From a marketing perspective, several uncertainty issues come up. The release of end-of-life products does not only depend on the technical life cycle of the product. In fact, the economic life cycle depends on many factors such as termination dates of lease contracts and underlying sales strategies related to the release of new products. Furthermore, prices for reusable products, parts, and materials are notorious for their volatility (see, for example, http://euro.recycle.net). Customer behavior provides several instances of uncertainty in logistics systems. The description of uncertainty in timing, place, and volume of customer demand is well documented in the logistics literature, and can be found in textbooks such as Silver et al. (1998). In reverse logistics, the customer has become an integral part of the logistics network, resulting in additional instances of uncertainty, such as timing, place, channel, and quality of returns. The first point drawn from this is that customer behavior is never fully autonomous. Indeed, customer demand is influenced by marketing efforts and availability of products. Furthermore, the setup of the collection network has an impact on product and packaging returns. For example, old-for-new discounts at retailer shops make this return channel favorable to alternative channels. Besides manipulation of customer behavior, the aforementioned forecasting methods are also of use

Table 16.1. Average masses of components in computer monitors

components	m_1	m_2	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}
masses (kg)	0.76	1.90	0.07	0.29	4.45	0.19	1.03	0.94	1.01	0.06

here. Information systems can play a role in monitoring planned or actual returns at an early stage in the collection process.

Although it is obvious that uncertainty is a complicating factor in the management of reverse logistics processes, it is not obvious how to assess the value of reducing it. This value needs to be assessed to support investment decisions in ICT. An example of how this can be done for a typical reverse logistics process, namely disassembly, is shown in the next section.

16.3 Value of Information

In this section, an example is given of a quantitative assessment of the value of information in disassembly. A planner of a disassembly line is faced with a heterogeneous supply of brown goods, computer monitors in this case. The objective of the disassembly activities is to enhance the recovered value from these products by offering components to specific recovery processes or markets. The disassembly process is part of a variety of recovery strategies, including cannibalization, remanufacturing, and material recycling. The disassembly process is steered by two types of decision questions. 1) Should a particular product or product component be (further) disassembled, and 2) to which recovery process should the product or product component be forwarded? The decisions are made taking into account

1) the objective of revenue maximization,
2) capacity of recovery installations, available resources, and markets, and
3) recovery targets set by corporate policy or governmental regulations.

Observe that, for example, separation of specific materials from the product prior to shredding may enhance the purity of the released fractions and henceforth the market value of these outbound flows. Of course, disassembly activities induce costs (manual or robotized labor), so an optimal degree of disassembly needs to be found.

The heterogeneity of the product flow comes from diversity in brands and product types. The characteristics of the products are modelled by means of a disassembly tree (see Figure 16.2). Each component of the product has a certain (average) mass measured in kilograms (see Table 16.1). Here the total average mass of the whole product $m_0 = 10.71$ kg and the total average mass of the chassis unit $m_3 = 3.05$ kg. The batch of products considered here consists of 48 computer screens. This data set originates from a pilot experiment and has been used in a previous study in Krikke (1998). In order to

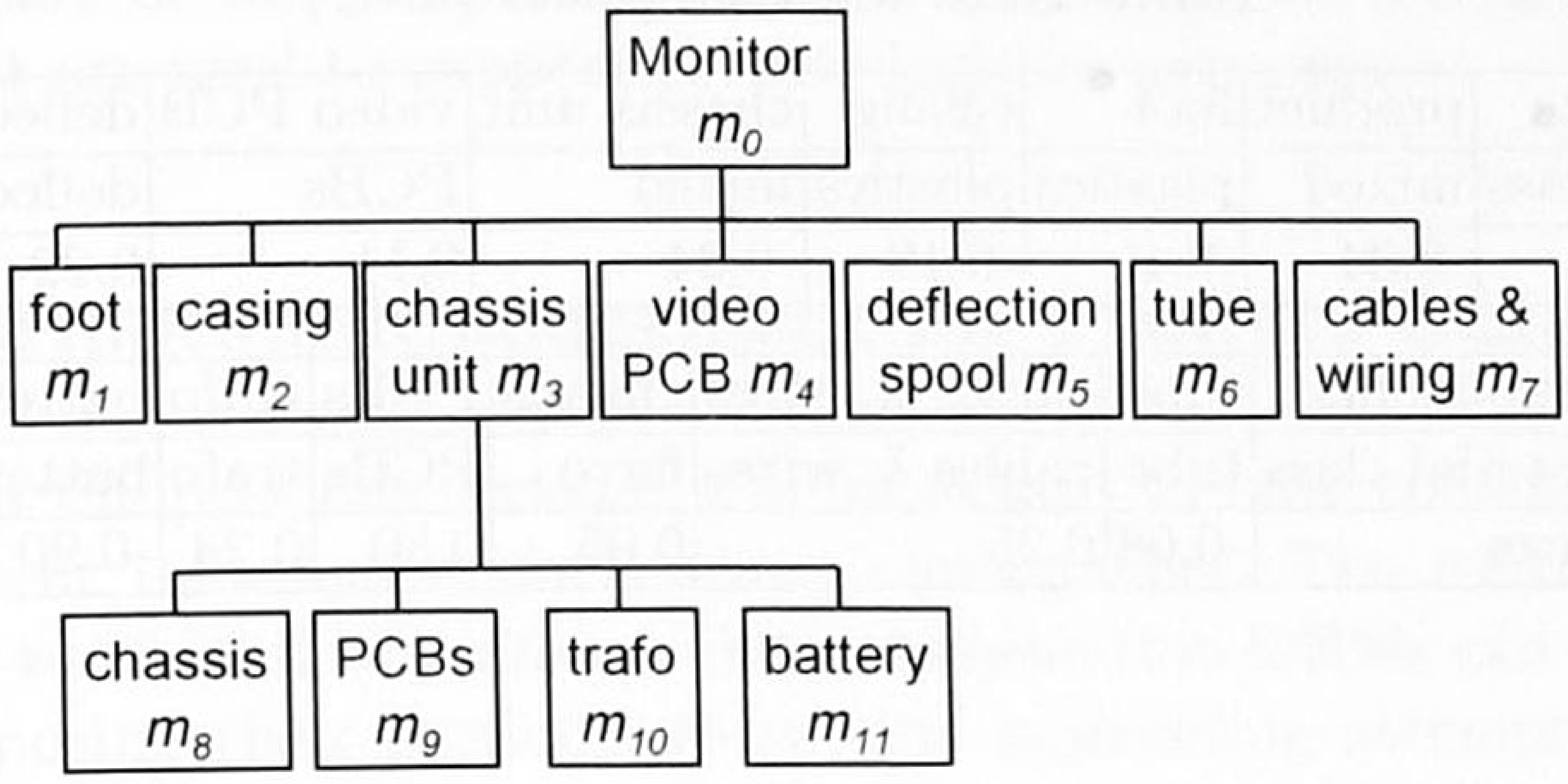

Fig. 16.2. Simplified disassembly tree for computer monitor

make the calculations below, these computer screens have been disassembled completely. Information on the mass of all components is available.

The disassembly decision question in this example comes down to 1) no disassembly, 2) disassembly of the first layer of the product (see Figure 16.2), or 3) complete disassembly. The estimated costs of disassembly are based on labor costs per minute and the average disassembly times for the whole product and the chassis unit (see Table 16.2).

The second decision question concerns the forwarding of product and components to recovery processes. We will assume that all components that are not further disassembled are forwarded to material recovery processes. Net prices are given in Table 16.3. Each component is put in a (possibly very specific) class of recyclable materials to which a price is attached. Observe that some prices are negative and that composite components are considered material mixes and henceforth provide less revenue per kg. (Note that a PCB is a Printed Circuit Board.)

We consider three scenarios that address the issue of the availability of information in the case of the batch of 48 computer monitors. In the first scenario, with full information, each monitor is disassembled in an optimal way, i.e. such that costs are minimized for that monitor. In the second scenario, with information on characteristics, two characteristics are known, namely whether a battery is present in the machine and whether a considerable amount of ferro material is present in the machine. Such information could be retrieved from the machines without prior disassembly, e.g. by X-ray scan or by using in-

Table 16.2. Labor costs and disassembly times

labor costs per minute (€)	0.30
average disassembly time, product (minutes)	5.25
average disassembly time, chassis unit (minutes)	3.50

Table 16.3. Material prices (in €)

components	product	foot	casing	chassis unit	video PCB	deflection spool
material class	mixed	plastics	plastics	mixed	PCBs	deflection spool
prices	-0.34	-0.10	-0.10	-0.34	0.11	0.22

components	tube	cables & wires	chassis	PCBs	trafo	battery
material class	tube	cables & wires	ferro	PCBs	trafo	battery
prices	-0.08	0.25	0.05	0.80	0.23	-0.90

formation available from the product itself (a chip containing an inventory of components inside). These two characteristics result in four classes (battery (y/n) and ferro (y/n)). For each of these four classes, an optimal disassembly strategy is given. All products in a class are treated in the same fashion. Finally, in the third scenario, all products are treated in the same fashion. Table 16.3 provides per scenario the average revenue per products and the average disassembly time per machine.

As mentioned before, establishing optimal disassembly strategies is often done under various constraints addressing resource capacities, regulations, etc. In order to model these constraints, linear programming techniques are used. We will not discuss the volatility of model parameters such as mass fractions and material prices. In Zuidwijk et al. (2001), stochastic programming techniques are discussed that deal with variations in material fractions for a similar example involving washing machines. A linear program that models the disassembly process with an additional labor constraint may also be found in Zuidwijk et al. (2001).

Current research addresses the fact that, from the pilot data, one should be able to come up with product design characteristics that are in line with optimal disassembly strategies for all individual products. The generation of a decision tree by means of data -mining techniques is an approach that is being pursued. Further, stochastic programming methods can also be used in this setting.

In this section, we demonstrate the value of information by studying disassembly costs for three scenarios with progressive amounts of information available. It has been indicated how, in this setting, capacity constraints can be modelled in a linear program. The analysis above indicates that information systems can be of value to the management of recovery processes. The

Table 16.4. Results from three scenarios

	full information	characteristics	no information
average revenue per monitor (€)	-2.10	-2.18	-2.25
average labor time (minutes)	5.72	7.51	8.75

remaining part of this chapter provides a systematic review of information systems that are used to support reverse logistics processes.

16.4 Information Management for Product Data

As shown in the previous section, it is important to have coherent, updated, and consistent information for returns management. The central question, however, is what kind of product-related information OEMs can make public without exposing their products to reverse engineering attempts, and what kind of information can be reconstructed upon the collection of a return. In this section, we examine the ICT approaches that collect and maintain product data.

16.4.1 PDM Systems

Product Data Management (PDM) systems focus on the engineering aspects of product development, dealing primarily with engineering data. The basic functionality of a PDM system, see Hameri (1998) and Peltonen (2000), is summarized as follows.

Secure storage of data objects in a database with controlled access. In many cases, the first motivation for the introduction of a PDM system comes when people cannot find the last updated document they are looking for.

Mechanism for associating objects with attributes. The attributes provide necessary information about an object, or they can be used in a query to locate objects.

Management of the temporal evolution of an object through sequential revisions. In a product development environment, users often modify existing designs as opposed to creating completely new ones. The evolution of drawings and other design objects is usually captured in the form of successive revisions in a PDM system.

Management of alternative variants of an object. Many products and documents have alternative variants. For example, a user's guide for a particular product can be available in different languages.

Management of the inspection and release procedures associated with a data object. Typically, engineering data must be checked and approved through elaborate procedures before they are released.

Management of the recursive division of an object into subassemblies in all possible ways. Almost all products have a hierarchical subassembly structure of components.

Management of changes that affect multiple related objects. One of the basic functions of a PDM system is to support change management, that is, management of the revisions and variants. However, it is also necessary to view a set of related objects as a single unit with respect to change management.

Management of multiple document representation. A PDM system must provide support for storing a data object in different formats. For example, a CAD tool can be available both in the original file format and in a stripped-down version for viewing and printing only.

Viewing tools. PDM systems can provide different views of the same data object to different user groups.

Tool integration. PDM systems provide integration capabilities with other software packages employed by the end-users.

Component and supplier management. The management of standard components provided by external suppliers is a rapidly growing field for PDM systems.

An indicative list of PDM software packages includes Agile PDM, Optegra, MatrixOne, and Metaphase.

PDM systems use a large number of concepts that are more or less related but for which there are no internationally accepted standards: for example, although PDM systems support change management there is no agreement on the meaning of the terms 'version,' 'revision,' 'variant,' etc. One standardization effort for the representation of data related to products is ISO 10303, also known as the STEP standard; see Ownen (1997). STEP provides a large representation of geometric data, but it is presently difficult to incorporate generic product structures in the general STEP framework.

Incompatibility of product data structures between actors in the supply chain that use different PDM software packages renders the exchange of such information problematic. PDM software packages support integration to ERP systems through Application Programming Interfaces (APIs). PDM systems are used in many industries, including airplanes (Boeing), vehicles (Ford), electronics and mobile phones (Nokia, Erickson, Siemens), and software development (Microsoft).

From the reverse logistics perspective, the main contribution of PDM systems is their potential to provide an informational backbone to integrate eco-tools, MRP/ERP systems for returns, and installed base monitoring systems and waste-management systems for returns, and thus to support consistent and updated product data through its entire life cycle.

It is necessary to examine what extensions are required for the information systems that interact with PDM systems to update product data. In Table 16.5, we present the systems that interact with PDM systems and their main functional requirements.

16.4.2 Installed Base Monitoring Systems

Product data collection regarding the product's condition and configuration for the duration of its life cycle is generally referred to as condition monitoring of the installed base, where the installed base is defined as the total number of placed units of a particular product in the entire primary market. New

Table 16.5. Information systems for returns management

Information Systems	Functional requirements
Eco-tools	Product design for optimal end-of-life recovery
Installed Base Monitoring Systems	Support extended value-added services for returns
MRP/ERP Systems	Support different recovery options of returns
Waste-Management Systems	Environmentally friendly disposal

communications protocols can be combined with embedded control systems to monitor product data dynamically and transmit the data logged upon some event. For example, the remote monitoring system of OTIS elevators is based on sensors that constantly monitor the critical parameters of the system, and if a problem is detected a message is sent to the OTISLINE, a 24/7 communication center for further action. It is the same center that receives voice communication from passengers in a stalled elevator.

This comes as the latest development in this direction, where traditional installed base monitoring methods included end-user surveys, competitive interviews, trade associations, and maintenance records. Installed base monitoring is used for product improvements, product upgrades, introducing a peripheral device, and maintenance/repair services.

We use as a case example the Electronic Data Log (EDL) to demonstrate how condition monitoring is used for remanufacturing. The Bosch Group, a worldwide operation with 190 manufacturing locations and 250 subsidiary companies in 48 countries, is known for automotive supplies, power tools, household goods, thermo technology, and packaging technology supplies. In collaboration with Carnegie Mellon University, Bosch was looking for ways to capture data on the use of their range of power tools that would yield better decisions about their recovery options; see Klausner et al. (1998). As a result, the Electronic Data Log (EDL) was developed to measure, compute, and record usage-related parameters of motors in power tools aiming at the end-of-use of a tool to get the values of the recorded parameters for analysis and classification between reusable and non-reusable motors.

The following components are used in this approach.

- A low cost circuit (EDL) that measures, compiles, and stores parameters that indicate the degradation of the motor (including number of starts and stops), accumulated runtime of the motor, sensor information (such as temperature), and power consumption for an accumulated runtime of approximately 2300 hours of operation. Also, EDL computes and stores peak and average values for all recorded parameters.
- An easily accessible interface to retrieve data from the EDL circuits without disassembling the tool.

- An electronic device (reader) connected to the interface to retrieve the data values.
- Software data analysis and classification into two main categories: reusable motors and non-reusable motors.

The main benefits of EDL compared to conventional disassembly and testing can be summarized as follows.

1) Easily accessible interface to EDL, which does not require disassembly of the product, offers labor cost saving for non-reusable products.
2) Easy and speedy retrieval of information stored in EDL.
3) EDL data reconstruct the entire usage history of a product leading to the assessment of reuse for other components besides the motor.
4) EDL data can be used to improve design and support market research and quality management.

The economic efficiency of this method is the subject of Klausner et al. (1998). The trade-off between initially higher manufacturing costs and savings from reuse is analyzed, taking into account return and recovery rates as well as misclassification errors. The analysis shows that the use of EDL can result in large cost savings. Developments such as increased service obligations (product lease, extended warranties, service level agreements), environmental liabilities (producer responsibility/product stewardship, consumer demand for recycling), and product modularization will enable and necessitate the establishment of product life-cycle management and hence of closed-loop supply chains. The EDL case presented considered storing data on the product itself by inserting a chip. However, new sensor and transmission technology enables online and remote sensing. Moreover, the transaction capacity of (wireless) networks drastically increases and related transaction costs will decrease accordingly. This enables online monitoring not only of capital-intensive products but also of somewhat cheaper consumer goods such as cars or TVs.

16.5 ICT Systems that Support Reverse Logistics Processes

In forward logistics, Warehouse Management Systems (WMS) fulfill administrative tracking and handling support. To support the returns process, either special purpose reverse logistics ICT systems have been developed or WMS were extended with proprietary systems to control returns. We examine these issues in more detail in the following subsection. Also, we discuss some web applications, mainly interfaces, that aim to facilitate reverse logistics processes in Subsection 16.5.2.

16.5.1 Reverse Logistics/Warehouse Management Systems

Retailer returns, supplier refusals, and packaging returns are gathered to specialized warehouses called 'return centers,' or through conventional distribution centers. According to De Koster et al. (2000), returns cause additional labor-intensive processes in the warehouses, which constitute around 6% of total logistics costs.

Warehouse Management Systems (WMS) fulfill administrative tracking and handling support. WMS can provide decision-making for further recovery options and communicate this information to other actors involved. It also collects product information to optimize the processing of incoming returns. We present two examples of Warehouse Management Systems: the first one was specially developed to handle returns and the second refers to a proprietary system.

Genco has designed and developed R-log, a reverse logistics software program that controls returns and is often coupled with specialized warehouses called 'return centers,' which are also operated by Genco. Within R-log, each product delivered to a return center is labelled with a barcode. Within the return center, each product is tracked by its unique number and is routed to its container and/or storage area. R-log selects an optimal recovery or disposal option, based on secondary market channel opportunities (vendors, salvage, charity), cost, and constraints such as the condition of the returned product, hazardous contents, or specific customer instructions. R-log interfaces with other information systems to facilitate financial control of returns and their impact on planning and production through its powerful report-generating mechanism. R-log provides qualitative and quantitative information to management (compliance on recalls, reason for return, returns per vendor, etc.).

After determining optimal recovery/disposal channels, it bundles similar products to reduce handling and shipping costs, and provides management control in checking whether intended recovery/disposal operations are actually carried out. Because radio frequency computers and barcode scanners are used, the paperwork regarding the returns and the number of human errors are strongly reduced.

The proprietary system developed at Estèe Lauder for the control of the returns process required a 1.5-million-dollar investment in IT infrastructure (scanners, business intelligence tools, and an Oracle-based data warehouse); see Economist (1999). Based on these, the system leads to a yearly cost saving of 475,000 dollars through increased reuse and less handling. It also reduced the amount of products scrapped from 37% to 27%, improving the company's green image with the consumer. A summary of the functional requirements for WMS, as outlined in De Koster (2001), is shown in Table 16.6.

Table 16.6. WMS functional requirements for returns management

WMS must block lots with detected defects for forward delivery.
WMS must be able to delete lots of scrapped materials.
WMS must uniquely identify the lots of returns which will be forwarded to secondary markets.
WMS must be able to provide debit to suppliers with refused supplier lots.
WMS must be able to provide credit to customers with customer returns, if eligible by the return policy.
WMS must trace customer returns to supplier lots and keep track of return codes.
WMS must keep original product specifications for recovery operations.
WMS must uniquely identify returns kept at distinct locations.
Inventory levels must be adjusted according to process option (recover, sell, etc.).
WMS must support decision-making among recovery options (testing, inspection, and registration of decision taken).
Returns being recovered must be registered as (temporary) shipments and receivables, and recall functions must support control.
Repair/recovery instructions must be provided.
WMS must be able to analyze historical data of returns and generate comprehensive reports.

16.5.2 Web-enabled Applications for Returns Management Operations

Web-enabled applications for the support of reverse logistics operations are interfaces that interact with customers to address aspects of returns uncertainty.

Effective control on the volume of returns. Frequently, the concept of control of the volume of returns is interpreted as minimization of incoming returns. In general, however, we can not exclude the possibility for a firm to proactively search for returns (e.g. to use them as cores in new products). Online tracking and tracing of orders contributes to controlling forward logistics operations. Another way to minimize returns is to cross-examine each order for incompatibilities between ordered items and to notify the customer accordingly. For example, when someone orders a color printer and refill cartridges that do not fit that printer, then the user interface will point out the incompatibility and ask for customer confirmation. Finally, firms have set up gatekeepers for their returns on the web, that is, when customers declare their intention to return some products, they are directed to a web interface (www.e-rma.com, www.yantra.com) that minimizes customer returns due to some misunderstanding of its functionality. Dell's gatekeeping system contributes to keeping returns to around 5% for their computers sold online, versus about 10% for CompuUSA for computers sold in their stores.

Minimization of returns uncertainty factors. Uncertainty regarding returns makes planning and management a very difficult task. Web interfaces are used to minimize uncertainty associated with returns, i.e. when a customer declares a return, she is directed to a web interface that collects data on the product's condition, the intended collection method, and the time and the place of the return. These collected data support preliminary management for returns. Beyond a passive collection of data, however, the web interface can be designed in a way that gives financial incentives to customers to follow the optimal alternative for each return (www.return.com). In a more structured way, the experimental prototype we have developed, Kokkinaki et al. (2002c), demonstrates how processes for monitoring and benchmarking can lower uncertainties associated with the number, type, and quality status of returns in the sector of Information and Communication Technology (ICT).

Effective control on the processes of returns is the first step toward returns fulfillment. It is certain, however, that the topic of ICT systems for effective returns management remains still insufficiently addressed, and in the future we can expect to view a higher exploitation of ICT in this respect.

16.6 ICT Systems and Marketplaces for Reverse Logistics

In our research in Kokkinaki et al. (2002b), we have examined how e-commerce has enabled defragmentation of reverse logistics markets and in doing so has facilitated the redistribution of returns to the market.

In particular, the e-business model of returns aggregators brings together suppliers and customers, automates the procurement of returns, and creates value through high throughput and minimal transaction costs. Returns aggregators handle returns from many different OEMs, without owning products. There are returns aggregators for different returns flows, namely, production waste (www.metalsite.com), commercial returns (www.qxl.com), end-of-use products (www.ebay.com), or the combination of all return types (www.180commerce.com).

Typically, returns aggregators do not support logistic operations for returns, which are stored at their initial location until a transaction is completed. Third party logistics operators (3PLOs) support logistics services to returns aggregators. Most returns aggregators are open to all buyers, whereas sellers may have to register and pay fees. Overall, the level of control on trading parties remains low. A notable exemption is AUCNET (Lee (1997)) for the procurement of used cars in Japan. In AUCNET, the level of control is high, because it is restricted to partners who have established relations through conventional interaction or have been recommended by a member.

Web design and effective searching mechanisms are essential tools for increasing the visibility of returns aggregators and extending the participation of traders. Moreover, a dynamic price-determining mechanism (often an e-auction) enables high throughput of transactions and the de-fragmentation of a highly fragmented market. By employing auctions to track the demand and set the price, returns aggregators can overcome difficulties associated with conventional means for managing returns.

Returns aggregators offer added value in markets which have a large number of transactions with low individual transaction value. Their added value increases with the increase in the number of different SKUs they handle, because that increases the critical mass of their potential clientele. Despite their potentials to become truly global marketplaces, U.S.-based returns aggregators (like www.ebay.com) concentrate within the North American market due to their demographics or a managerial decision to simplify the logistics operations involved. Their global expansion is achieved via sister returns aggregators operating in different countries (i.e. Ebay sister companies in over 20 countries). In the EU, returns aggregators are member-state oriented (www.viavia.nl), as they follow cultural, logistic, linguistic, and financial diversities between different member states. For example, www.qxl.com offers different content in its sites in the UK, France, Netherlands, Germany, and Italy. Beyond the described functionality, some returns aggregators like Aucnet or Autodag (its U.S. equivalent) have promoted the redesign of business processes in their industry. Within these new e-business models, new processes have been devised to accomplish certified inspection and multimedia representation of the cars with registered flaws.

16.7 ICT Systems that Support Product Data and Reverse Logistics Processes

In this section, we start examining ICT systems that address a combination of two out of the three main aspects in reverse logistics. We start with those systems that address both product data and reverse logistics processes. In this category, we describe eco-tools and ERP systems for product recovery.

16.7.1 Eco-tools

Eco-tools are analytical tools that provide estimations of the environmental effects of production processes, recovery options, and the end-of-life disposal of products. Based on these estimations, users of eco-tools can examine alternative design scenarios and select a design strategy that is optimal with respect to environmental effects and production costs. Thus, eco-tools promote sustainability of products over their entire life cycle.

Eco-tools receive input information about a product, both its parts and subassemblies, including labor rates, disposal rates, cost benefits of reuse and recycling, item weights, and disassembly sequences. Details on the production, disassembly, and end-of-life processes for parts and subassemblies are also input to eco-tools. Eco-tools employ disassembly and environmental databases together with the provided input to calculate end-of-life recovery options and optimal product design, including disassembly optimization, by changing the input parameters. Eco-tools are distinguished into Life-Cycle Analysis (LCA) tools, Design for Disassembly (DfX) tools, and Waste-Management tools; De Caluwe (1997). LCA tools analyze products regarding the environmental behavior over the product life cycle. In general, LCA tools encompass the following phases.

1) Definition of goals and boundaries
2) Inventory analysis
3) Impact analysis
4) Improvement analysis

In phase 1, users specify the product to be analyzed. During the inventory analysis, quantifying inputs (processes) and outputs (e.g. emissions or toxicity) of the product's processes and activities are computed for the duration of its life cycle. In the phase of impact analysis, the qualitative or quantitative outputs of the previous phase are used for the computation of the environmental impact of the product, both in direct effects (e.g. ozone depletion) and long-term damage (e.g. increased risk of health hazards). The improvement step, which may not be included in each LCA tool, systematically evaluates opportunities to reduce the environmental impact over the entire life cycle, comprehending all product-related processes.

The massive data requirements of LCA tools raise major problems regarding their widespread applicability. A way to lower these data requirements is to develop mechanisms for the interactivity of PDM systems or CAD/CAM systems with LCA tools to enable them to extract product-related data. At another level, the use of simplified approximation methods, based on energy, waste, and toxicities parameters, could also lower the data requirements for related parameters of LCA tools.

Design for Disassembly (DfX) tools are similar to LCA tools. DfX tools focus on improvements of the product design regarding manufacturing methods, fastening methods, and materials used. A subcategory of DfX tools, namely the *Design for Disassembly/Recovery tools*, focus on the end-of-life/end-of-use stage and aim to enhance recovery options of components through reuse or recycling. If these options are not feasible, DfX tools can help reduce the environmental burden of incineration or disposal. *Waste management tools* receive input information on product design and production materials and processes, and present alternatives of EOL options at different levels, taking into account time- and context-dependent characteristics such as return quality, geographical data related to returns, legislation, and prices of returns in secondary markets. Most of the tools are related to regularity compliance and tracking of materials and emissions, and matching their values with defined checklists of materials and maximal emission values.

16.7.2 ERP Systems for Product Recovery

In this section, we discuss Enterprise Resource Planning (ERP) modules that support reverse logistics processes. ERP systems, if successfully integrated, link financial, manufacturing, human resources, distribution, and order-management systems into a tightly integrated single system with data shared horizontally across the business. Well-known ERP systems include SAP R/3, Oracle ERP system, and Siebel. Van Hillegersberg et al. (2001) reports on the use of ERP to support several process areas. Here we focus on the use of ERP to support manufacturing and recovery processes.

An important step in product recovery is disassembly. ERP systems are used to support disassembly scheduling to retrieve cores from returns. Cores are disassembled to a specified set of parts, which are then inspected and tested. Parts which meet the quality standards are stocked for reuse. Parts with minor defects need first to be scheduled for repair and are then stocked for reuse. Disapproved parts are scrapped. The disassembly process presents additional data requirements, including the yield of reusable/repairable components from the disassembly process, as well as the repair time of repairable components. These data are kept in the recovery BOMs. Recovery BOMs are not merely reversed BOMs, since in many cases disassembly is (partly) destructive.

Recovery BOMs cannot be uniquely defined. Recovery BOMs may have multiple versions for alternative recovery options which could address varying degrees of disassembly processes, quality standards, disassembly times, and yields of spare parts. ERP software packages do not support recovery BOMs, thus they need extensions to address the additional data requirements.

Furthermore, in order for ERP software packages to manage returns they need to be enhanced with new functional requirements. Based on Thierry et al. (1995), Krikke et al. (1999), and Van Hillegersberg et al. (2001) , the additional requirements to ERP systems are summarized below.

First of all, ERP software packages usually do not support disassembly scheduling, which needs to be performed periodically. A way to bypass these limitations is to insert the expected yield into the ERP software as negative requirements on a component level. In this way, unnecessary external orders for new components are prevented and hence reuse is maximized. Yield factors are monitored and, in the case of structural deviance, adapted. In the case that the actual yield after disassembly is more than expected (oversupply), the quantity of negative requirements is adjusted downward accordingly in the next planning cycle. When the actual yield is less than expected (undersupply), negative requirements are shifted backward in time, assuming that the average yield will be achieved over time (by oversupply in the next period). If not, a manual correction of the negative requirements is necessary, automatically leading to external orders.

Secondly, cores need to be registered under inventory control in the ERP system. Inventory control of returns has the additional complexity of multifunction, that is, the possibility to retrieve certain components from various types of cores or even from completely new ones. Identification of identical components retrievable from various cores can be solved by labelling these components. Current ERP software tools are not capable of distinguishing between different statuses of returns, i.e. 'to be dismantled,' 'for scrapping,' 'to be repaired,' or 'to be reused,' and between owners of returns inventory. This could be addressed by adding a status identifier to the article code and also by distinguishing different lead times for different states.

Thirdly, facilities for final assembly in manufacturing and remanufacturing are often shared. These introduce new requirements to ERP systems because the subassemblies from which final products are assembled can either be new or remanufactured. Due to dual sourcing, the integration of both input streams adds planning complexity to inventory control (as described above) and also to capacity planning, because in hybrid (re)manufacturing systems facilities are shared. Some of the aforementioned issues are discussed in more detail in Chapter 10 of this book.

16.8 ICT Systems that Support Reverse Logistics Operations and Marketplaces

Web-enabled applications that have been employed to facilitate reverse logistics processes have also introduced competitive advantage, which leads to the creation of new business processes in reverse logistics. As presented in Kokkinaki et al. (2002b), web-enabled applications have enabled structural modifications in reverse logistics activities and have resulted in new e-business models, which are described in this section.

16.8.1 Speciality Locators

Speciality locators are vertical portals which focus on highly specialized used parts or products. Usually they emerge from existing businesses that have been operating offline and have gathered expertise in their market; that is, they can provide some of the required services in reverse logistics. In that sense, internet exploitation is not essential for their core business processes, but it offers an omnipresent platform for conducting business.

Such electronic marketplaces can serve the need for authentic antiques, exact replicas parts or equipment in historic restoration projects, or the maintenance process for vehicles and industrial equipment. The main characteristics for this model are twofold. First, speciality locators are region-bounded and vertically structured, focusing on a limited range of used parts or equipment over a geographical region.

The major asset in this model is the ability to provide specialized (and thus highly priced) service. Provided services include training, frameworks for catalog search, selection and configuration, financing, and technical support.

Participation of suppliers in speciality locators is usually subject to financial contribution and this acts as a control mechanism on their trading partners. Besides participation fees, value is generated from reference fees, advertising fees, and from mining buyers profiles.

This business model has high entry barriers; for someone to enter this business model, he needs to design and impose new standards in a specialized topic, structure of information, and market liquidity. Identification of the part or product requested is a central issue to the success of this business process, and it implies the use of a common, unique, and unambiguous framework to describe requested products or parts. Independent schemes for parts identification offer high added value to customers, because contrary to suppliers coding systems, independent schemes enable customers to interchange spare parts from different suppliers. Standards and structure vary from one implementation (www.find-a-part.com) to another (www.bigmachines.com), whereas conventional catalogs of spare parts offer a unique coding system related to one supplier only. Identification of a part can be enhanced through special-purpose, web-accessible search engines that focus on some prominent features of the part (brand, description, code, etc.).

Some speciality locators address the issue of preventative or reactive maintenance for heavy industrial equipment which may operate in geographically remote places and under very stressful conditions. Remanufacturing industrial equipment is often a closed-loop process, in the sense that users send in a piece of their equipment and sometime later receive it back remanufactured. Severe time constraints and quality guarantees are important factors for remanufacturing. Addressing urgency is a determining factor for speciality locators' competitive advantage. In the future, we expect that speciality locators will address this point and their competitive advantage will likely shift to provide dynamically customized online expertise.

16.8.2 Integrated Solution Providers

The integrated solution providers capitalize on their distinctive expertise and integrate web technologies to offer unique services for handling returns. This positioning enables them to offer high value-added services that cannot easily be undertaken by their competitors. Furthermore, they actually become the owners of the returns instead of implementing a brokering mechanism as in the previous two models. For that, they also mark high in the degree of inclusion of reverse logistics activities.

This model aims to forge strong relationships with long-lasting customers in industries where the cost of a return itself may not be high, but its speedy handling is essential to its core business process. By definition, each integrated solution provider focuses on the reverse logistics network in an industry/sector, i.e. pharmaceuticals (www.returnlogistics.com, www.pharmacyreturns.com), machine tool manufacturers (www.milpro.com), or cellular phones (www.recellular.com). Returnlogistics provides an integrated solution to authorize, document, pack, and ship returns of pharmaceuticals by different manufacturers. Returnlogistics has included in its web-accessible databases around 80,000 product descriptions. Assisted by a search mechanism, users specify their returns and select a disposition method (return to OEM, destroy, sell, exchange, or donate). Returnlogistics enables returns processors to seamlessly track and document authorization for returns and enables credit managers to eliminate invoices of deduction. Furthermore, it assists users with the appropriate packaging and shipping documentation. Finally, it provides the full range of logistics services including destruction of controlled substances and unpacking and repackaging of products.

Along the same line of value-added services for returns, ReCelluLar acquires cellular phones through airtime providers or charity foundations (i.e. www.wirelessfoundation.org), grades and sorts them, remanufactures them if necessary, and repackages, distributes, and sells them globally. ReCellular exploits diffusion difference at a global level and creates value through cascades of reused or remanufactured cellular phones. Because the cellular communications industry is a very dynamic market, it is essential for ReCellular to develop fast responses. ReCellular B2B exchange shows the current stocks (model, price, grade, and quantity) and facilitates fast throughput of transactions.

The model for Integrated Solution Providers is still in its infancy, probably because it does not view e-commerce as a migration of existing practices and services over a new infrastructure but rather, as a new tool to restructure a business activity and offer new services. This e-business model creates value through escrow and processing fees and through locking in the customer for add-on services or products.

16.9 ICT Systems for Product Data Collection and Marketplace Formation

So far, we have examined how product data have facilitated operations in reverse logistics. In this section, we examine how e-marketplaces enriched with product data can facilitate both the collection of returns and their redistribution into the market. The added value of an e-marketplace in this dual role would be

1) to act as a consolidation channel for the collection of returns from a highly fragmented market;
2) to receive information from the users about the incoming returns;
3) to motivate users to follow optimal recovery policies for their returns;
4) to facilitate better planning and control of returns management;
5) to facilitate reintroduction of recovered products or parts back into the original or secondary markets; and

6) to collect historical data that would enable cost-efficient multi-echelons of the reverse logistics networks (i.e. to collect and disassemble products with known reusable components locally and forward only the reusable components to a centralized facility).

To outline these points, we present this example of an e-marketplace for end-of-use PCs.

16.9.1 An E-marketplace for End-of-use PCs

We have developed an electronic marketplace and an agent-based framework in Kokkinaki et al. (2002c,2002d) which uses web technologies to lower the uncertainty related to ICT returns. This electronic marketplace enables interested users to perform configuration detection and benchmarking of their PCs remotely, just by connecting them to the internet and accessing the electronic marketplace. The main concept is to provide users with

1) an accurate assessment of the condition and configuration of their end-of-use PC,
2) to inform them of their recovery options and to give them an indication of the value they can retrieve from each option, and
3) to bring them in contact with other users interested in their end-of-use PC.

Similar functionalities have appeared recently to Amazon, which has extended its services to reselling used books from their clients or partners. More specifically, Amazon customers, as soon as they access Amazon, get a message that informs them that they can resell their books and provides them with an estimated price. If they agree, Amazon lists their books together with the brand new copies. Amazon acts as a broker and brings interested parties together; for this service Amazon gets a transaction fee for each completed transaction.

Our system is more complicated because end-of-use ICT equipment has more recovery options than used books. The system builds on a set of communicating agents that act on behalf of the related actors (i.e. interested sellers and buyers) and perform a series of tasks for them (see Figure 16.3). Actors are logged onto the system, 'hire' their personal agents (by paying subscription fees that depend on the time they want them to 'live'), create a profile for them, and launch them into the e-market. A potential seller may initiate a configuration request; this triggers a trusted third-party agent to perform configuration detection and benchmarking of the PC currently used to access the e-marketplace. Upon the seller's agreement, the information on the screened PC is registered in the system's repository and is marked as a new offer. Potential buyers (i.e. OEMs or recyclers) can register their collection intentions as requests. Requests can be issued either for entire PC units or single PC modules. The system integrates mechanisms to match the above offers and

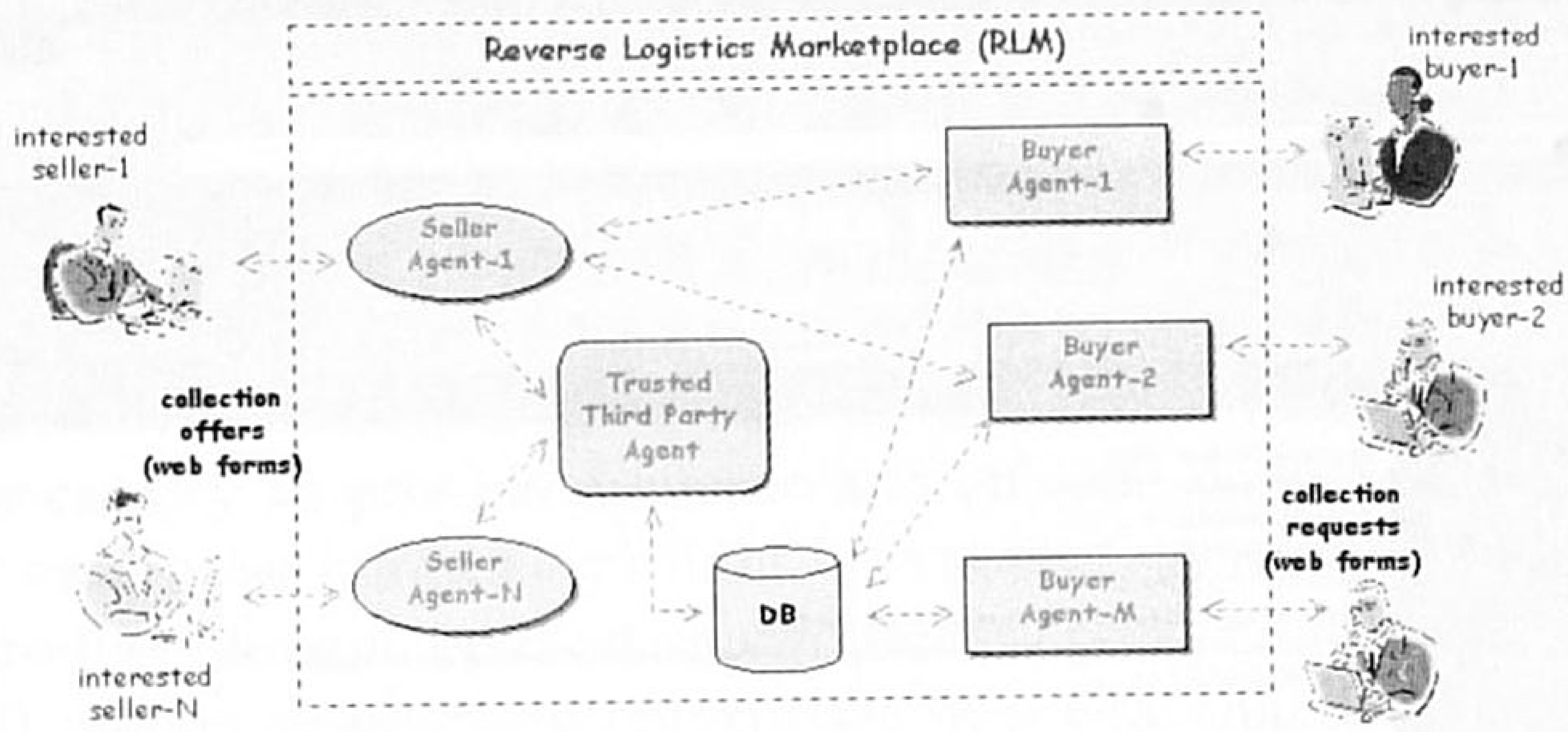

Fig. 16.3. The overall e-marketplace framework

requests. In addition, potential buyers may be instantly notified about incoming offers. Whenever a match is identified, the corresponding seller is notified through the mail services of the system. Then, the seller may launch an agent to comparatively evaluate all requests retrieved.

Transactions can be initiated either by human actors or software agents. An actor who has been notified that some requests match her offer may perform a comparative evaluation of all relevant requests before reaching an optimal decision. Agents are proactive and semi-autonomous, so they can also initiate transactions. For example, a buyer agent whose profile matches a seller's offers may take the initiative to contact its actor and ask his/her opinion on proceeding if an interesting offer has been inserted into the system's repository.

From a business perspective, the proposed system is very appealing, because it lowers transaction costs and automates several, previously manual, operations. Furthermore, it offers a trustworthy mechanism for configuration detection and quality assessment. Even more importantly, it provides a cohesive platform that consolidates the returns market and releases trapped value. From an ICT perspective, the proposed system maintains profiles for all potential buyers (through the personalization of the agents involved) to give recommendations in alignment with their interests and preferences. Also, agents may take the initiative to contact their actors when they identify a seemingly interesting transaction. Third, seller agents in this system may perform a progressive synthesis and comparative evaluation (across a set of attributes) of the existing requests. This requires a highly interactive tool, based on multiple-criteria decision theory, that enables customers to examine alternative scenarios (by selecting which of the attributes of the matched requests to be taken into account) and recommends the best recovery options, concerning reuse, remanufacturing, or recycling, according to the information at hand (an example of which is shown in Figure 16.4).

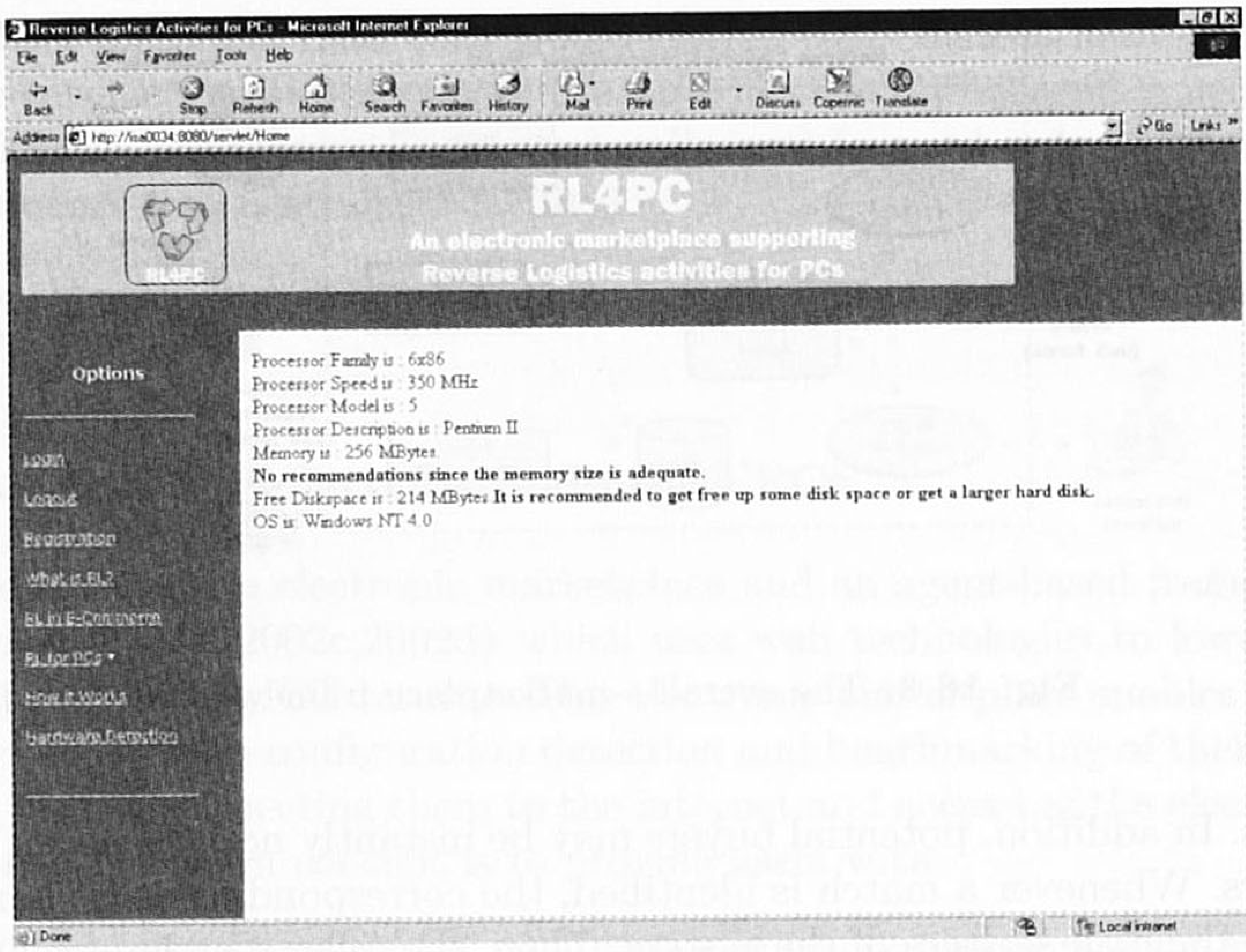

Fig. 16.4. Recommendations for a specific PC configuration

16.10 Conclusions

In this chapter, we have examined ICT systems related to returns management, covering the whole spectrum of applications for product data management, reverse logistics operations support, and formation of e-marketplaces. Special-purpose software tools have been developed, and their use is widespread in business practice.

As mentioned in Section 16.2, the development of techniques in order to handle uncertainty requires further research. In addition, information systems as described in the remaining sections require further systematic research in order to cater to the specific requirements of reverse logistics. Following the framework for the research in ICT systems for reverse logistics, we consider in this section challenges for further research regarding products, processes, and markets in reverse logistics.

As mentioned in Section 16.2, the role of information systems in reducing uncertainty requires further systematic investigation. For example, monitoring the customer base of a product provides both opportunities (proactive collection) and challenges (data management of field measurements). If one considers the extended product (including after-sales services, besides the physical product), then customer-base management and the management of product returns both belong to the package of services around a product.

The reverse logistics network is even more complex than the classical forward supply chain, since more organizations are involved and the underlying processes are more complex from an information processing point of view.

For those reasons, the use of inter-organizational information systems can be both rewarding and challenging. Standardization of information exchange on reverse logistics processes, such as proposed by the Reverse Logistics Executive Council (see www.rlec.org, which reports on EDI disposition and return codes that enable information exchange on product returns), show that solutions are under development. Beyond standardization of information exchange, it is also necessary to provide dynamic and efficient communication infrastructure for enterprise information inter-operability; that is, to enable sharing of data (product design, product development, product use, and conditions of disposal) among value-chain enterprises in a way that is more efficient than the point-to-point communication embedded in EDI.

The implementation of 1) environmental performance indicators, 2) planning and control of recovery processes, and 3) cost accounting in reverse logistics in standard ERP modules certainly is an area that requires further exploration. These issues have already received some attention in the literature (see e.g. Van Hillegersberg et al. (2001) and Lambert et al. (2000)), but require further research.

The development of business models that support the match of supply and demand of returned products is still an open research issue.

Table 16.7. A comprehensive list of all e-businesses mentioned in this chapter

E-Business Name	E-Business URL
180Commerce	www.180commerce.com
Aucnet	accessible to trade only
Autodag	www.autodag.com
Bigmachines	www.bigmachines.com
Dell	ww.dell.com
E-rma	wwww.e-rma.com
Ebay	www.ebay.com
Fairmarket	www.fairmarket.com
Find-a-part	www.find-a-part.com
Genco	www.e-genco.com
IBM	www.ibm.com
Metalsite	www.metalsite.com
Pharmacy Returns	www.pharmacyreturns.com
QXL	www.qxl.com
ReCellular	accessible to trade only
Returnlogistics	www.returnlogistics.com
TheReturnExchange	www.thereturnexchange.com
Yantra	www.yantra.com
Viavia	www.viavia.nl