The environment as a resource : developing environmental information systems based on enterprise resource planning software

BETA

THE ENVIRONMENT AS A RESOURCE

Developing Environmental Information Systems based on Enterprise Resource Planning Software

Monique Jansen

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DEVELOPING ENVIRONMENTAL INFORMATION SYSTEMS BASED ON ENTERPRISE RESOURCE PLANNING SOFTWARE

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Summary

Some decades have passed since the first steps have been taken to reduce negative environmental effects (Club of Rome (1972), World Commission on Environment and Development (1987)). At present, industry is facing an increasing amount of environmental laws and regulations, enhanced by requirements from customers and suppliers. However, organisations find it hard to meet both economic and environmental requirements. State-of-the-art environmental information systems neglect this fact and lack tuning with existing systems. As a result, gathering correct and consistent environmental data is very laborious, if not impossible. To improve this situation, this research provides an overview of environmental information requirements from the viewpoint of a manufacturer and a design of an environmental information system that meets those requirements.

Research statement

Environmental information is particularly requested by authorities, supply chain parties and neighbours and it contributes to organisation internal targets. The most striking difference in environmental information requirements is found in the aggregation level. Authorities usually request detailed data on waste, emissions, nuisance, while supply chain parties, including customers, are satisfied with highly aggregated data, e.g. labels or certificates regarding extensive product groups or even the entire enterprise or supply chain. Existing environmental tools merely anticipate on supply of aggregated data, e.g. for environmental management systems, life cycle assessment tools, or annual reports.

An important deficiency is observed here: no tools are available to collect detailed data, both in relation to authorities and as basis for aggregation. This deficiency is based on:

(1) lack of integration between environmental information systems and environmental applications;
(2) lack of integration of the necessary environmental information systems;
(3) lack of integration of environmental information systems with other business information systems.

Detailed environmental data, especially concerning waste and emissions, are based on product and process data. Considering the desired combination of

economic and environmental targets, connection has been sought and found in software for Enterprise Resource Planning (ERP), which is also based on product and process registration.

Modelling approach

Based on this idea, a modelling method has been developed: the multiple-input multiple-output process (MIMOP) approach. This approach covers materials balances for production processes, ranging from the smallest production step to the complete business process. The MIMOP approach distinguishes:

- supply of materials, production means and energy at the input side of a process;
- a black box in which a transformation is performed; and
- products resulting from the transformation, usually accompanied by several co and by-products, the used production means and energy.

A black-box approach is a good starting point for modelling environmental effects. In the MIMOP approach, some refinements are added: mechanisms for aggregation and decomposition of processes, of components and constituents and aggregation over a certain period of time. This reduces inherent disadvantages of a detailed method and enables an enterprise to adjust to (changing) requirements from customers, suppliers and legislation. The main benefit of this modelling method is that companies can store and retrieve environmental data rather straightforwardly in close co-operation with already existing business information systems, e.g. for logistics, finance and quality.

Information System

Integration between environmental and ERP information systems takes place on several levels. The most important is the registration level, which enables non-redundant registration of basic data, especially product and process data (Environmental Registration System).

From the registration level, environmental information can be obtained, integrated with other functional areas (Environmental Information System).

Finally, environmental applications can be defined, frequently based on conventional functionality applied on new data or on new functionality (on conventional and new data). The following environmental applications have been researched: within an enterprise and on supply chain level.

Environmental Registration System (ERS) Evaluation of existing ERP systems for possible application in environmental information systems has led to the conclusion that the implementation of materials and capacity requirements as can be found in traditional discrete Material Requirements Planning (MRP) software is unsuitable. Extensions which can be found in dedicated software packages proved to be valuable, especially with respect to the modelling of recipes and divergent product structures as in process industries.
In practice, strictly converging production processes are very rare: from an environmental viewpoint, few processes result in a single end-product without any waste or emission. Therefore, a shift towards integration of information systems for discrete and process oriented production processes appears to be natural. This doesn't conflict with the nature of many processes which already show both discrete and process oriented characteristics.
In the ERS, the materials balance concept has been introduced. A materials balance can be considered as a view on the existing data model, and doesn't necessarily require new entity types. In addition to complete material balances in which all constituents are involved, partial material balances are defined which are restricted to a (small) subset of applied materials. In both cases, the relevant materials should be registered in the composition of products. To some extent, this may be handled in the bill-of-materials, although on a more detailed level additional registration is required.
The environmental reference data model that results from this approach is a basis for adequate data supply for existing environmental applications. The effect of a particular process and its alternatives can be used e.g. in a life-cycle assessment. Furthermore, the extensions as developed for the ERS can be considered as an interface between already implemented ERP and environmental information systems.

Environmental Information System (EIS) The ERS has been used as a basis for an integral environmental information system. This environmental information system is composed of a number of (mutually dependent) components: (1) legislation, (2) production, (3) economics, (4) purchasing and (5) quality and safety.

The *legislative* aspect system turns out to be loosely coupled with the other aspect systems. It mainly provides the domain scope for relevant topics to be discerned in an environmental information system.

For *production*, it is described on which levels environmental topics can be considered. These topics concern processes, products and production means. For processes, an environmental effect can be calculated for a single process step or an aggregation of steps, often onto the level of the entire enterprise. For products, an effect can be calculated for a single end-product, and for a particular customer order. Finally, the effect of production means can be assessed. Dependent on the registered data, the effect may be state-independent (preliminary calculated) or state-dependent (actually measured), and is considered over a particular period of time.

In the cross-section with the *economic* aspect system, especially environmental costs are important. The calculation of these costs isn't really different from other costs. However, it is difficult to determine which costs should be considered as environmental costs and how these costs should be allocated to a particular product group.

For *purchasing*, it turned out that automated support is merely available for the operational level, which involves the ordering process. Environmentally oriented purchasing, however, especially concerns initial purchasing: the selection of products and suppliers. Initial purchasing is not implemented in ERP systems yet.

The *quality* and *safety* aspect systems, finally, turn out to be closely related to the environmental aspect system. Information is based on the same kind of data, although the control of primary processes is different. Due to this, management of this control level can be dealt with in a similar way and quality assurance, environmental and safety assurance can be integrated. In practice, this is often called an 'integral' or 'combined' assurance system. Additionally, as an example, a safety system requires generation of MSDS sheets. Those can be realised by a view on the same database, extended with risk and safety data.

Environmental Applications The preceding focused on local systems. Environmental applications, however, may also relate to an entire supply chain. This issue is discussed in the next section.

The most important local environmental application is an environmental management system. Three issues are discussed that may be covered by an environmental information system. First, support of the *audit cycle* is described, which is based on work-flow management systems. For *registration* and *monitoring* of environmental effects, as may be required in an environmental management system or for other internal objectives, the ERS is used. Finally, the role of *reporting* is illustrated. At present, environmental

reports are already being made, though adequate and consistent data may not always be available. An ERP system, extended with an environmental registration system and environmental information system could provide such data.

Environmental Information in Supply Chains

Incentives for environmental supply chain applications are comparable with those for individual enterprises: customer requirements, environmental image of the supply chain, viability of the supply chain and its parties and legal obligations.

From an environmental viewpoint, the object of a single enterprise is limited, and enterprise boundaries are subject of discussion. However, if the fixed enterprise boundaries are abandoned, it has turned out that delineation of the object of modelling is difficult, since an unambiguous begin and end of a chain cannot be defined. For this purpose, so-called information decoupling points (IDPs) are defined. An IDP enables delineation of parts of the supply chain and results in a decoupled network. In such a network, environmental information can be modelled based on locally available environmental information systems.

Supply chain modelling, subsequently, is based on modelling of interfaces between enterprises in a supply chain. An interface may concern product information and specification and can be described according to the minimal model approach. One of the constraints in a minimal model may be related to product responsibility, as a means to guarantee that products meet particular customer requirements. Two application types are mentioned: product tracing and product tracking.

Other environmentally oriented applications beyond the scope of an individual enterprise include product certification and reverse logistics. All things considered, these applications are not specific to *environmental* applications, though they can also be applied for e.g. quality purposes. However, an approach with decoupled networks presumes that local, usually more detailed data are available. For environmental applications this concerns information systems for enterprise internal registration, information and management.

The research revealed that use of already existing enterprise information systems contributes to environmental data integrity. Integration with such systems enables use of more consistent (environmental) information in environmental applications, on local and supply chain level.

1. Introduction

This thesis discusses environmental information systems for enterprises. Such environmental information systems should meet environmental requirements of an enterprise's internal and external stakeholders. For this purpose, it should be able to retrieve 'environmental data' from its information systems. It has turned out that, at present, this is very strenuous, if not impossible.
In this chapter, the motivation of the research is presented. The definition of what is considered to be 'the environment' and 'environmental information' is formulated. Based on this definition, the research context and problem definition are given. Finally, the research method and the structure of the remainder of this thesis are described.

1.1 Development of Environmental Awareness

For ages, man has been exploiting natural resources of the Earth for its survival, well-being, prosperity and for improvement of the quality of life. Natural resources, and especially fossil fuels were considered to be cheap and amply available (Wolters, 1994). However, rapid population growth, fast depletion of resources on account of rapid technological development, particularly during the past two centuries, has resulted in severe environmental pollution and damage to fragile eco-systems through which life on Earth survives (Misra, 1996). Only in 1972, after a period of strong growth of production and consumption of goods following WO-2, the existence of an environmental problem was more and more recognised. In 1972, a first warning was given that population and production growths would stagnate in the near future. The Club of Rome published their findings in 'The limits to Growth' (Meadows *et al*, 1972) in which they concluded that:

> *'there are five factors that determine, and therefore, ultimately limit, growth on this planet - population, agricultural production, natural resources, industrial production and pollution'.*

This statement of the Club of Rome is important because it has triggered a broad public's environmental consciousness. This resulted in an increasing number of nature conservation and environmental protection organisations, and on political level in several environmental laws and acts with respect to pollution of air, surface water and soil, and with respect to noise nuisance and discarding chemical waste.

Additionally, governments concentrated on other ways to influence public behaviour. Well known are stimuli from financial or economic regulations, both positive - subsidies - and negative - charges. In the same period, governments started with social regulation or internalisation by means of information services and education (Cramer, 1991).

A new peak in the amount of environmental ideas came up in the late Eighties. In 1987, the World Commission on Environment and Development (WCED) published their report *Our common future* (Brundtland, 1987). This report played a stimulating role in the change of ideas that more structural measures were required to make the environment liveable. Awareness arose that current consumer behaviour should be economised towards a more sustainable manner. In 'Our Common Future' they state:

> *'... ensure that [development] meets the needs of the present without compromising the ability of future generations to meet their own needs'*

They concluded that priority of environmental measures should equal those for reduction of financial deficit, controlling unemployment and stimulating business community. The impact of the Brundtland report has been far reaching. Various governments (e.g. Norway, Denmark, the Netherlands, Canada) have officially adopted a sustainable development policy, which means that new policy initiatives will be judged on their contribution to achieving sustainable development. Also on international level various new developments have taken place. For instance, the World Bank has increasingly adopted the idea of sustainable development by including sustainability criteria in project evaluation (van den Bergh, 1996).

Nowadays, 25 years after publication of the Club of Rome's report, industry is facing environmental requirements which are mandated by direct and semi-direct regulations. Additionally, industry should meet a growing amount of requirements from their industrial buyers and end-consumers. Apart from more environmentally benign products, consumers ask for better product quality, improved production methods and acceptable conditions for employment. Accordingly, the traditional quality procedures have been developed towards total quality management (TQM) (Willig, 1994) and integral supply chain management (Ellram, 1991; Lee and Billington, 1992). Therefore, environmentally benign production does not so much replace other requirements for manufacturing, but rather complements these.

1.2 The Physical Environment

Several definitions of 'the environment' or 'the physical environment', as distinguished from our social environment, are commonly used. To be able to describe environmental requirements of an enterprise, it should be made explicit which definition of the physical environment is used in this thesis. For our purpose, the physical environment is defined as (Glynn Henry and Heinke, 1989):

> *'the physical and biotic habitat which surrounds us; in which an organisation operates, including living systems (human and other) therein; that which we can see, hear, touch, smell and taste'*

As the environmental effects of the business processes may influence all parts of the world, the physical environment in this context is not only restricted to the enterprise itself, but it takes up the global system (ISO, 1997). An *environmental effect* in this context is considered as any direct and indirect consequence of activities, products and services of an enterprise upon the physical environment, whether adverse or beneficial. The International Organisation for Standardisation (ISO) has published an overview of possible environmental issues in an international agreement, see table 1-1 (Rothery, 1995). (NB these issues are mutually related). The ISO is a non-governmental organisation, acting as the world-wide federation of national standards bodies. Consequently, the ISO-14000 documents serve as environmental standard in over 90 countries.

TABLE **1-1:** Elements that may be involved in the ISO-14000 Environmental Management Standard (Rothery, 1995)

❑ Amenity, trees and wildlife	❑ Emissions to the air
❑ Water supplies, sewage treatment	❑ Discharges to water resources
❑ Urban renewal and physical planning	❑ Packaging
❑ Nuisances	❑ Materials use
❑ Noise	❑ Energy use
❑ Odours	❑ Product use and disposal
❑ Radiation	❑ Waste

The environmental issues that are covered by the ISO-14000 series come up in several ways. On strategic level, the environmental policy preparation takes place. On this level, there is sufficient insight in external developments and

legislation. Consequences of environmental policy are translated into the (environmental) mission statement of an enterprise. Based on this statement and the environmental policy, the environmental organisation takes shape, resulting, amongst others, in an environmental reference book in which the consequences for all business functions are dealt with. The lines of policy are further detailed in concrete consequences for the operational level, for example in terms of target or standard values, or in terms of precautionary measures.
In this way, each business function has its own environmental directions, which enables the best control of environmental effects. Also, it is clear which effects should be measured and reported, e.g. to the environmental manager. This environmental manager uses the data to monitor environmental effects of the enterprise as a whole, to report to other management levels, and to exchange environmental information with third parties, e.g. in an environmental annual report.

1.3 Environmental Information

To define the term environmental information, first the term environmental data is introduced. *Environmental data* is simply defined as data concerning environmental aspects of an enterprise (see for example table 1-1). *Environmental information* is a set of environmental data, which enables a receiver to take environmentally related decisions. This may require processing of environmental data, for instance by selection, interpretation or association, by an *environmental information system*. This information may be manually or automated and is used to process environmental information either at by the sender or the receiver.
Environmental information and environmental information systems can be used to meet environmental requirements. Actually, such information is ultimately meant to 'protect' the physical environment, i.e. to reduce negative effects of business processes. This requires control of each of the issues mentioned in table 1-1. The type of control, however, varies largely. Urban renewal or physical planning, for example, are social-geographical issues, whereas various others are more product or process oriented.

Another distinction originates from the possibility to determine an effect caused by an enterprise more or less objectively. In this research, the focus is on enterprise (product or process) oriented, and objectively determined environmental information, in the knowledge that this view on 'the environment' is a subset of the entire problem.

The term 'objectively determined' is used here to stress that no judgements will be made to which extent a product, process or material is environmentally benign. Environmental information can be used to meet environmental requirements of a particular stakeholder; this stakeholder determines his requirements. This condition plays a role, for example, in the discussion whether a substance (in a particular concentration) is a pollutant or not. Furthermore, this restriction applies in judgements such as whether substance *A* is 'worse' than substance *B*, or whether increased energy use due to recycling is 'better' than land-fill.

1.4 Research Context

In this section, an overview is presented of the fields of research that are related to environmental information requirements in enterprises. The following fields can be distinguished:

(1) the environment; (2) enterprise management; and (3) information systems.

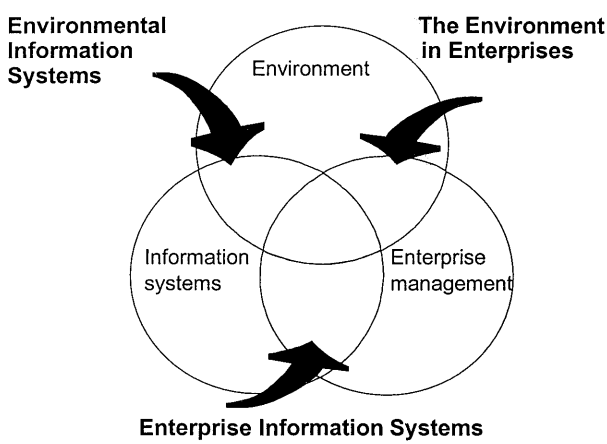

FIGURE 1-1 Research context

In each of these fields, much research has already been done, which is for a large part beyond the scope of this thesis. In this section, an overview is presented of the intersections between those fields, see figure 1-1.

1.4.1 Environmental Information Systems

Information systems are developed to support the control of processes. Therefore, those systems should mirror processes in an organisation. This is, amongst others, described in the Process - Control - Information (PCI) - model (Bemelmans, 1987). The type of process (P) determines the type of control (C), which in turn determines the type of information support (I). Consequently, a different process may require a different kind of information system. One could discern, for example, manufacturing processes (in goods production) and information intensive processes (in production of services, e.g. for authorities). Each of the, internal or external, stakeholders of an enterprise may ask for different support by information technology (IT), as is found in existing environmental information systems.

Quite a number of environmental information systems are already commercially available (Tempelaars, 1995). The largest part of implemented systems can be categorised as support for specific operational decisions. Very popular are waste management systems with emphasis on hazardous materials (e.g. for chemical industries) and waste water management systems. Those systems, however, cover environmental issues of an enterprise only partially and are not integrated with other environmental and business information systems. Another kind of support that is frequently used by the same target group are so-called environmental management systems, which are discussed in the next section. The main worry of industry about (environmental) management systems, however, is that existing environmental information systems don't sufficiently address information needs that are required to effectively and efficiently apply those environmental information systems and additional IT-support is required to support environmental data acquisition.

Other target groups of environmental information systems are 'buyers': collectors of used material, waste processors, recyclers or refurbishers for upgrading and downgrading of discarded material. Their environmental information needs are highly specific at the moment and don't occur in other types of industry.

Furthermore, IT-tools are available to support life-cycle analysis; these are merely applied from time to time, e.g. if products and processes are (re-) designed. And last, but not at least, governmental applications should be mentioned: databases with regulations, standard values, statistical tools with respect to a specific theme, waste stream, or region. Finally, table 1-2 provides an overview of the available environmental IT-support.

TABLE 1-2: Existing types of environmental IT-support

Existing Environmental IT-support	*Target Group*
Environmental management systems	manufacturers
Support for specific applications	manufacturers
Waste management systems	recyclers etc.
Cradle-to-grave analysis	R&D departments
Statistical tools	authorities, branch organisations
Databases	authorities, branch organisations

It is concluded that several kinds of environmental information systems are commercially available for various target groups. As far as manufacturers are concerned, however, research revealed that they mainly rely on stand-alone systems, which merely support one specific environmental function and which are usually not integrated with other systems.

The stand-alone position of environmental information systems is remarkable, because industry has put considerable effort into the integration of quality, safety and environmental management, see e.g. Willig (1994) or Zwetsloot (1994). Integration of those issues is incited, amongst others, to reduce costs and to realise a coherent picture for employees and management. Also for information with respect to those issues, it would be advisable to create a consistent picture to contribute to the data integrity. The wish or necessity to improve the level of data integrity is nowadays frequently shown for quality management. Operational quality measurements and production data are included in a 'quality module' in an Enterprise Information Systems, and are coupled with a quality management information system which supports, for example, ISO-9000.

1.4.2 The Environment in Enterprises

When for the first time developing their environmental policy, enterprises were used to wait and see. In Western Europe and the United States, as well as in other regions, enterprises increasingly begin to achieve and demonstrate environmental control and active management of their environmental performance (self-regulation). They started with the introduction of Environmental Management Systems, aiming to integrate overall management activities and address all aspects of desired environmental performance. This resulted in certified systems, such as the Environmental Management and

Audit Scheme (EMAS: Hillary, 1994), the British Standard (BS-7750: BSI, 1992) and finally a world-wide standard (ISO-14000 series: ISO, 1997). These systems have the same basic structure and consist of the following elements.

- environmental policy statement
- environmental program or action plan
- integration of environmental assurance in the organisation
- monitoring, measurements and record keeping
- internal reviews
- internal education
- internal and external reporting
- evaluation of environmental management system

The main idea behind such management systems is self-regulation; by explicitly formulating an environmental policy statement and action plan, an enterprise will improve its environmental performance. Application of, for instance, ISO-14000, should guarantee 'to do the job right' which is merely a means for 'doing the right job'. Actually, guarantees for real improvements should also include evaluation of the contents of mission statement and action plan.
Furthermore, in practice, it has been shown that it is hard to effectively and efficiently use an environmental management system. Collection, registration and reporting of environmental data is often insufficiently supported, because of which supply of correct, consistent and timely environmental data as input for the environmental management system is inadequate. This phenomenon is also recognised for quality and safety management systems, as well as for combined management systems. For quality management, this has resulted in integration with enterprise information systems and a higher level of data integrity.
In addition to the introduction of environmental management systems, enterprises started with design for the environment (DFE), life-cycle analysis (LCA) (Guinée, 1995) and other chain approaches such as reversed logistics, recycling and waste management (Flapper, 1993; Rautenstrauch, 1995). These concepts are frequently applied as a basis for product and process design, and for publication of eco-labels.
Application of DFE and LCA encounters similar difficulties in data supply as can be found in the application of environmental management systems. Although the design methods as such are conceptually correct, it should be taken into account that the possibility to apply the principle is limited in practice (Idenburg, 1993; Heijungs, 1997).

Introduction of extended producer responsibility makes original equipment manufacturers increasingly responsible for product take-back, recovery and reuse of discarded products. One of their key problems is to determine to what extent return products must be disassembled and which recovery and disposal options should be applied. Besides technical, commercial and ecological criteria, also uncertainty on those criteria due to lack of information, are essential factors in solving this problem (Krikke *et al*, 1998). Lack of information in this context is related, a.o., to product composition (Lambert, 1997) and product quality (Krikke *et al*, 1998).

In the context of environmental approaches also eco-labels should be mentioned, which are used by enterprises to show their environmental control. An eco-label is attached to a trade-mark and adds the image of 'environmentally benign' or 'green' to the regular product. However, one should be rather careful in one's judgement whether a product is 'green'. Various systems have come up, such as *Blaue Engel* (Germany) or *Milieukeurmerk* (the Netherlands). Some of those are externally certified, but many others are based on rather vague criteria. Furthermore, although a label is certified, it isn't beyond doubt that this product is better than any of the competing products. Issues which are implicitly left aside in certification may be of decisive importance and evaluation of the criteria under consideration may be difficult (Hees, 1994).

It is noticed that labelling products is not restricted to environmental issues, but can be considered a general idea to settle a certain image in the market. Especially quality labels are well-known, e.g. for wine 'appellation contrôlée' and many ISO-9000 certified products and organisations. Variants on quality labels are, for example, 'animal friendly' (for example free-range eggs), 'public health' (e.g. hormones-free meat) and 'human friendly' (Max Havelaar products, which support small entrepreneurs in Third World countries).

It can be concluded that various environmental approaches contribute to an improved environmental quality of products and production processes. Nevertheless, the environmental effect of each approach is limited in practice due to lack of sufficient and consistent environmental information.

1.4.3 Enterprise Information Systems

Enterprise Information Systems primarily aim to support business operations. Traditionally, there is a strong emphasis on logistics and finance. Logistic operations of (medium- and large-sized) enterprises are supported by software for purchasing, production planning and control, and physical distribution. It appears that there is no 'one-best-way' to design such production systems and hence production information systems (Bertrand *et al*, 1990). Consequently, based on various types of goods flow and production control, several types of production information systems arise which especially focus on a particular issue, such as customer-order-driven production, capacity management or dealing with uncertainty. Vendors of standard software packages aim to integrate a diversity of concepts, and to extend the existing functionality towards aspect systems, such as the financial information system and quality information system, and along the supply chain, either within the enterprise (multi-site concept) or with other organisations (external integration (Kornelius *et al*, 1993)).

The role of information technology (IT) in shaping tomorrow's business operations appears to be a distinctive one. IT, especially Electronic Data Exchange, Product Document Management and Internet facilities, have become a fundamental enabler in creating and maintaining a flexible business network (Davenport and Short, 1990; Venkatraman, 1994). Capabilities of IT are applied to redesign business processes (BPR), resulting in higher profits, shorter lead times and developing co-operation between organisations. Additionally, various external forces in the industrial environment make individual enterprises work together across the value chain: increasing globalisation of manufacturing, the awareness of the environmental effect of manufacturing and changing business and organisational structures, e.g. towards lean production (Browne *et al*, 1995). The manufacturing system must be considered in the context of the total business and the linkages in the business back through the supply chain and forward into the customer chain. This requires inter-enterprise networking across the value chain, supported by information systems.

Presently, environmental aspects are not included in Enterprise Information Systems. It has also turned out that environmentally related questions with respect to the goods flow can hardly be answered. Generally, enterprise information systems don't support quantification of waste and of raw materials squandered this way. Also concepts such as recycling and reuse are hardly covered in those information systems.

1.4.4 Conclusion

Previous subsections argued that existing environmental information systems are stand-alone systems, which merely support a specific environmental function and which are usually not integrated with other systems. Enterprise information systems, on the other hand, are not specialised for environmental information and aren't adequate yet to answer environmentally oriented questions. Finally, it has been argued that environmental concepts for enterprises (e.g. environmental management systems, product labels, chain approaches) are not sufficiently adequate because they lack input of consistent environmental information.

It can be concluded that enterprises have an information problem with respect to environmental issues. Even though enterprises may be able to meet today's environmental information requirements somehow, this is in spite of, and not thanks to an elaborated environmental information policy. Additionally, insights and demands will change over time, resulting in other and more demanding information requirements. In an increasingly dynamic situation, it will be more and more complicated to comply with all requests. This is the motivation behind the research domain, as depicted in figure 1-2.

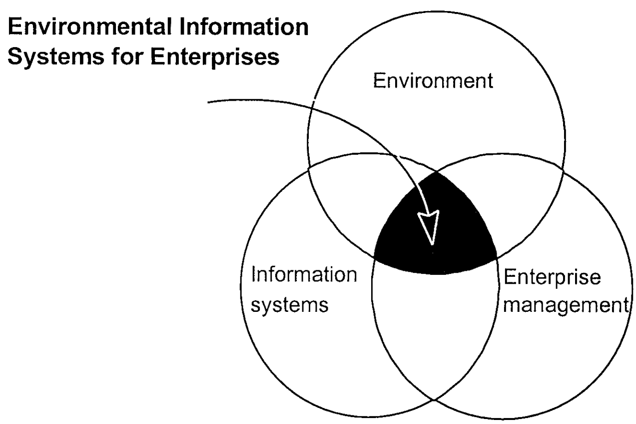

FIGURE 1-2 Research domain

1.5 Research Statement

In the foregoing, it has been argued that society's environmental awareness has increasingly been developed. Gradually, this has resulted in more pressure on those who burden the environment. Especially manufacturers have been, and are, hit by expanded environmental regulations. Manufacturers, however, make use of the environment and consider it primarily as a resource for production.

Their priority is to assure economic sustainability, which may be in conflict with environmental sustainability. This effect is strengthened due to the short term (financial) costs with respect to long term (environmental) benefits. In addition, financial costs are unambiguously clear, whereas environmental benefits are more abstract and not well defined yet.
Although this is true, manufacturers are not acquitted from ignoring environmental benefits at all and they should pursue an optimal balance. This research is carried out from the viewpoint of manufacturers, who try to meet requirements that originate from a more ecological viewpoint.

1.5.1 Problem Definition and Research Questions

To meet environmental information requirements of the main stakeholders, amongst others authorities and supply chain parties, an enterprise should be able to retrieve what is considered to be 'environmental data' from its information system. It turns out that, at present, this is very strenuous, if not impossible. To settle this problem, the following research questions are formulated:

- What kind of environmental information is requested of an enterprise by its main stakeholders;
- What kind of information systems will be able to support environmental information flows effectively and efficiently, within the enterprise and with other stakeholders.

The following research objectives are stated:

- Give an overview of environmental information requirements from the viewpoint of manufacturers; give an overview of existing environmental applications which should enable them to meet those requirements;
- Develop an environmental information system to fulfil environmental information requirements as stated in the overview, making use of already existing environmental applications and business information systems.

1.5.2 Research Method

The research is primarily design oriented and passed through three phases. Phase 1 is exploratory and aims to define the research statement. Phase 2 specifies and evaluates the modelling approach. In phase 3, finally, the system is developed. An overview is presented in figure 1-3.

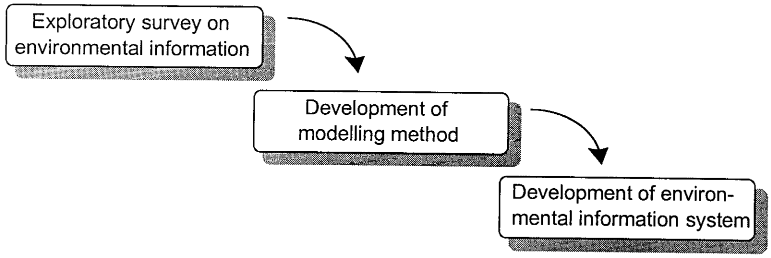

FIGURE 1-3 Research method

The research starts with an exploratory survey on environmental information exchange between manufacturers in the supply chain. The main conclusion of this survey is that, presently, the amount of environmental information exchanged between parties in the supply chain is very limited. An important reason is that manufacturers don't have that much environmental information available yet.
Zooming in on enterprise level firstly shows what kind of environmental (information) requirements should be met. The research reveals that environmental information is largely based on logistic data. Such data on processes and products is already available, although on a different level of detail. The result of the first phase is twofold: an overview of environmental information requirements and focus on the physical background of production and production means: materials, energy and information, a vision which is also shared by, for example, (Boulding, 1976).

In the second phase, a multiple case study, is carried out in a number of industrial organisations. The concept of a multiple-input multiple-output process approach is developed and proved its value in retrieving environmental information. The kind of information that is acquired can be formulated as *which material, in which composition, left the enterprise at which time to which destination*. The main problem remained, however, the lack of consistent and reliable input data. However, it is proved that logistic data can be re-used to improve the availability and quality of input data.

The third phase of the project can be defined as the development phase, in which the design of a generic environmental information system is developed. The information system should be based on mass and energy balances and should meet requirements with respect to environmental annual reporting, environmental registration and information exchange as stated in, amongst others, environmental management systems. The contents of the resulting information system proves the principle of integrating environmental and logistic information systems. The design is validated in a single case study.

1.6 Overview of this Thesis

Starting from the research objectives as outlined in this chapter, two different lines can be traced. The *first line* starts from the environmental requirements of an individual enterprise. Chapter 2 provides an overview of environmental requirements of the main stakeholders and chapter 3 elaborates existing environmental applications. It shows that existing environmental applications insufficiently fulfil the requirements. The *second line* starts from general environmental requirements and the existing modelling methods. The research reveals that existing modelling methods don't cover environmental requirements of an individual enterprise, and additionally uncovers a weakness in data acquisition for existing models (chapter 4). This part is completed with an overview of environmental information requirements.

Two conclusions are drawn which contribute to the development of a new environmental information system. First, different stakeholders require environmental information which shows large similarity, and merely differ in aggregation level once the information should be communicated. Secondly, existing environmental modelling methods are not specialised for individual enterprises. This often results in inconsistency of environmental data, which is used by enterprises, as well as in environmental modelling methods for other target groups. In figure 1-4 the structure of these chapters is summarised.

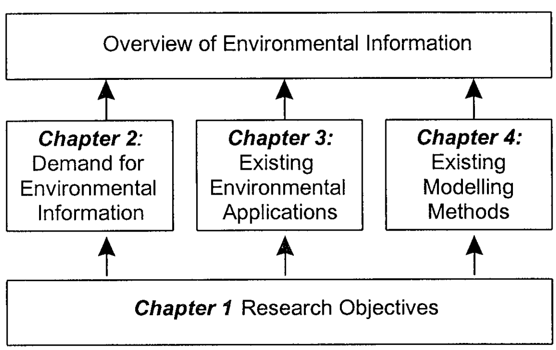

FIGURE 1-4 Overview of chapters 1- 4

Subsequently, a modelling method for an individual enterprise is derived from existing models. This so-called multiple-input multiple-output process (MIMOP) approach is rather detailed, though it is found suitable to make use of existing enterprise information (chapter 5).
To be able to do so, existing business information systems should provide mechanisms for product and process decomposition, as is described in the reference model in chapter 6. Based on that reference model, the composition of output products, amongst others waste and emissions, can be registered (chapter 7).
Finally, the actual environmental information system is developed, first for an enterprise (chapter 8), subsequently in supply chains (chapter 9). In figure 1-5, the structure of chapters 5-9 is summarised.

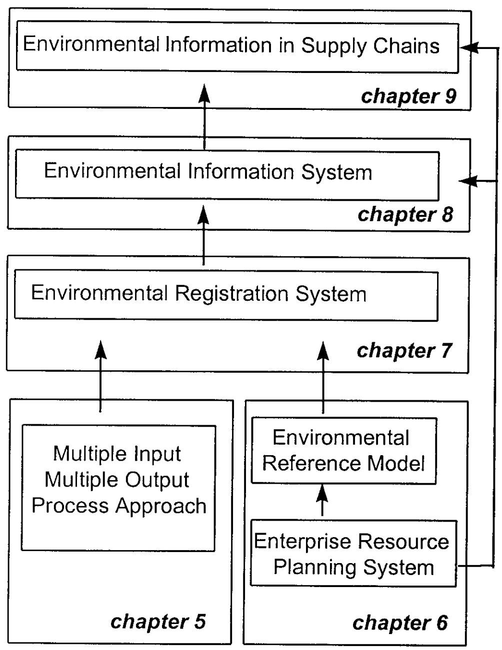

FIGURE 1-5 Overview of chapters 5 -9

2. Environmental Information Requirements

In this chapter, internal and external requirements on environmental effects of an enterprise are specified. Different roles are distinguished for authorities, buyers and suppliers, the internal organisation and others (section 2.1). Following this classification, the requirements per stakeholder are detailed. In section 2.2, the authorities' requirements on an enterprise are specified. Next, in section 2.3, a supply chain viewpoint is elaborated, first requirements of a customer on an enterprise and secondly requirements on a supply chain as a whole. Finally, organisational internal requirements, e.g. for production or management control, are described (section 2.4). In conclusion, environmental information requirements of an individual enterprise are summarised.

2.1 Environmental Requirements

Several kinds of organisations and persons are interested in environmental effects of production. In this section, an overview of various stakeholders and fields of environmental risks is presented.

2.1.1 Stakeholders

Quite a number of parties are present in the neighbourhood of enterprises, each with an impact on the organisational policy, including their environmental policy. An enterprise may be influenced by legislative pressure, or more indirectly by measures such as social and financial incentives. This may manifest itself in customer requirements or in the brand image and has repercussions on the internal organisation, for example in the design of production processes or the purchase of raw materials. The parties which may put those pressures on the enterprise include internal ones, such as stockholders, employees and the management, and various external parties. The latter can be subdivided in those which are part of the supply chain, of which the enterprise is directly economically dependent, and others, such as authorities, branch organisations and public (e.g. environmentalists and direct neighbours). An overview is shown in figure 2-1.

In this chapter, supply chain parties, the organisation itself and authorities are discussed as main parties. In this thesis, less attention has been paid to other stakeholders; as far as their environmental requirements are concerned, the main parties are considered as representatives. As a result, a large part of their requirements should be met by (aggregated) information that is gathered to meet the requirements of the main parties.

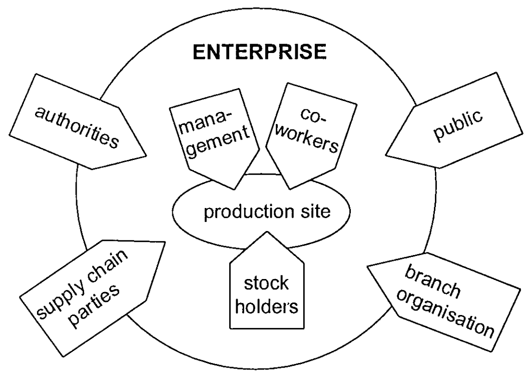

FIGURE 2-1 Powers in the environmental policy domain

2.1.2 Sources of Environmental Risks

Production can be defined as the transformation of materials. It means that anything that happens to an object, or set of objects, *increases its value*. The basic physical condition necessary to effect any of these changes, is that *energy* must be applied to the material in some form (Chenery, 1949). Energy is then defined as 'a non-material object, able to transform objects'.

Due to production, materials are extracted from, and finally returned to, the physical environment. The return flow, however, usually consists of materials in a different (chemical or physical) quality, it takes place at a different time and at another location. As a result, extraction may cause exhaustion of particular raw materials on a local or even global level. Due to production processes, a physical location is occupied and may violate someone else's environment. The production may cause air, water and soil pollution, waste and nuisances such as smell, vermin, dust, noise, etc. Besides regular production, also calamities may occur, which cause additional inconvenience or risk. Furthermore, produced products are sold, and their use might cause harm to the human or physical environment.

Finally, it should be taken into account that the manufacturing process requires energy. This should also be produced, and for its production process the preceding equally holds true. In this way, a process description leads to a tree-like structure. The relation between the extraction of materials, the energy production and the manufacturing process has been described by Splinter (1994). This view is represented in figure 2-2.

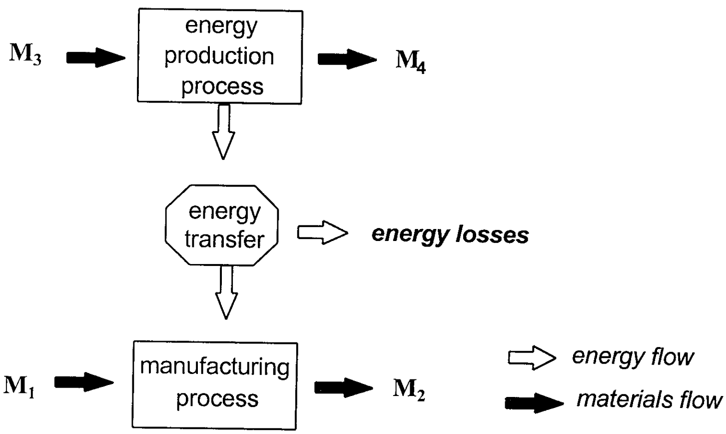

FIGURE 2-2 Materials transformation in production (Splinter, 1994)

A production system aims to add value to materials by application of energy. For effective production systems, information is required. *Materials, energy and information* are the basic elements to model a production system. In this section, the role of materials and energy in environmental applications is elaborated. Later on, in chapter 3, the significance of information is shown.

Summarised, sources of environmental effects can be described from various, related, viewpoints: materials-oriented, process-oriented and location-oriented. In the following subsections, these are further elaborated.

Materials-oriented View

Environmental effects may be location dependent. Euthrophication, for example, which results from an over-measure of nutrients, may be adverse in areas of factory farming and beneficial in a desert. Furthermore, different authorities may attach different importance to the effect of materials and, as a consequence, formulate different regulations. Also in the course of time, insight in the consequences of environmental effects may change. It follows that it is impossible to specify a uniform classification with respect to the environmental effect of materials. The classification given below, based on (Ruwel, 1991) should be considered as a framework and the application on individual materials merely as an example.

Materials in general Many materials are used and applied in everyday life and are usually not considered to be harmful. Some of them, however, can be harmful to a certain extent. This form of harm is caused by *toxic materials.* Toxicity is defined as the quality or degree of being poisonous. The toxicity may concern human-beings (*human toxicity*) or the environment (*eco-toxicity*) and is dependent on the combination of the material, the quantity and the characteristics of the receiver (human-being or particular location). In this field, environmental and safety issues are closely related to each other.

Materials may have additional *hazardous properties,* both for the physical environment and human-beings. Examples are safety aspects such as explosion sensitivity or self-ignition. Finally, some materials may not be harmful in themselves, but only in mixtures which have other characteristics than each of the constituents. Both materials and mixtures may cause air, water and soil pollution. Some materials are not directly dangerous for organisms, the abiotic system, e.g. ozone depletion. Especially large concentrations should be prevented and an effort is made to determine Maximal Acceptable Concentration (MAC) - values.

Prioritised materials Some materials are considered to be harmful in more than one respect. Consequently, those materials are subject to a number of sub-fields of environmental policy. For the consistency of policy making, especially from an authorities' viewpoint, integration of policies per material is required. Per material, a description of name(s), characteristics, distribution properties and possible control mechanisms are recorded. In view of the large number of this kind of materials, prioritising is necessary. As an example, the current list of prioritised materials in the Netherlands is included in appendix C-I. Note that this list is not limited and subject to changes.

Materials which require special attention Apart from prioritised materials, a list of materials is available which got priority with respect to the collection of environmental information. Those materials have impact on the environment but lack a general insight in the actual exposition. It enables authorities to ask for information on prevention, application and distribution, on which they can base new prioritised materials, or withdraw a material from the list. Also this list is not limited and subject to change. As an example, the current list of those materials in the Netherlands is included in appendix C-II.

Black materials Some materials are, often in an international context, placed on the black list on account of their environmental harm. The proliferation of those materials in the environment should be avoided. Per material, the authorities may decide to restrict the application of the material, or to ban the material completely. Application of those materials enforces notifications in trade and use as a product. Also this list is not limited and subject to change. As an example, the current list of black materials in the Netherlands is included in appendix C-III.

Waste and emissions The former three categories concern the composition of any product or material, independent of a particular production process. Waste and emissions are caused by production processes, because input materials usually result not only in the primarily intended product(s). Furthermore, a remainder of various categories is also considered as waste, e.g. rejected products in production, discarded batteries and packaging material, used oil, paint, etc. NB All inputs, outputs and other products may consist of materials from the above mentioned categories. This approach is further elaborated in chapter 7 of this thesis. Finally, waste and emissions can be solid, fluid or volatile. The following division is generally accepted.

- household waste: organic materials, e.g. food, paper, glass;
- business waste: household waste, supplemented with remainders of construction materials, wrecks, sludge, etc.
- hazardous or chemical waste: materials which are placed on the list for chemical waste.

In all categories, waste flows are increasingly separated; therefore the resulting waste flows can more easily be applied as input materials for other products. Logistics is important in relation to control and minimisation of waste streams. Materials oriented risks arise due to lengthy storage of raw materials, production losses and low product quality, which can be controlled in a good logistic system. Furthermore, improvements can be reached through a higher efficiency of raw materials and re-use of the waste streams.

Process-oriented View

In addition to materials-oriented aspects, various process-related issues arise, although this view should be considered in relation to the materials oriented view, as described in the previous subsection. In the processing of materials, *chemical reactions* might occur; one process may cause more risk than another. Production means which are in process might cause vibrations and other *nuisances* for direct neighbours. Several factors may increase the chance for calamities, for example technical wear, possibly in combination with overdue maintenance and complexity of process control. Hazardous materials demand specially adapted storage conditions. Finally, organisational control largely determines overall control of the production process.

Location-oriented View

The location of business is an important determinant for the likeliness of risks. First, the planning policy of local authorities establishes the preconditions in which way the organisation and its neighbourhood may interact. Furthermore, the geo-hydrologic and chemical properties of the soil is important, for example in the distribution of hazardous materials: clay allows less transportation than sandy soil. Finally, protected areas might prohibit certain business activities partly or completely. In such a case, activities which are generally accepted, are unacceptable under special conditions, e.g. running a petrol station in a water treatment area. Drawing up a so-called 'environmental effect report' of a proposed investment is usually the correct method to evaluate the risks of the intended and alternative plans.

2.2 Authorities' Viewpoint

The main task of national, local and other authorities is to formulate their policy, to establish standards and values related to that policy, and to implement these in rules and regulations; this also holds true for environmental tasks. In this section, existing kinds of rules and regulations are described, supplemented by sources of environmental risks that, from an authorities viewpoint, are distinguished.

2.2.1 Rules and Regulations

Due to growing understanding of environmental effects of production, enterprises are confronted with a growing amount of environmental rules and regulations, issued by local, national and international authorities. After two decades of introducing and changing regulations, enterprises didn't see the wood for the trees. The authorities answered on this, first by structuring legislation and afterwards by simplifying laws. The latter is achieved by issuing environmental laws and regulations, which are gradually more based on the principle of *self-regulation*. Formerly, laws and regulations specified *how* something should be done, regardless of the fact whether it was the best solution in a specific case. By means of self-regulation, an organisation is enabled to realise environmental objectives, which are stated by authorities, on their own way and on their own responsibility. Authorities acquire insight in the effort and its effect by monitoring and reporting. The result of those two types of physical regulation is a diverse system of granting and maintaining permissions, supplemented by a number of other instruments. The following overview, based on Tempelaars (1995), distinguishes compulsory instruments and incentives.

Compulsory Instruments

One of the most traditional ways in which authorities assess the environmental effect of an enterprise is by means of *physical regulation*. Physical regulation is applied by prescribing specific environmental conditions with respect to products and processes, as a part of an environmental permission. Two types are distinguished: *goal-oriented regulations* in which a certain environmental objective should be met and *method-oriented regulations* in which a prescribed way of management should be implemented. The current priority of authorities and those who are subject to regulation is on the first one, aiming at integration of environmentally benign production in business processes and the internalisation of this attitude in the behaviour of people.

Secondly, *product responsibility or accountability* should be mentioned. Product responsibility, sometimes combined with an obligation for third-party insurance is more and more applied. Responsible is either the owner or the party that had the actual power at the moment a calamity has occurred.

Finally, a number of *organisational measures* can be issued. In the framework of self-regulation, it may be specified which standards the organisation should meet. Large enterprises and smaller ones with large environmental risks, for example, should have a complete environmental management system.

Incentives

Given the fact that environmental regulations might influence business management, it may be beneficial to take the opportunity to gain some advantage.

Well-known are *financial instruments*. Financial stimuli should affect the environmental behaviour. Discerned are *anti-pollution taxes* based on the environmental effect of a product or process and *taxes on raw materials*, applied to gain capital to reduce environmental pollution (curatively) and to reduce activities which are harmful to the environment (preventively). Apart from taxes, a system of *subsidies and other financial benefits* can be realised to encourage new environmentally benign technologies. Other instruments are *deposit systems* and *tradable rights*, such as emission rights. In a deposit system, the customer pays an additional amount to incite him to return (the remainder of) the product, e.g. for recycling or refurbishing. Tradable emission rights may be part of a policy to reduce the emission of a particular material, without explicit prescriptions for changes in the production process.

> In a period of swine fever, in June 1997, the Dutch government proposed to introduce tradable production rights for pigsties. The introduction should be coupled to a reduction of 25% in comparison to one's current production volume. The main motive is to drive back the emission of ammonia by decreasing the number of pigs and pigsties. This should enable the remaining pigsties to improve the (environmental) control of the production processes and to produce a better quality of pork.

Furthermore, *environmental agreements* may be formulated. A policy to favour goal-oriented regulations implies a well-developed, constructive relation between authorities and an intended target group. Intermediaries may mediate between those two parties to establish environmental agreements for a specific branch of industry. The resulting agreements specify the objectives and the allowed period of time to meet them.

2.2.2 Information Flow

The above mentioned instruments require a growing flow of environmental information between an enterprise and the executive authorities. The actual obligations to be able to provide this information, are summarised:

- *Measuring obligations;* prescriptions on the methods for measuring, applied in combination with registration and reporting obligations.
- *Registration obligations;* authorities may oblige industry to record measuring data, as a check on assumed emissions and as evidence in case of malpractice.

- *Reporting obligations*; obligation to publish periodically (usually per year) an environmental report with a summary of the results of that period. It should result in a better communication between industry and society, and also between industry and authorities.
- *Information exchange obligations*; establishes the information exchange of organisations with third parties. A well-known example is a label for end-consumers with product information with respect to the environmental effect of the product, e.g. with respect to the content of cadmium.

Laws, regulations and accompanying obligations result in an information flow towards local and national authorities, either occasionally or structural. In this thesis, the focus is on both, though merely from the viewpoint of individual enterprises. Although enterprises nowadays discharge their obligations, practice has shown that they generally have difficulty in effectively and efficiently meeting the information requirements. Additionally, insights and demands will change over time, resulting in other and more demanding information requirements. In an increasingly dynamic situation, it will be more and more complicated to comply with all requests.

2.3 Supply Chain Viewpoint

In addition to environmental requirements which are enforced by authorities, several influences originate from the supply chain. A supply chain is usually defined as an integrative approach to dealing with planning and control of a materials flow from suppliers to end-users (Jones *et al*, 1985). From an environmental viewpoint, it should be stressed that waste treatment companies and the like also belong to the supply chain. Co-operation of enterprises in a supply chain aims to contribute to the benefits of all parties involved and to maximise efficient use of resources to be able to meet requirements of the supply chain's customer. To be able to do so, two types of requirements are made: requirements of suppliers and customers (*in* the supply chain) and requirements of the end-customer *on* the entire supply chain. In this section, both views are elaborated.

2.3.1 Requirements in Supply Chains

Customers have -specified and unspecified- requirements on products they would like to buy. Satisfying these requirements is entitled as Total Quality

Management (TQM). In this respect, the environmental performance is considered as an extension of quality. Customers, however, also have specific reasons to include environmental aspects in their purchasing policy (Baars, 1996). The most apparent reason is to meet *legislative* requirements with respect to raw materials, production means, semi-finished products and packaging. Their production process should not be hampered by preconditions of supplied material. Furthermore, an indirect legislative consequence is the environmental impact caused by the *supplier*. The supplier has to be able to guarantee continuous supply of purchase goods, regardless of the conditions of environmental legislation and shortage that might be induced.

Internal objectives, further, are to lower environmentally-related costs, either due to environmental levies or ineffective usage of raw materials for any party in the supply chain. Environmental costs are part of the integral costs charged over the complete supply chain, which has negative effect on the sales to the final customer. The other way around, an optimal usage of environmental characteristics will create opportunities to exploit new markets by making environmental purchasing part of the green image. Last but not least, from an ethical point-of-view, enterprises should consider environmental care as an integral part of complete enterprise management, though this is not always the case.
Depending on the value of the purchased goods and the volume of supply of those goods (per time period, e.g. a year), a number of applications for environmental purchasing are found (Baars, 1996): (1) supplier selection; (2) selection of purchased goods; (3) return logistics of the product and/or the packaging; (4) environmental redesign; and (5) transportation optimisation.

2.3.2 Requirements on Supply Chains

Initially, environmental requirements on the supply chain are related to the products which are jointly produced. In the context of this research, the environmental quality should be specified (e.g. by environmental labelling, environmental product information) and guaranteed (tracking and tracing). Finally, special attention should be paid to environmentally friendly solutions in the last phase of the product life-cycle after discarding the product and the resulting demands on the supply chain (reverse logistics).

Environmental Labelling

A so-called environmental or eco-label is attached to a trade-mark and adds the image of 'environmentally benign' to a product. It implies that all phases in the production of the product should be controlled and that each phase, each party in the supply chain, should meet a number of environmental requirements, in such a way that the end-product is considered 'better' than another product not meeting those requirements. The underlying ideas are based on concepts such as design for the environment (DFE), life cycle analysis (LCA) (Guinée, 1995) and other chain approaches, such as reverse logistics, recycling and waste management (Flapper, 1993; Rautenstrauch, 1995).

It is noticed that such an approach is not restricted to environmental labelling. Nevertheless, it can be considered a general idea to settle a certain image in the market. Well known are quality labels (ISO-9000 certified products and organisations), but also other labels appear, such as 'animal friendly' (free-range eggs), 'public health' (hormones-free meat) and others (*Max Havelaar* products, supporting entrepreneurs in Third World countries). Several labels are supported by management systems in the participating organisations, under the name of quality, environmental or safety management system.

Tracking and Tracing

To be able to guarantee a certain level of product quality, it is inevitable that products have to be identified. *Product quality* can be defined as 'the complex of characteristics of a product or service, which makes it meet the specified and unspecified customer requirements' (ISO 8402, 1986). Consequently, customers, or their representatives, might require reliable and complete information on their unique product. *Identification* of a product means that it can be discerned from other products of the same type, usually by adding a unique number to the physical product, for example a serial number. Two concepts contribute to the guarantee of a particular quality level: tracking and tracing.

Tracking of a product implies that a particular product is continuously followed, in such a way that it can always be known where this product is located (forward in the supply chain). This may be applied, for instance, in the automotive industry, where each car on the production line, and all its components on the shop floor, correspond to an individual and particular customer order. *Tracing* of a product, contrarily, involves the once-only search for the history of the creation process (back in the supply chain).

Usually, customers are rather indifferent and thus ignorant with respect to the details of the creation process of products they buy. This changes, however, in exceptional cases, for example if the product turns out to be unexpectedly hazardous or toxic due to mistakes during the production process somewhere in the supply chain.

> An example of an unexpected environmental effect is the radio-activity of chair legs. In the United States, some years ago, chair legs have been sold which showed signs of radio-activity. Once it was determined that the effect was independent of the location where the chair was situated, the production process of chairs had been analysed. It turned out that the chair legs already showed radio-activity when delivered. The trace led to the supplier, and the production site of chair legs. It turned out that the chair legs were constructed from waste material from containers of a nuclear power station.

The level of radio-activity of a material can be measured; in the example, the manufacturer could recall the products from the market to determine the level of radio-activity. If such exceptions concern effects which are hard to determine after the product has been produced, tracing of the product is insufficient. If a product turns out to 'contaminated', it should be traced back in the supply chain until the source of contamination is found. The next step is to determine all products which could meet the same requirements as the contaminated product, for example the group of products that are produced from the contaminated batch of a particular raw material. This especially holds true for food production.

> A well-known example in Europe is the attention for BSE (mad-cow disease) that paralysed the production of beef in 1996. For decades, it was known that large groups of British bovine animals were infected with BSE, and also that some relation exists between the mad-cow disease and a human brain disease (Creuzfeld-Jacob disease). Nobody paid much attention to this information, until the British government, in a fit of sincerity, made a minor remark. This minor remark resulted in distrust of the entire European beef market, a shift from 'safe, unless' towards 'safe, only if' and consequently extermination of almost the complete British herd. It also had international consequences, directly because all European beef had to face the more critical customer requirements, which caused considerable production loss and fall in price. Finally, it nearly paralysed also all other European decision making, since the British seemed not to be willing to fulfil the urgency measures and underlined this by blocking all procedures.

The question is whether this matter could have been solved more elegantly. Probably, this would have been possible, if, in this case the birth, movement, diseases and death of animals had been registered adequately. This kind of information, the product history data, could enable the producer to trace a particular product back in the supply chain, to identify the damaged group of products and to take action effectively by tracking all those products, forward in the supply chain.

Unfortunately, this kind of data registration is expensive and merely proves its use in the long run. The BSE example, however, explains why such a detailed and expensive behaviour might be beneficial, both for the producer and for society. In chapter 9, this view will return to apply the acquired environmental knowledge in a supply chain context.

Reverse Logistics

Another environmental requirement on supply chains is the wish or obligation to process discarded products. Reverse logistics is defined as all activities required for the re-use of materials, finished and semi-finished products, once the product has been discarded by the final user (Flapper, 1993). In this context, two types of products are distinguished: the customer product itself and its packaging (Boodts, 1995).

For both types, the product life can be considerably extended. The main idea with respect to the product's environmental impact, is that a longer product life will request less raw materials and sometimes also less processing. The extension of the product life cycle can be achieved either, for example, by a higher product quality or by maintenance and re-use. In general, it is stated that the result is consequently a reduction of environmental burden. As will be made clear in the subsection on life cycle assessment, this is not necessarily the case. At this stage, it will be sufficient to outline the phases after use of the product.

- Purchasing and collection of the discarded products, which might include a deposit system, transportation and separation;
- Processing of the used product, like maintenance (product preserves its original function), part recycling (product is applied as a part in a product with less value) or material recycling (possibly for completely different application);
- Distribution, and sales or lease of the 'new' products, depending on the new function via the original or other distribution channels.

Obviously, the upgraded product causes less environmental burden provided that the burden of those 3 phases is less than the production out of virgin materials increased by the effect of discharge of the original product. Usually, the comparison is not as obvious as should be desirable. The production of virgin materials requires new raw material and energy, whereas recycling or re-use at least requires energy for transformation and transportation. Moreover, the recycling grade is usually less than 100%. Depending on the kind of materials, the yield and the required quantity of energy, a comparison should be made based on a number of criteria and weight factors that indispensably introduce a subjective element.
Application of reverse logistics has to be realised in a supply chain perspective, if not back to the original equipment manufacturer, it should at least include parties for collection and distribution. Once the strategy of the reverse chain has been designed, it comes to the implementation in the individual organisations. These are facing two types of questions: the implementation of the operational logistics and the information requirements. Those topics are a complete subject of research on their own right (PAWS, 1996). In this thesis though, the focus is on information requirements.

2.4 Enterprise Viewpoint

In this section, enterprise requirements are described and classified. Next, some developments in the approach of such environmental requirements are shown.

2.4.1 Requirements

The environmental policy of an enterprise may be based on internal and external requirements. External requirements have been described above. Internal requirements are largely based on these and may include (1) the continuity of the enterprise, (2) meeting legislative and supply chain requirements, (3) safety and well-being for employees, and (4) management aspects: fulfilling requirements against minimal costs.
Managers, employees and stockholders don't like to conclude that the continuity of the enterprise is endangered because it doesn't meet (particular) external environmental requirements. Examples are the withdrawal of a licence, a (too) long way behind of competitors, pricing the product out of the

market, or a bad image, resulting in the ban on a product or even a boycott on all products.

Legislative and customer requirements have considerable impact on the management of an individual organisation. Environmental laws and regulations, more and more based on the principle of self-regulation, require a complex of environmental instruments for an individual organisation. Also customer requirements can be met by such instruments, if these comprise the relevant topics as mentioned before.

> The (temporary) ban of all products due to a bad environmental image happened, for example, to Shell in 1997. One of their oil drilling platforms, the Brent Spar, had been discarded and Shell intended to sink it in the Atlantic Ocean. Greenpeace, however, occupied the platform and took the view that it still contained a large amount of oil which should cause serious environmental pollution. Greenpeace incited the public to ban Shell products to extort the promise to dismantle the Brent Spar ashore. The ban was effective and Shell submitted under the pressure of the public. Unfortunately for all parties concerned, the quantity of oil proved to be only a tenth of the suggested quantity and, moreover, dismantling ashore proved to be more harmful than sinking.

2.4.2 Classification

In the following, an overview of requirements is provided, based on a classification for business information systems (Bemelmans, 1987). Point-of-departure is the coherence with other enterprise objectives.

- *Strategic requirements* to support long-term decisions. In this classification decisions are distinguished that are taken only once or that are taken from time to time. Once-only decisions are, for example, the construction of a new airport or another part of the infrastructure; in the Netherlands, this requires the evaluation of several alternatives in an environmental effect report. Decisions that are taken periodically, once in say 2 years, are the (re)design of products or production processes and the purchasing of investments goods.
- *Tactical requirements* to provide management information based on operational data, covering about 1 year. To that order, operational data is aggregated and represented in a management report, such as the (environmental) annual report (EAR) and (environmental) management system (EMS), as in the ISO-14000 series).

- *Operational requirements* covering weekly to monthly periods, require coupling or integration with, amongst other, logistic, financial and quality systems such as Enterprise Resource Planning (ERP-) systems and Manufacturing Execution Systems (MES).
- *Instrumental requirements* are based on (non-aggregated) data: tracking and tracing of product data, continuous measurements of production processes and other registrations, samples e.g. for control purposes.

2.4.3 Approaches

The question is how individual enterprises respond to requirements of changing circumstances in their environment, and especially in their natural environment. Regardless of the fact whether the organisation aims at a pioneer position (pro-active) or shows a more obedient behaviour (re-active), in practice it is demonstrated that 'the environment' has a special position in the organisation. Unfortunately, this position is frequently an isolated one, in its full interpretation: remote, foreign and confined. On the short term, this kind of stand-alone manner proves very helpful to the environmental image, though less to the actual environmental performance. It often occurs that the environmental co-ordinator uses stand-alone systems and instruments, which are not exploited by others. Integration in and improvement of processes are a long-term issue, even when reporting directly to corporate management. Furthermore, in smaller enterprises, the introduction of environmental management may sometimes coincide with a re-organisation of business activities and suits several purposes.

Enterprises should respond to ever changing requirements from society, and find a way to integrate environmental and other management issues. Two types of approaches have been proposed the past years: horizontal and vertical integration. Horizontal integration involves the integration of environmental issues with, amongst others, quality and safety systems, sometimes referred to by the phrase *combined systems* (Didde, 1995). Vertical integration, either based on environmental or combined systems, involves a rather rigid type of co-operation with suppliers and buyers, ultimately from extraction until use. The key should be found in circumstances that environmental requirements are complemented by various internal requirements which are related to the environmental issues, such as production control, costs, product quality and brand image. Actually, each of those requirements is related to effective and efficient production, and provides a subsistent and therefore sound basis for the implementation of some environmental application.

2.5 Conclusion

Environmental information requirements as discussed in this chapter, are now summarised. This summary is used to determine deficiencies in existing environmental applications (chapter 3) and to specify requirements for a new modelling method and application (chapter 4).

Requirements from Authorities

Authorities may oblige an enterprise to measure, register and report and to exchange gathered information regarding environmental issues with third parties. The requirements and consequently the information obligations may concern purchased, produced and sold materials, applied production processes and locations in use.

Generally, two reasons may cause information exchange: when submitting requests for a licence (occasional information exchange) and as part of maintaining a licence (structural information exchange). In chapter 1, it has been argued that this research covers environmental information exchange with respect to production, namely the materials and process oriented views.

Requirements from within Supply Chains

Buyers are interested in the continuity of their supplier. Environmental effects, and any consequence of this, shouldn't endanger this continuity. To gain insight in the environmental status of their partner, two decisions should be taken: supplier selection and goods selection. Selection of the supplier could be based on certification of the production processes within a rather high level of aggregation. Selection of goods, for example, can be based on a label, by application of LCA or the presence/absence of a particular raw material, e.g. as specified in the lists for prioritised or black materials.

Requirements on Supply Chains from Outside

Requirements of society, end-customers and others on the supply chain, or usually on its products, have repercussions on the individual enterprise that is part of this supply chain. Two types of requirements are distinguished: strategic and operational.

Strategic requirements are based on principles such as DFE and LCA, which specify preconditions for production of a product. Once the production lay-out has been designed, all products are produced accordingly.

Operational requirements, e.g. tracking and tracing and reverse logistics, demand for additional effort for each individual (group of) product(s), in the first case merely registration, in the latter case also decision making and further material processing.

Organisation Internal Requirements

The main objective for enterprises is continuity, Therefore, organisation internal requirements are largely based on the above described external requirements. Additionally, well-being for employees and (economic) effective production contribute to continued existence. For this purpose, several types of requirements can be discerned: strategic, tactical, operational and instrumental.

Often, environmental requirements are approached differently from other enterprise requirements, resulting in a stand-alone manner. Gradually, environmental requirements are more integrated in other management issues by means of horizontal and vertical integration.

In the following chapter, existing environmental applications are described and evaluated against the requirements as formulated in this chapter.

3. Environmental Applications for Enterprises

In the previous chapter, an overview has been provided of environmental information requirements on an enterprise. In this chapter, it is depicted which environmental applications are currently in use. First, a classification of environmental applications is defined (section 3.1). Next, in section 3.2, the most comprehensive standard for environmental applications (ISO-14000 series) is outlined. Subsequently, the application types, which are derived from the classification, are elaborated (section 3.3 - 3.5) and evaluated (section 3.6). Finally, existing types of environmental information systems are summarised (section 3.7) and it is concluded which deficiencies exist to fulfil requirements formulated in chapter 2.

3.1 Definition of Concepts

The general term *environmental application* includes all kinds of environmental systems or tools which may be in use by an enterprise and which can be considered as a part of the enterprise's environmental policy. In this chapter, the following types of environmental applications are described:

1. *Approach oriented:* applications which prescribe an environmentally-oriented approach, for example how to design processes and products. The approach for process design shows *how* environmentally-oriented organisations have to be designed (environmental management systems). The approach for product design shows how environmentally benign products have to be designed (product life- cycle assessment and product labelling).
2. *result oriented:* applications which prescribe a required result. It is specified which environmental topics should be covered, e.g. 'emissions of solvents' or 'radioactive waste', and their quantities, e.g. in an environmental annual report or as part of legislative obligations.

Finally, to make effectively and efficiently use of environmental applications, those may be supported by one or more *environmental information systems* (EIS). An EIS could include data collection, storage, reporting and exchange of environmental information (Plötz *et al*, 1995). An EIS plays a key role as environmental information supplier for the above-mentioned environmental applications.

In the next section, an overview is provided of the most comprehensive world-wide series of standards for environmental applications, the ISO-14000 series, but it should be taken into account that some of those standards are still under development. For that reason, individual applications are further detailed based on various other, national and international, standards. Finally, existing types of environmental information systems are summarised.

3.2 ISO-14000 series

The most recent standard (ISO-14000 series) is designed as a framework, in which the other, nowadays rather frequently applied applications can be situated. The International Standardisation Organisation (ISO) is a world-wide federation, composed of member bodies of about 120 countries. It has assigned responsibility to a technical committee (TC 207) to develop the international environmental standards (ISO-14000 series). These describe a management system that will help companies to assess their environmental credibility and make improvements where necessary. The system is voluntary and based on international consensus. It contains of basically two types of documents: specification and guidance.
ISO-14000 is currently under development; although text books are available, e.g. (Rothery, 1995), up-to-date information can be found on the world wide web, e.g. (ISO-14000, 1997). The already published standards of the new series are 'ISO 14001, Environmental management systems - Specification with guidance for use', and 'ISO 14004, Environmental management systems - General guidelines on principles, systems and supporting techniques'. These two documents are the pillars of the ISO 14000 series, and will allow it to fulfil business needs all the way from general guidance to self-assessment and registration/certification. The intention of TC-207 is to address five areas in the near future:

- Environmental Management Systems (EMS). There are three principal components to an EMS: a written program; education and training; and knowledge of relevant local and federal environmental regulations;
- Life Cycle Assessment (Committee Drafts 14041 -14043). All products have a life-cycle; they are born (extracted and manufactured), they live (operated

or consumed) and die (discharged). The standard aims to provide an overview of the total environmental impact and to generate and evaluate opportunities for the reduction of this impact over the total life-cycle;

- Environmental Labelling. Environmentally friendly products, if they meet consumer needs, have an advantage over non-friendly competitors. Many labels are available, but it is frequently unclear which criteria are evaluated. The ISO standard should provide unequivocal requirements for trustworthy labels ;
- Environmental Performance Evaluation. Environmental Performance is measured by quantifying the impact of a business on the environment. This is determined initially by an inventory of these impacts such as air emissions, and wastewater discharges. The evaluation is reported to various stakeholders;
- Environmental Auditing (committee Draft 14010-14012). An Environmental Audit is similar to a medical exam: a routine evaluation of a company's environmental performance controls. The audit should be conducted by an independent third party and may include all aspects of the EMS.

3.3 Environmental Management Systems

Following the increasing attention for environmental issues, pro-active enterprises started the development of their own environmental management systems. An *environmental management system* (EMS) is considered to be an integral part of the existing management system of an enterprise, covering the organisational structure, responsibilities, practices, procedures, processes and resources (BSI Standards, 1992). The last decade, this has been picked up by standardisation organisations, successively on national, international and world-wide level. Those standards have in common that they are all based on the ISO-9000 methodology for quality assurance. In this section, the general layout is described (3.3.1) and illustrated by the main existing standards (3.3.2 and 3.3.3).

3.3.1 General Lay-out

The development and implementation of an environmental management system is based on the 'Deming' cycle (Deming, 1982) It is a basic strategy for continuous improvement of processes and their output performance. It divides the enterprise actions in four phases, which aimed at continuous improvement, see figure 3-3:

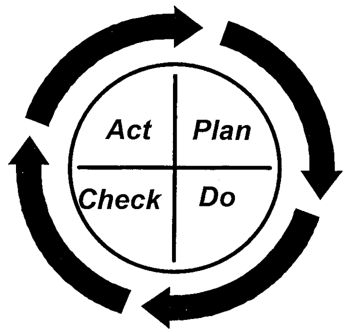

FIGURE 3-3 Deming Circle

- Plan: a *planning phase* - the overall objectives and goals of the enterprise are established and methodologies for achieving them are developed.
- Do: an *action phase* - the plan is implemented and the agreed measures are taken in pursuit of the enterprise's goals.
- Check: an *evaluation phase* - the actions taken under the plan are checked for effectiveness and efficiency, and the results are compared to the plan.
- Act: a *corrective action phase* - any deficiency or shortcoming identified is repaired, the plan may be revised and adapted to changed circumstances, and procedures are reinforced or oriented if necessary.

Environmental management systems, based on the Deming-cycle usually cover, to some extent, eight elements, as summarise in chapter 1. In practice, it turns out that enterprises run up against difficulties when using such a system completely, because it remains unclear how environmental data should be collected, registered and reported, at least without making it a major task. Furthermore, it is shown that, though a good starting point, environmental management systems ascertain 'to do the job right' instead of 'doing the right job'. In other words, those systems do not in themselves set levels of environmental performance but rather offer the means to meet the requirements. ISO-14001 states:

...This International Standard does not establish absolute requirements for environmental performance beyond commitment, in the policy, to compliance with applicable legislation and regulations and to continual improvement...

3.3.2 British Standard BS-7750

One of the first applications of the Deming Cycle in an environmental context is implemented by the British Standardisation Organisation, which resulted in the BS-7750 standard. This standard is frequently used as a starting point for certified environmental management systems and has been the basis for the International Standardisation Organisation (ISO) to specify the ISO-14000 series. Note that the environmental review is only dedicated to the environmental management system itself, and hence not to the significance of the system within a organisation.
The first step in the cycle is the planning phase, in which the environmental policy is set. In the subsequent cycles, the policy is each time adapted based on the changed circumstances. The following six steps cover the preparation and implementation of the policy, and the production takes place under the adapted control. Finally, in the evaluation phase, the management record is analysed, the management system audited which result in an environmental review.

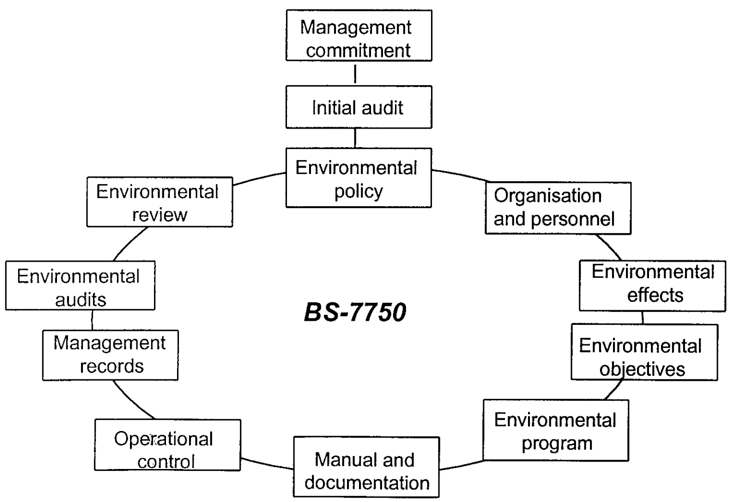

FIGURE 3-4 Overview of BS-7750 standard(BSI Standards, 1992)

3.3.3 Eco-Management and Audit Scheme (EMAS)

In June, 1993, the first specification of the Eco-Management and Audit Scheme (EMAS) was published by the European Commission (Hillary, 1994). The EMAS is a European regulation within the context of the 5th action program *Towards Sustainability*, aiming at:

- establishment and implementation of environmental policies, programmes and management systems;
- periodic evaluation of the performance of the site elements in a systematic and objective way;
- provision of environmental performance information to the public.

As a matter of fact, those objectives are not essentially different from the BS-7750 standard. However, the EMAS additionally provides an explicit and independent system for accreditation of the implemented environmental management system. Participation in the EMAS is on a voluntary basis, open for any company operating an industrial site in one of the 12 member states of the EC. An overview of the structure of the audit and accreditation scheme is depicted in figure 3-5 on the next page.
The core of the scheme is the audit cycle, which shows large similarity with that of the BS-7750 standard. In fact, BS-7750, and consequently ISO-14001, are compatible with, and can be used as a sub-set of the Eco-Management and Audit Scheme. If all requirements are met, a European certificate is issued, implying that the enterprise has implemented (the main parts of) an environmental management system.

3.4 Environmentally Benign Products

The second type of approach oriented applications concerns the product approach. The first application aims to assess *all* environmental effects, the second to certify particular product characteristics, including environmental effects.

3.4.1 Life Cycle Assessment

Life Cycle Assessment (LCA) aims to assess *all* environmental impacts of a product or process, from cradle to grave. It is a -potentially- objective instrument to be used in situations where environmental information is required: policy making, product design, product certification and bench-marking for product and process comparison. Subject of study are products, production processes and production means, throughout the complete life-cycle of the service of a product.
The LCA method is necessarily quite complex and often requires commitment to detailed measurements (Welford and Starkey, 1996) and quantification of

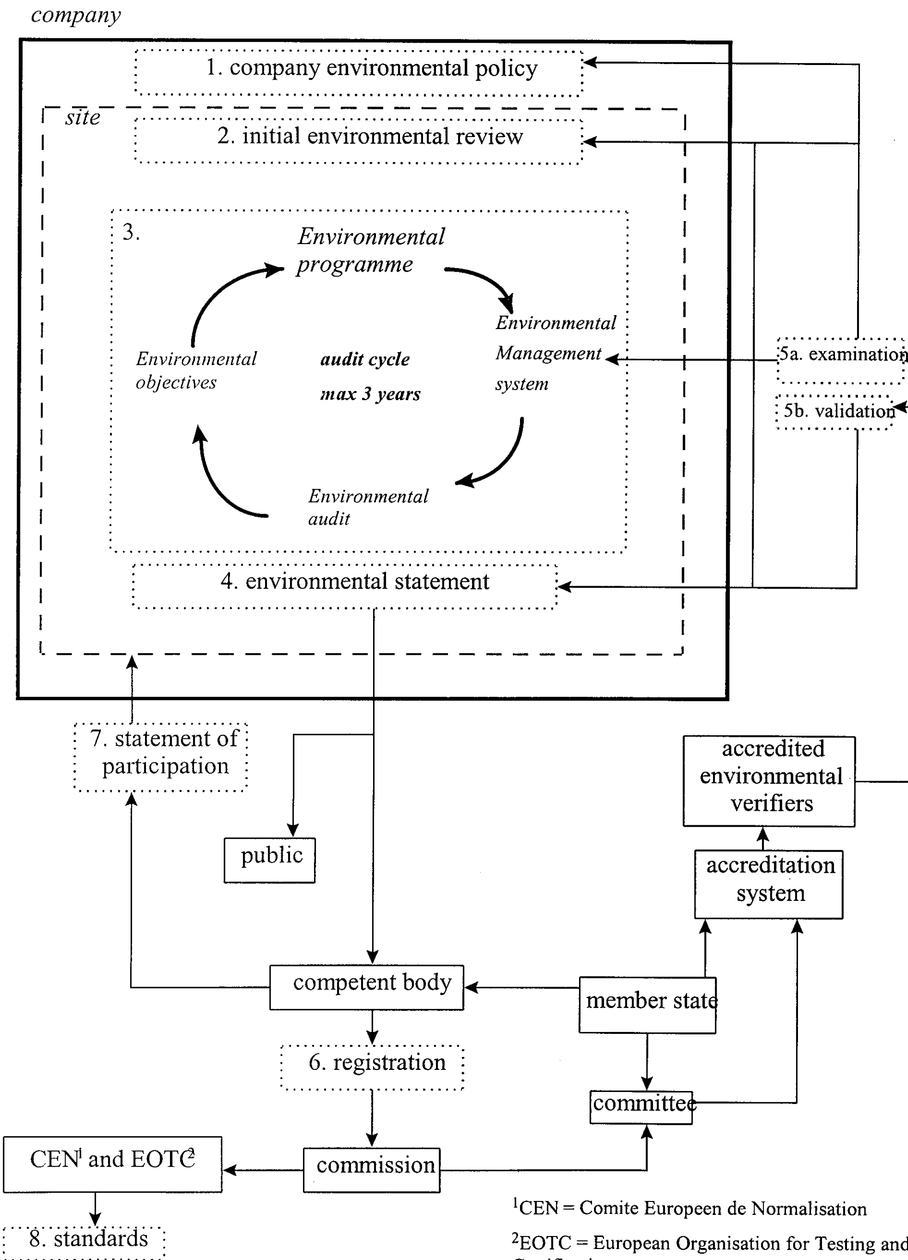

FIGURE 3-5 Overview of the Eco-Management and Audit Scheme EMAS (Hillary, 1994)

all entries is extremely demanding (Heijungs, 1997; Idenburg, 1993). Also rough screenings are being used, although, dependent on the level of detail, it is more difficult to substantiate the conclusions. Especially that part of the LCA that is used to compare, for example, two products should be well-described. Just referring to literature, already many different figures are summarised, see e.g. Boustead and Hancock (1979).

Confidentiality problems and continuous changes of processes and production means complicate the maintenance of an accurate database. Moreover, many products and processes turn out to be an aggregate of completely different entities. LCA hardly produces exact figures, these rather possess a relative significance, useful for comparison purposes. Accuracy of input parameters can not always be guaranteed to the same extent. Some inputs, however, represent second order effects, as is often the case with resources (capital goods). Sensitivity analysis is the appropriate tool for estimating the effect of inaccuracy in input data on the final result (van Hees, 1994). Methods to perform an LCA are discussed in more detail in chapter 4.

3.4.2 Environmental Labelling

The second type of product-based, approach oriented applications is environmental labelling of products. The objective is to certify particular product characteristics, including environmental effects. The principle of labelling a product is basically to guarantee the customer that a product is produced according to particular requirements. For the producer, it is a means to communicate that products and compounds meet particular requirements with respect to contents, properties and related process characteristics.

Labelling is since long widely applied, however, the increasing demand for 'good', 'safe', 'animal-friendly produced' and 'environmentally benign' products has caused an increase of such labels. Nevertheless, one should be rather conservative in one's judgement whether a product is provided with a 'green' label. Some of such properties of a product are directly or indirectly measurable, e.g. the cadmium content. A guarantee, by means of a certificate or label, may also include various intrinsic values, which concern properties of a product that can only be revealed by tracing the applied processes. The *Max Havelaar* label, for instance, includes both requirements on environmental production methods and the benefits for the local population. These values cannot be measured on the physical product.

Frequently, it is not commonly known which values should be included to obtain a label. Additionally, even for a one-aspect label as for environmentally benign products, it is not clear which parameters are included, such as effects of the production, characteristics of raw materials, pollution due to use of the product, use of recycled materials and possibility or obligation to recycle the product after use. Mostly, the criteria for a label remain unclear, which usually implies that either the product is only partly better, due to multi-criteria evaluation, or the product is only slightly better (Hees, 1994). Furthermore, it may remain unclear how strict a requirement is specified, e.g. when pollution should not exceed a particular absolute or relative value. Finally, it is often unknown in which way a labelled is registered, certified and audited. A trustworthy label, however, should meet unequivocal requirements and guarantee.

Concluding, the increasing use of eco-labels throughout the world requires harmonisation of the criteria used to determine which products are allowed to bear the labels. In the near future, the ISO standard will provide requirements for three types of labels. The first type is a 'seal of approval' for products that meet specified requirements within a product class. The second type will consist of single-claim labels for such things as recycled content, energy efficiency, etc. The third type will be an 'environmental report card' that uses a life-cycle approach and allows comparison of the environmental effects of the manufacturing and use of different products.

3.5 Environmental Reporting

Result-oriented environmental applications prescribe which environmental issues should be covered. This is rather apparent for regulations issued by authorities; in a goal-oriented regulation, it is prescribed which requirements should be met, and as a result, this should be reported. Other applications of reporting can be found in communication purposes, comparable with financial annual reports. Though nowadays, environmental reporting is still not obliged for the greater part of enterprises world-wide, the tendency is towards a more compelling, more detailed reporting policy. Leading initiatives have been started in the USA (Emergency Planning and Community Right to Know Act, 1987) and EC (mainly based on national legislation in Germany, United Kingdom and the Netherlands). This contributed in 1992 to the 'Declaration of Rio de Janeiro concerning the environment and development'. Part 10 is stated as follows:

> *... On national level, every individual has the right to have access to information concerning the environment which is controlled by the government, amongst others information on hazardous materials and activities in their direct neighbourhood; and the right to participate in decision-processes. States have to facilitate and stimulate public awareness and co-operation by supplying information on a large scale...*

The initiatives first started as a means to gain goodwill from customers and neighbours of industrial sites, but are nowadays extending towards a more detailed and formal level of environmental management accounting, supplemented with external verification.

Organisations that should be eligible for environmental reporting are medium and large sized industrial enterprises which cause a considerable environmental burden. Main fields are: metal industry, electro-technical industry, chemical industry, textile and carpets, energy production, etc. In general, those organisations are already used to a high load of (environmental) reporting; it should be noted that the annual environmental reporting is supplementary. A new aspect, however, is the distinction of two different audiences: local and federal authorities and the public.

The reports cover two issues. The first, for *environmental burden*, reports on negative environmental effects, which have been caused by the enterprise; the other concerns *organisation-internal environmental management*. All relevant measures, activities and efforts are summarised which are performed to provide insight, to check, reduce and prevent negative effects of the enterprise on the environment.

Because both the authorities' and public reports are based on the same data, a single information infrastructure should be able to support the environmental requirements for both internal and external communication. The methods to register those data should guarantee the integrity (correct, consistent, complete and timely) of the data. Main issues are the quality of measurement and registration systems, and distribution of data via computerised systems (VROM, 1996).

3.6 Applications Meeting Demands?

Existing environmental applications, as described in the previous sections, are summarised in table 3-1, and matched with the environmental demands, as specified in chapter 2.

TABLE 3-1: Applications meeting demands

APPLICATIONS / DEMANDED BY	approach oriented applications			result oriented applications	
	LCA	EMS	labels	goal-oriented regulations	annual reports
authorities	X	X	—	X	X
in the supply chain	X	X	X	—	X
on the supply chain					
product	X	—	X	—	—
tracking/tracing	—	—	—	—	—
reverse logistics	—	—	—	—	—
internal					
strategic	X	—	X	—	—
tactical	—	X	—	—	X
operational	—	—	—	—	—
instrumental	—	—	—	—	—

Several environmental applications are available to meet requirements from authorities and supply chain parties, though the more production-oriented requirements are not met by 'typical' environmental applications. This is consistent with internal applications on the strategic and tactical level. Nevertheless, it turns out that organisation-internal demands are, as yet, *insufficiently met on operational and instrumental level.* At this stage, the use of environmental information systems should be elaborated. Environmental information systems should support the environmental applications and may support transaction processing, thus contributing to the operational and instrumental level.

3.7 Environmental Information Systems

In the introduction of this chapter, it is stated that effective and efficient use of environmental applications requires support of one or more environmental information systems (EIS). An EIS could include data collection, storage, reporting and exchange of environmental information (Plötz, 1995). In this section, an overview is presented of existing types of environmental information systems especially tailored for individual enterprises, thus excluding governmental and branch organisations. This overview is based on an existing overview of commercially available environmental information systems in the Netherlands (Tempelaars, 1995) and study of literature on such systems in other industrialised countries, amongst others (VDI, 1995). The classification is based on the types of systems which are generally found in enterprises. The following types are discerned.

Strategic Environmental Information Systems

On strategic level, especially means for product design are offered. From an environmental viewpoint, *support of product improvement* involves means to design products which are suitable for recycling or re-use, with a minimum use of scarce resources and other environmental burden. This kind of information systems is used to support life-cycle analysis, design for the environment and design for disassembly. Apart from that, life-cycle analyses can be used for, for instance, environmentally oriented purchasing. As far as information systems are available which support this (see e.g. van Stekelenborg, 1997), these may occur not only on strategic but also on tactical and operational level.

Tactical Environmental Information Systems

On tactical level, several kinds of information systems are available. *Support of environmental management systems* involves registration of activities, effects, environmental objectives and programs, procedures and manuals, responsibilities, business acquaintances, etc. The system is often characterised by limited functionality, but may also be intended to support a particular certificate, such as EMAS. In addition, the system may include the integration with quality and safety management, for example with regard to procedures for personnel. *Legislative systems* aim to support for granting and maintaining licences, often as a component of an environmental management system. *Geographical information systems* are used to process location-bound data to support management decisions, e.g. for zoning plans. By individual enterprises, these are frequently used in combination with soil management. *Soil management* itself involves registration of locations and related historic measuring data. Finally, *water management systems* are meant to measure quality of groundwater, registration of meteorological observation data and water purification, and to report to authorities.

Operational / Instrumental Environmental Information Systems

The operational level involves a variety of information systems. *Support of waste management* may be used by original equipment manufacturers (OEM), waste collectors and refurbishing companies. Special attention is paid to hazardous waste. Covered topics include costs, materials management, route planning and hazardous materials classification and registration. *Energy management* aims to register of energy sources, energy use, time series and statistical data (which may also be translated in more strategic data). *Management of emissions* registers stacks and other sources of emission, including diffuse ones, and supports administration of quantities and composition of emission. Finally, *particular effects* may be calculated Examples are the calculation of optimal quantity of fertiliser, based on soil and crop characteristics (so-called precision agriculture), or calculation of risks due to emission of inflammable materials.

This overview may create the impression that all fields of environmental information are covered. Nevertheless some remarks should be taken into account. Generally, existing information systems merely cover part of the functionality as summarised in the overview. A waste management system, for example, may support registration of hazardous materials, but leave logistic aspects out of consideration and is not connected to related functionality, like purchasing and production. Furthermore, the combined use of the above mentioned types of information systems is generally not supported, although it may be more effective and more efficient. This especially holds true for registration and communication of data, for instance the registration of waste management and the information exchange with respect to licences. Finally, this can be extended to the integration with other business information systems. Especially materials related registrations are only partly covered, for example in purchasing and sales information systems. The stand-alone applications cause that data should be registered more than once, which may lead to inconsistency but also inefficient work, leading to costs.

3.8 Conclusion

The overall picture of environmental applications is that these are roughly meeting a great part of the important external requirements, which can be recognised in strategic and tactical applications that are used in enterprises. The practical application, however, depends on the underlying operational and instrumental levels. Although research on existing environmental information systems revealed that all levels could be supported by a collection of environmental information systems, the weakness is based on:

- Lack of integration of environmental information systems. In practice, the required 'subsystems' cannot be integrated easily, which leads to ineffective and inefficient procedures and probably inconsistent (environmental) data. The obvious conclusion can be drawn that environmental applications are equally hit by inadequate data supply.

- Lack of integration with other business information systems. This manifests itself in two ways. First, environmental data and other 'business data' may overlap, for example the registration and transportation of waste (logistic and financial data) or the composition and quantity of hazardous waste (safety data). This also leads to inconsistency and inadequate data supply. Secondly, requirements for product responsibility or recycling have repercussions on 'general' business design, rather than on a particular environmental system.

It is concluded that a need exists for an integral environmental information approach from the viewpoint of manufacturers, particularly on operational and instrumental level. This idea has been subscribed by vendors of integrated enterprise information systems, vendors of environmental software, environmental research institutes. Such an integral approach includes environmental applications, enterprise information systems and their combination. This thesis focuses on this topic, in which the main obstacles to efficient, effective and integrated environmental functionality came across. An integral approach requires an environmental modelling method based on the viewpoint of manufacturers. In the next chapter, the existing modelling methods are evaluated against the conditions stated in this study.

4. Environmental Modelling

In chapter 2, an overview is provided of stakeholders and their requirements with respect to the environmental effects of an enterprise. In chapter 3, these requirements are put together with the available environmental applications. It turned out that existing environmental applications and information systems insufficiently fulfil the requirements, especially because an integral approach from the viewpoint of manufacturers is lacking. In this chapter, it is outlined to what extent existing environmental modelling methods contribute to such an approach and fill the gap between practice and requirements.
From various viewpoints, many methods have already been developed to gain insight in environmental impacts. In this chapter, the resulting variety of models have been aggregated to five basic concepts, from which many existing models are derived. First, a typology of modelling aspects is presented, including type and focus of a model, time aspects and spatial scale (section 4.2). In section 4.3, an overview is provided of commonly applied methods. In conclusion, the methods are evaluated for applicability (section 4.4). Finally, part 1 of this thesis is concluded by an environmental information system specification for an enterprise (section 4.5).

4.1 Introduction

A milestone in the description of materials and energy flows was the report of the Club of Rome (Meadows 1972; Forrester 1961, 1971) that extended the method of Industrial Dynamics, developed by Forrester, to global systems. A further stimulus was created by the energy crises of the seventies. Since then, different methods have been developed to describe and analyse materials, energy and product flows. The *materials flow* is interpreted broadly which means that not only chemical elements, but also substances and compound materials, such as wood, are included. This flow is measured in kilograms. The *energy flow* is defined accordingly, however, it is measured in Joules. The *product flow*, finally, is related to a service. A service is here defined as a function that may be provided, e.g., the packaging of a litre milk or the transportation of a product over a particular distance. Product flows are measured in units of product or in functional units and is useful for comparison purposes.

The existing methods are related, though not interchangeable, but are related and show some similarities. In this chapter, an overview is provided of the characteristics and those models. Section 2 describes the following aspects: the type of model; the focus of the model; the time and spatial scale, and the integration of environmental aspects. In section 3 an overview is given of the most common methods of materials and product flow analysis with an emphasis on environmental problems. The described methods have different data needs, aggregation levels, purposes and applications. Therefore, the type and quality of results are highly dependent on both the chosen method and the problem to be solved.

4.2 Modelling Aspects

The real world is, because of its comprehensiveness and complexity, not directly accessible to human mind. Modelling is an appropriate tool to gain insight in certain aspects of reality. According to a particular research objective, a part of the reality is taken apart from its environment, and elaborated with regard to the aspects under consideration. In this way, system boundaries, the level of aggregation and the choice of elements and relationships are defined. This implies that a particular part of the reality can be modelled in completely different ways, dependent on the focus of the model. Once a method for physical flow analysis is applied to a specific problem field, the results will be used and re-used with various objectives. Therefore, the type of model, the data and the assumptions should be made explicit. It is obvious that these results should only be applied within the domain of analysis. This section provides a framework for the classification of the most widely applied types of model from an environmental point of view.

4.2.1 Type of Model

One of the characteristics of a model, which usually remains implicit, is its type. Here, two main types are distinguished: descriptive and optimisation models.

Descriptive models represent the situation on a specific instance in time or over a period of time. These models can generate an inventory of the state of the environment, or determine how much emissions and waste have been discharged. Based on historical data or time series, these models may be used for forecasting purposes, provided that no major changes in the historical trend will take place during the period under study. Major external variables are clearly not predictable although the system under study reacts strongly on them. In such cases, scenarios can be made to simulate various possible trends in these external (policy) variables.

Optimisation models may concern one single or multiple objectives. An example of a single objective is to assess the optimal extraction rate at a given welfare or demand function. A special type of optimisation models are so-called equilibrium models. They are characterised by two or more objective functions, one per actor, of which the solutions should be in equilibrium. In economics, the actors are, for instance, consumers, who optimise the utility, and producers, who optimise their profit. The result reveals itself in the market price, which balances the two objective functions. In environmental models, consumers still optimise the utility, whereas 'society' aims to minimise the waste disposal. Those models may also be used for forecasting purposes.

4.2.2 Aggregation Level

Another typical implicit constraint is the field of application. Complex systems can only be appropriately described by aggregated models with a specific focus. Generally, aggregation proceeds hierarchically. Within the order of decreasing aggregation three levels can be discerned.
Models on *macro level* are applied to studies on population, Gross National Product, employment, national energy and materials use, large-scale environmental degradation and related topics. Those are usually associated with a country or region.
Meso models are used, for example, for investigating interactions between industrial sectors and for describing product life-cycles. This involves the study of the flow of materials and energy between the objects under consideration, e.g., companies or industrial sectors. This enables analysis of the effects of changes in a definite sector with respect to other sectors within the system under consideration.
Micro models are characterised by a still lower level of aggregation. Here a company, plant or production system is the usual system to be analysed. Commonly considered issues are process integration, process or product comparison, evaluation of investments, energy conservation options and enhancement of environmental performance.

4.2.3 Focus and Scope of a Model

The focus of a model also highly determines the result of modelling. Various approaches are distinguished. First, macro-economic and physical models are discerned. *Macro-economic models* are widely applied; results of such models are expressed in monetary units and cover rather large systems, like geographical regions (usually countries) or branches of industry. Standard input-output models are usually based upon this ideas. *Physical*, or technically oriented models basically refer to materials and energy flows, like raw materials, products and waste. In such models, quantities are expressed in physical (SI-) units, like kg and Mjoule.

Object of study

In addition, several modifications of these two basic types are in use, mainly designed for dedicated applications. *Environmentally oriented models* are based on physical models and focus on depletion and discharge of materials and energy. They usually account for (eco)-toxicity and other harmful effects. *Logistically oriented models* are applied to obtain data on product flows, usually expressed in physical quantities of functional units. Although they focus on time, timeliness, unities and locations, they are based on materials flows and can be used to gather information on environmental topics. Finally, *micro-economically oriented models* are applied to obtain data on costs and economic value, expressed either in monetary or in physical units. They are, contrary to macro-economic models, related to specific organisations or production processes.

Subject of study

Besides that, a third classification in the focus of a model can be considered. *Materials oriented* studies focus on specific materials for which the flow is described and for which alternatives and regulations are analysed. *Process oriented* research investigates either alternative options for certain processes or improvements of existing processes. *Product oriented* studies focus on a specific product. The material and energy flows that are related to its life-cycle are described in relation with, e.g., technological innovations. The units occurring in the study are related to a unit of the product that is considered. This may be a unit or item in the case of a discrete product. Finally, a *service oriented* approach focuses on the desired function of the product, e.g. the comparison between packaging materials (a milk bottle of glass versus a carton of milk). This approach takes the service offered by a product as the basic criterion, rather than the product itself that is designed to provide this service. So it is appropriate to account for substitution of different products that all are designed to provide similar services. Substitution is here the basic mechanism that is studied in interaction with, e.g., policies and decisions. Services are expressed in functional units (in the example: packaging of 1 litre of milk) enabling the comparison of alternative products that provide similar services.

4.2.4 Time Aspects

If one takes a decision, in general, this doesn't directly result in a sudden transition of one 'permanent' state into another. Moreover, systems that are studied with models described here are mainly complex, large-scale systems subject to external conditions that continuously change in time. So time is an important aspect in modelling. Nevertheless, often *static models* are frequently applied, where time aspects are neglected or not studied in detail. This can be obtained by considering a single instance or equilibrium state. The aim of *comparative static models* is the comparison of two situations at a particular point or short period in time. *Dynamic models*, on the contrary, are used for studying systems at several moments or time-intervals. In these models time is an explicit variable, which makes that changes in technology and demand, accumulation, time lags can be modelled.

4.2.5 Spatial Scale

The spatial scale of a model is related to the environmental problem studied. Space aspects can be considered on a local, regional, national, international and a global scale. For economic-environmental modelling the issue studied is an important factor in determining the spatial level. Some examples of environmental problems on different spatial scales are given here.

- ❑ Global: global warming, deforestation, trade of toxic waste
- ❑ International: acidification, water pollution
- ❑ National: exhaustion of landfills
- ❑ Regional: pollution of ground water
- ❑ Local: soil pollution, noise, urban air pollution

The above mentioned examples depend on the size of a country. For instance, the pollution of the river Rhine is international because Switzerland, France, Germany and the Netherlands are involved, but for a similar river in the United

States it would be an interstate, though still national problem. Therefore, not only the type of problem but also the borders of the countries are relevant. Another example is deforestation which is happening in some countries, but it is important for the whole world and therefore a model and a solution should be looked for on a global level.

4.2.6 Integration of Environmental Issues

Environmental aspects can be included in a model according to the disturbance oriented and the impact oriented approach respectively. Three types of *environmental disturbance* are distinguished:

- ❑ Extraction of non-renewable or fund resources, e.g. fossil fuels, ores and minerals.
- ❑ Discharge of residual materials and energy, e.g. by emission and disposal.
- ❑ Occupation of renewable or flow resources, e.g. area, wind, sun, hydropower.

The above mentioned issues are relatively easily quantifiable. Depletion and discharge are interconnected by laws of mass and energy conservation and are appropriately described using a materials and product flow approach. This is, however, not straightforwardly applicable to occupation. Disturbances of the eco-system result in three types of *impact*, two of them are related to human well-being, the third being of a universal character:

- ❑ Depletion of non-renewable resources, in general leading to a gradually increasing effort required to make the resource available, to a lower grade of the resource, or to both negative effects.
- ❑ Nuisances, by odours, noise, dust, ugliness etc. Although reversible, only locally noticeable and mainly governed by subjective criteria, it nevertheless may considerably degrade human well-being.
- ❑ Impoverishment of bio-diversity by degradation of the biosphere, i.e. organisms, soil, water, and atmosphere.

Depletion and impoverishment in particular counteract a sustainable development. So if materials and product flow models are used in assessing alternatives on sustainability, the environmental impact connected to these flows should be taken into account. This is explicitly included in, e.g., life-cycle assessment.

With respect to physical flow modelling, different levels of completeness are applied: In dedicated models, only a selected number of problematic flows is considered, e.g., NO_x-emission. This selection is based on the grade of detriment of the respective flows or on ad-hoc base, according to the scope of the respective study. Complete models cover the full materials and energy flows within the system that is studied, including products and relatively harmless wastes and emissions. Such an approach offers the advantage of applying the conservation laws. By going into more detail of the particular flows, relevant to a dedicated requirement, flexibility is attained.

4.3 Overview of Commonly Applied Methods

Within the literature (e.g. Ayres, 1989; Leontief, 1966; Guinée, 1995, Opschoor, 1994) many methods on physical flow modelling have been proposed and many names are assigned to them. Similarities and overlap between the different methods are evident, also specific differences can be discerned. Within this section, four basic methods are described. Although there can still other methods be found in literature, these are closely related to and can be covered by one of these basic methods.

- The basic characteristic of *Material Flow Analysis* is the study of anthropogenic physical flows in both the techno-system as the autonomous biosystem and studies the Industrial Ecology. It is actually an inclusion of the techno-systems within the models of natural cycles (water cycle, CO_2-cycle, energy cycle, etc.) as applied in ecology, climatology, geology, environmental chemistry and related sciences.
- *Physically oriented input-output analysis* is confined to the techno-system. It is characterised, while it is derived from a highly aggregated economic description, by a typically top-down approach. Therefore it does not include knowledge on processes but is limited to a descriptive orientation without going into technical details. Industrial branches are considered as black boxes characterised by their inputs from, and outputs to other branches.
- *Life-cycle assessment* is also confined to the techno-system, but goes into more technical detail, often up to the level of unit operations. It is principally physically based. Application of the method is well-documented and standardised. Translation of physical flows into environmental impact proceeds in a well defined way.

- *Material-product chain analysis* is closely related to LCA and may be considered as an extension of this method and can be used in combination with it. MPC-analysis deals with a more detailed structure of the product life cycle chain, and is applied for analysing and optimising strategic choices as well as operational control of the production process.

4.3.1 Material Flow Analysis

A materials flow analysis or substance flow analysis (MFA or SFA) describes the flows of a specific material in a specific geographic area in a certain time period, for example the flow of zinc in the Netherlands in 1990, see figure 4-1.

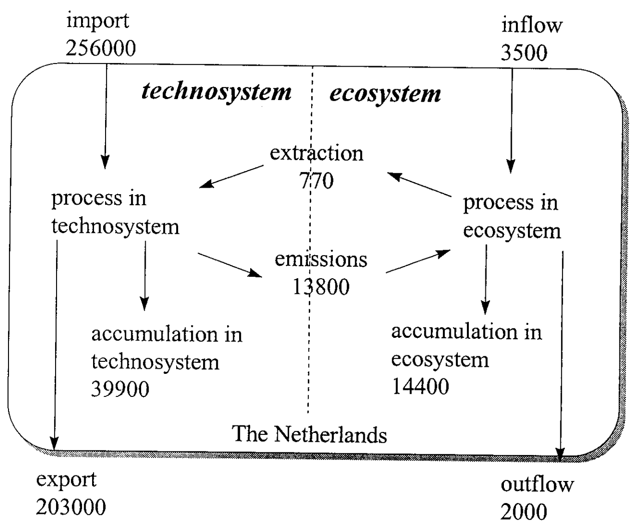

FIGURE 4-1 MFA study on the flow of zinc in the Netherlands in 1990 (in tonne) taken from: Annema *et al.*, 1995)

This description clarifies stages in which can be intervened to reduce the amount of materials extracted or disposed. This method considers the flow of one or more materials, but not the interactions between them, which excludes the analysis of substitution possibilities. Substitution in this case takes place on material level, e.g. two materials realise the same function. In general, it may also be applied on product level, where the same function may be more abstract. For example, for nutricial purposes, vegetables may replace meat, see e.g. Stigliani and Anderberg, 1992.

An MFA uses the materials balance (MB) principle which states that the input of materials equals the output minus the accumulation. The total flow through the economy of one material, thus including all products which contain or use that material, is described and analysed to trace (missing) flows of materials and to identify environmental problems which can be reduced with environmental policy. Accumulation may cause such a problem.

The concept of *industrial metabolism*, which can be made operational by MFA, also uses the MB principle to determine the flows of materials and energy in certain countries or regions. Industrial metabolism is defined as the set of physical-chemical transformations that convert raw materials (biomass, fuels, minerals, metals) into manufactured products and wastes (Ayres *et al*, 1994). It involves the materials and energy flows for production and consumption, i.e. the economic system.
Studies on industrial metabolism result in physical materials and energy flows for certain areas (Ayres, 1989). The materials balance principle is an important tool in justifying such physical flow schemes.
Besides static MFA studies which describe accumulated materials flow over a definite period, dynamic studies are frequently carried out. Those studies investigate (historic) materials flows over a specific period in time, and possibly include scenarios for future flows. MFA studies mostly refer to national or regional level, because those are the most relevant ones for (environmental) policy making. However, more detailed MFA is also conceivable, for example, on a company level. MFA studies seldom incorporate specific environmental indicators but provide a basis for those indicators. Based on the MFA studies, static or dynamic models can be made which optimise or simulate (future) flows of materials. Numerous examples exist of recent studies on the flows of one or more materials in a specific geographical area in a certain time period[1].

MFA studies usually give a description of flows of materials, which makes it difficult to analyse societal, economic or behavioural mechanisms caused by those flows. Moreover, the effects of changes on the materials flows and the economy is excluded in this approach. Another limitation of MFA studies is that substitution cannot be considered because the materials flows are described separately. Both the behavioural mechanism and substitution are important

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[1] The flow of *heavy metals*: Van der Voet *et al.*, 1994, Gilbert and Feenstra, 1994, Gorter, 1994, and Ayres, 1994, Anderberg *et al.*, 1989, Bergbäck *et al.*, 1992. *Chemicals*, nitrogen and sulphur: Ayres and Norberg-Bohm, 1992ab, Husar, 1994, chromium and lead: Lohm et al., 1994. *Regional materials balance:* The total flow of materials through a Swiss region (Brunner *et al.*, 1994), Carbon monoxide and methane in the United States (Ayres *et al.*, 1994). *Dynamic materials balance* for fly ash (Olsthoorn *et al.*, 1991).

issues for policy making, but with MFA they cannot be analysed. Thus, although an MFA study provides a good overview of the materials flow, it cannot be used for analysing policies.

4.3.2 Input-Output Analysis

Input-output analysis (IOA) was introduced by Leontief and has been since then widely applied and further developed and modified (see Leontief, 1966 and 1970). IOA is basically a quantitative macro-economic tool that is based on National Accounts. It describes, originally in *monetary units*, the mutual exchange of goods and services between the different sectors of industry and towards the final users. Analogous to monetary IOA, physical models are elaborated that are based on the same philosophy. The method uses the balancing principle, i.e. the inputs equal the outputs, either being expressed in monetary or in *physical units*. An example is shown in figure 4-2.

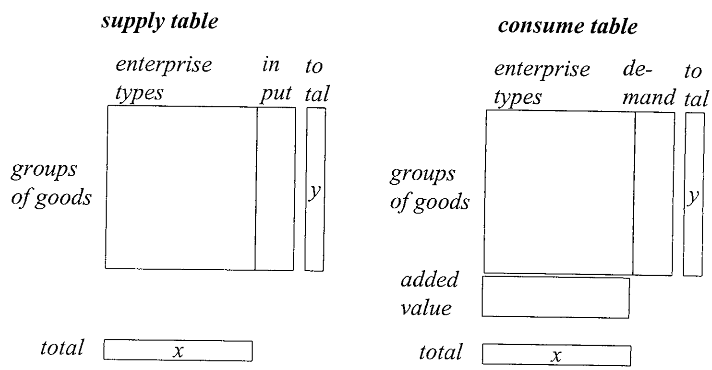

FIGURE 4-2 Schematic reproduction of supply and consume tables (in monetary units, taken from (Konijn, 1995))

The resulting input-output tables are preferably put in a homogeneous notation, with the industrial sectors and the corresponding groups of goods as the row and column elements respectively, thus providing square matrices. These enable calculation of, e.g., the reaction of a national industrial system on the autonomous increase of the demand for a definite product.
A number of differences between IOA at the one hand and MFA (section 4.3.1) and LCA (section 4.3.3) at the other hand should be stressed. First, IOA describes complete industrial-economic systems contrary to MFA and LCA that are dedicated to flows of specific materials and flows connected to

specific products respectively. Furthermore, IOA defines statistically based relationships between sectors without going into detail on process properties. Finally, the description by input-output matrices enables analysis of systems with complex mutual relationships, including recycles.

IOA is originally descriptive; dynamic analysis can be performed provided that a distinction is made between production of consumer goods and capital goods. These studies can be attuned using time series of IOA-tables from the past, and can be used as a basis for scenario analysis or simulation models.

Physical IOA can be extended by inclusion of the resulting waste, emissions, and use of resources thus providing a (coarse) tool for calculating the impact of changes in the production system on environmental impact. Since 1970 many papers appeared on this topic[2], most of them being related to energy use and the resulting emissions to the atmosphere, like CO_2 . Here, however, the original scope of IOA has been left and elements of MFA have been introduced within the methodology. IOA modelling is restricted by its lack on detail from a process point of view. With respect to dynamic analysis, no stocks are allowed in IOA-models, imposing a serious limitation on, e.g., its application to energy studies.

4.3.3 Life-Cycle Assessment

Although several definitions have been proposed, the ISO-14000 one has been set as a world-wide standard. 'Life-cycle assessment (LCA) is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle' (ISO, 1995). It should be stressed here that LCA is intended for comparative use, so results of LCA studies have a comparative significance rather then providing absolute values on environmental impact related to a definite product.

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[2] Early applications of IO analysis to environmental policy were due to Ayres (1969), Kneese *et al.* (1970), Victor (1972), James *et al.* (1978). More recent static applications are: Huang (1993) on solid waste, Konijn (1995) on primary materials and energy carieres, Weber (1995) on energy requirements in Germany. Dynamic applications are from Han and Lakshmanan (1994) on structural changes and energy consumption in Japan, Midmore (1993) on impact of definite policies using time series analysis, Henry (1994) on supporting growth policy, Heijungs (1997) on classification of environmental improvement options in combination with LCA. de Haan and Keuning (1994).

Essential to LCA is the 'cradle to grave' approach, referring to study of the materials flows related to production and consumption of a product from extraction up to final discharge. Effects of significant accompanying flows, arising from energy carriers, other utilities, capital goods, and by-products are all included, essentially leading to a branched process-product chain. The LCA-results usually interfere with human behaviour, in particular with respect to the consumption process. Therefore, integration of social and economical aspects within the analysis is frequently advocated. Although various aspects (economic, social, safety) of a product during its entire life-cycle might be studied, the concept of LCA is usually confined to quantitative and environmental LCA based on physical flows. Life-cycle assessment is carried out in five phases, see (ISO, 1995), (Guinée, 1995; Berg *et al*, 1995):

1. Goal definition,
2. Inventory of environmental inputs and outputs (like CO_2-emission),
3. Conversion of inputs and outputs to environmental impacts (like ozone depletion),
4. Evaluation i.e. comparison of environmental impacts to some standard (optionally),
5. Improvement analysis.

Because of the branched character of the process-product chain, particularly if recycling is applied, a proper choice of system boundaries is crucial (Tillman *et al*, 1994). Within the model, a core and a periphery can be discerned: the core encompasses the part of a chain to be studied into more detail, e.g. because processes or products to be compared are crucial here; the periphery consists of auxiliary processes (e.g. electricity generation) and is rather coarsely described. Crucial data on the periphery are usually taken from a database, compiled of results from restricted (product or process) LCA studies[3], not enclosing the full life-cycle. An example of an LCA is shown in figure 4-3. In the represented model, production of ancillaries, capital goods and energy, as well as consequences of re-use and recycling are not yet included. Each of those production phases should be modelled as actual production system under study. This shows the importance of good definition of system boundaries.

[3] Partial analysis has been applied to building materials, energy carriers (BEW, 1994), plastics, and petrochemicals, non-discrete products like paints and varnishes, margarine, hair sprays, detergents etc (Guinée, 1995), discrete products like packaging materials, face plates, computer cases, automotive parts and so on (Snowdon, 1994; Brinkley, 1994; Eyerer, 1993), complex assemblies, like automotive vehicles (Schuckert, 1993).

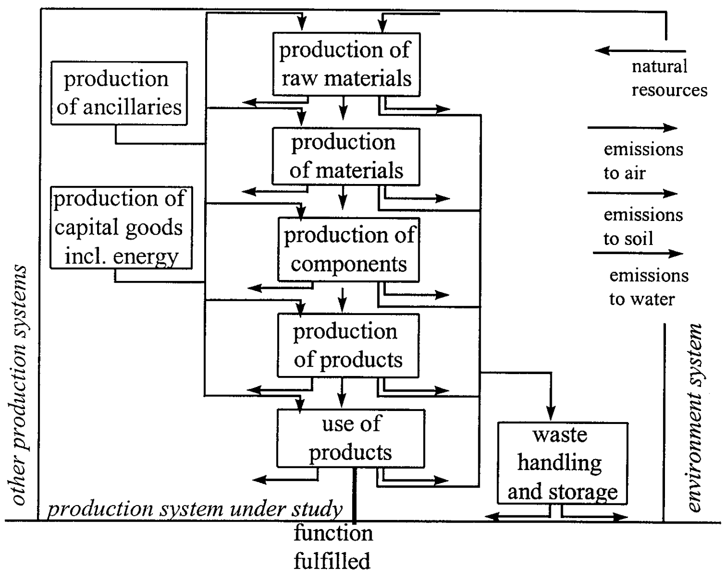


FIGURE 4-3 Example Life Cycle Analysis model (taken from Guinée *et al*, 1993)

The inventory part is directly related to physical flows. Conversion, valuation and improvement analysis are interpretations of these flows. LCA-studies generally do not cover complete material balances, only the environmentally most harmful flows are considered. Complete inventory (mass and energy balances), however, is recommendable and usually may lead to valuable raw materials and energy savings options. Although LCA is a potentially useful tool to perform this task, complete inventory is often not practised. LCA is essentially used to deal with static problems.

Software tools are available to support LCA. A database, containing relevant data on processes and materials, is a crucial component of such a tool. There are major restrictions on the stored data with respect to integrity, generality, actuality, level of aggregation and transparency of the way they have been acquired. LCA software supports administration of required data, supports a proper presentation of the results, and facilitates sensitivity analysis. Uncertainties and data errors tend to exert a large influence on the final results, even in a comparative sense. Environmental impact is characterised by multiple criteria. Features that lead to comparable impacts are aggregated, using equivalence factors.

LCA results can be further aggregated, finally resulting in one or more environmental performance indicators. Performance indicators, usually applied in financial and human resource management, are strongly aggregated characteristics that reflect the performance of a complex system. Environmental performance indicators (EPIs) have been introduced recently by (Rolf, 1994; Hauslein and Möller, 1995). Ultimately, only a single characteristic is derived, like the Material Intensity Per Service unit[4] (MIPS), which has been described by (Schmidt-Bleek, 1993). Like LCA, EPIs are only suitable to comparative objectives, and do not provide any reliable absolute figure. EPIs strongly depend on a large variety of applied weight factors, which makes it essential that figures are well documented when applied in reports. Such an explanation contributes some guarantee that exchanged information is relevant and appropriate to compare data. EPIs, and MIPS, are not appropriate for scientific or technical purposes, but may be useful in communication directed to employees and other stakeholders of companies, where recognisability and comparability are principal requirements.

4.3.4 Material-Product Chain Analysis

Materials and products are strongly interrelated on a physical base. However, the driving force for the consumption of products is the need for services (Kandelaars and van den Berg, 1997). Therefore, to study materials, products and services should be studied within their mutual relationship. The materials-product (M-P) chain is a possible approach to this issue. An M-P chain is defined as a subset of linked materials and product flows that are required for a certain service (Opschoor, 1994). This concept refers to a system or network which includes extraction, production and waste treatment as well as recycling, re-use and substitution of materials and products.

Study of M-P chains reveals important opportunities for reduction of the environmental burden that is caused by the demand for a particular service. First, *social-economic* aspects, such as prices and costs of materials and products, and the behaviour of consumers and producers, are considered, because these influence the use of materials and product largely. Such aspects are not

[4] Material Intensity Per Service unit (MIPS) refers to one single figure, representing the total materials intensity of a unit of service, expressed in mass units (kg), abstracting from the environmental characteristics of the different materials that are involved. This method is primarily designed for providing clearly understandable information as applied, e.g., in benchmarking.

included in LCA and MFA studies, and only on an aggregated level in IOA studies. Second, *recycling* of materials and *re-use* of products is taken into account. In LCA recycling and re-use may be included. For MFA only recycling of material is incorporated. Third, M-P chain analysis considers the possibility of substitution between different materials, between materials and other inputs, and between products. Both MFA and IOA studies, on the contrary, do not include substitution and for LCA *substitution* is mainly focused on the comparison between two products. Fourth, *changes over time,* such as technological developments and changes in demand are considered. Most other studies ignore time aspects, although in some MFA and LCA studies they are included (for MFA see Gilbert and Feenstra, 1994; and for LCA see Moll, 1993). Dynamic elements can have a great impact in the use of materials and products and their prices.

In M-P chain analysis, not all connections between materials and products are taken into account, only the most relevant ones. This provides the opportunity to analyse also *truncated M-P chains.* An example of such a chain is given for milk packaging. It clarifies the various flows of materials and products for a particular service, see figure 4-4. The milk can either be packed in new or re-used glass bottles or in carton. For the new glass bottles new or recycled glass is needed; for the cartons, carton and plastic is required (not depicted in this figure). The new and the re-used glass bottles are perfectly substitutable. The demand will be met by glass bottles and cartons. After the bottles and packs are discarded the carton and plastic waste is dumped, while the glass bottles are either re-used, recycled or dumped.

Depending on the goal of the M-P chain analysis, a certain model is chosen. In principle, both descriptive and optimisation models can be used (see section 4.2.1). M-P chain analysis deals not explicitly with a region or a country, but the demand for a service needs to be applied to a certain geographical area. The environmental aspects, which are listed in section 4.2.6, can be dealt with either separately or simultaneously. For example, to reduce the depletion of a material and the disposal of waste materials, an M-P chain analysis that studies the influence of a tax on new materials or on waste disposal can reveal the effects of that policy on both problems.

Static, comparative static or dynamic models can be used for M-P chain analysis. Additionally, the choice of the time horizon in dynamic models depends on the goal of the analysis. Services and their related products are the central issues of M-P chains. As a matter of fact, the level of aggregation of this method is confined to the lowest, the micro level. For product groups meso level studies may be done.

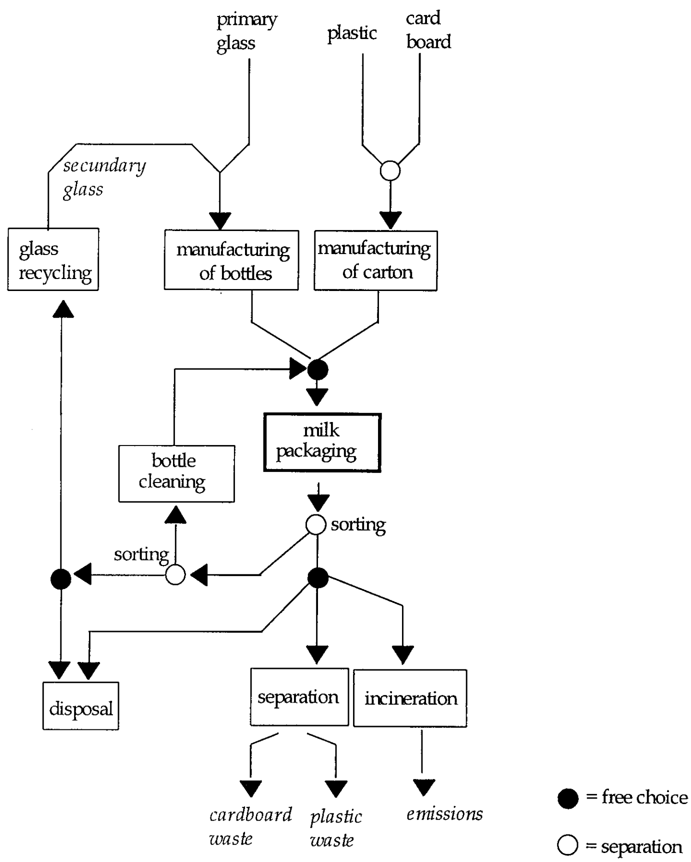


FIGURE 4-4 Truncated M-P chain for milk packaging

The application of M-P chains faces a number of limitations. Arbitrary choices have to be made on the truncation of the related materials and product flows, the uncertainty of prices. As well as the reaction of policies on consumers' and producers' behaviour. Furthermore, also the well-known difficulties in LCA and MFA with respect to data availability and unpredictable future flows appear.

4.4 Evaluation of Existing Methods

From the overview of the most commonly applied physical flow modelling methods, in combination with a typology of their relevant characteristics, the following main conclusions can be drawn:

- In present applications there is an emphasis on descriptive and static representation of systems. Only in a few case studies, chain approaches as applied in LCA and MPC analyses, have been modified to adaptive models that deal with changing external parameters by optimising their internal degrees of freedom.
- In most of the studies described in literature, the level of aggregation is relatively high. In particular, extensive quantitative studies on enterprise level are virtually failing. This is mainly due to difficulties on data acquisition, lack of knowledge of exact systems structure, and threat of a surplus of complexity.
- Physical flow models are useful in analyses that are characterised by a broad spectrum of time and spatial scales, level of aggregation and orientation. As has been pointed out, however, for different purposes, different modelling techniques might be optimal. For sake of compatibility, it is highly recommended to care for appropriate agreement between inputs and outputs of the different models.

Many data are required to meet information requirements of the above described methods. Usually this information is not completely, or not at all, available, which causes discrepancies in the integrity and accuracy of information and which makes conclusions rather weak. Further research in this field is required. It should ultimately result in collections of linkable models, e.g. at the level of sub-processes, aggregated processes or even entire business processes in an enterprise. The models can be used as building blocks for the construction of complex, but still detailed, and flexible and thus more realistic models of physical flow systems within a techno-system. Such models could play a useful role on both operational and strategic level, in control and policy, on micro, meso and macro level.

For the purpose of this research, to develop an environmental information system tailored for enterprises, especially environmental modelling methods on micro -enterprise- level are required. For this reason, such a modelling method is first described, before switching the system design.

4.5 System Specification

The conclusion drawn in chapter 3 was that, although environmental applications sufficiently meet the demands, problems arise by collecting adequate environmental data. At first sight, this data could be supplied by environmental information systems. However, three deficiencies came to light:

(1) lack of integration between environmental information systems and environmental applications;
(2) lack of integration of the necessary environmental information systems;
(3) lack of integration of environmental information systems with other business information systems.

A survey on existing environmental modelling methods led to a similar picture, which revealed that existing methods equally lack adequate environmental data specialised for enterprises.

In part 2 of this thesis, an approach is developed that contributes to settle the above mentioned deficiencies. Special attention is paid to aggregation issues: starting at a rather low and thus detailed level of aggregation, it is possible to guarantee a higher level of data integrity. As already argued in chapter 1, the research focuses on production-oriented environmental data, such as waste, emissions, energy and packaging material. Consequently, the modelling method is highly dependent on product and process data aggregation. The application of building blocks, finally, contributes to better environmental modelling and decision making.

The environmental modelling method and building blocks may contribute to existing environmental applications:

- ❑ Life-cycle assessment, design for disassembly, design for the environment and product labelling;
- ❑ Environmental management systems and combined management systems based on TQM;
- ❑ Product responsibility, tracking and tracing and reverse logistics;
- ❑ Environmental reporting, including communication for goal-oriented regulations.

Finally, extensive use will be made of already existing environmental and other business information systems. Existing product and process data in business information systems is used and extended. Existing functionality is re-used and some new functionality is added. Finally, such an extended information system can be used as support for existing environmental applications and information systems. This approach is depicted in figure 4-5.

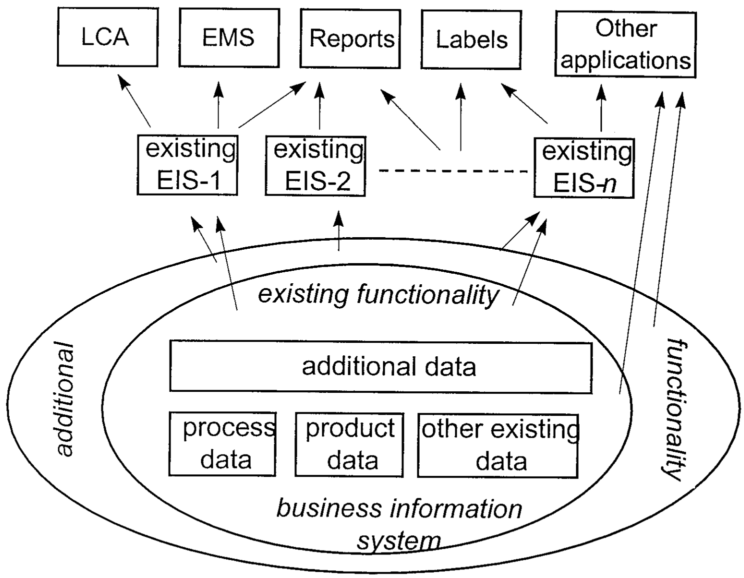


FIGURE **4-5** System Specification

This approach is starting point for the environmental modelling method that is designed in the following chapter.

5. Enterprise Modelling and the Environment

In part 1, it has been concluded that existing environmental applications should roughly meet many aspects of internal and external demands of an enterprise. However, it turned out that these lack adequate and consistent environmental information because there is no integral environmental modelling method. In this chapter, the focus is on such a modelling method. In the remainder of this thesis, this modelling method is point of departure for the development of an environmental information system, as part of an integral approach with respect to environmental applications, environmental information systems and other business information systems.

First, the point of departure for the support of environmental applications is summarised in section 5.1. In section 5.2, the modelling method, the multiple-input multiple-output process (MIMOP) approach, is described. Next, two case studies are elaborated and evaluated for possible support by information systems: case 1 in the automotive industry (section 5.3) and case 2 in the packaging industry (section 5.4). Finally, conclusions are drawn for the development of an integrated environmental information system.

5.1 Introduction

In part 1, an overview of environmental requirements for enterprises is presented, which resulted in the conclusion that various stakeholders ask for basically the same data, though on a different level of detail. Furthermore, it has been concluded that existing environmental applications are not suitable to collect correct and consistent environmental data. Finally, it turned out that existing environmental modelling methods aren't specialised for individual enterprises, but for macro-economic or for product oriented cases. Besides this, environmental applications and modelling methods both lack environmental data on which clear and unambiguous conclusions could be drawn.

The conclusion was, that an environmental information system is required, which is especially meant for individual enterprises. This system should be made integrated in business information systems and flexible with respect to different enterprise activities. Consequently, it should be able to supply environmental information of the enterprise, based on the effects of its production processes or produced products. The resulting environmental information can be used for already existing and forthcoming environmental applications and modelling methods. The following sources of environmental effects have been distinguished.

Production processes The environmental effect of a production process includes the produced quantity of waste and emissions per period of time. This quantity is either preliminary calculated or estimated, or it is actually measured. It may concern all materials which are of interest to any stakeholder. The process subject to analysis may range from a single production step to the entire business process.

Products The environmental effect of a product is more complex to determine. It covers the quantity of waste and emissions caused by all production processes necessary to produce this product. Contrary to the effect of a process, the environmental effects need to be allocated on all output products involved. Especially, if one production step results in multiple outputs, allocation might be difficult. Allocation issues are further elaborated in chapter 8. Finally, environmental effects are restricted to the enterprise itself and hence exclude production steps before purchasing and after sales. The determined quantities are either preliminary calculated or estimated, or it are actually measured. It may concern all materials which are of interest to any stakeholder.

The next step is to model environmental effects of production by modelling production processes and produced products. In the next section, such a modelling approach is described.

5.2 Description of the Model

An environmental modelling method for an individual enterprise asks for the modelling of production processes and aggregations of those processes. For each process, it should include the inputs and outputs, of which a number may be considered as waste or emission. Such a method is the multiple-input, multiple-output process (MIMOP) approach, which is derived from Input Output Analysis (IOA). However, where IOA analyses relationships between sectors of industry without going into detail on the physical properties of the production process, a MIMOP approach is carried out on micro level and is based on process characteristics. It is also based on the Materials Balance principle that is used by Materials Flow Analysis (see section 4.3.1), but it may concern an arbitrary number of materials and is not related to a particular geographical area. The multiple-input multiple-output process approach distinguishes (see figure 5-1):

- supply of materials, production means and energy at the input side of a process;
- a black box in which a transformation is performed; and
- resulting product, usually accompanied by several co- and by-products, the used production means and energy.

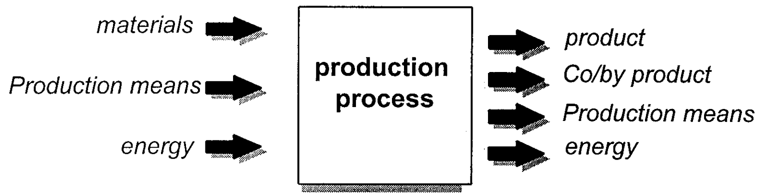


FIGURE 5-1 Black-box approach of a production process

Although a black-box approach is a good starting point for modelling environmental effects, a number of refinements should be added, namely the introduction of aggregation levels for production processes and materials, and the role of time aspects in environmental modelling.

5.2.1 Aggregation of Processes

Inputs and outputs of a particular production process can be modelled on all levels in the enterprise. At the highest level of aggregation, an enterprise is supposed to be a single business process. The enterprise is considered as a black-box; the purchased materials, production means and energy are the inputs and produced products, including waste and emissions, the used production means and energy are the outputs.

For several reasons, this may be an inadequate approach, for example if the system boundaries are insufficiently determined, e.g. if a number of (parts of) production sites are involved. In addition, economic and technical constraints impose restrictions on the aggregation level that can be obtained for the assessment of the produced quantity of 'waste' and 'emission'. Calculations, for example based on mass equations and other methods, should be added. However, calculations on a high level may be inaccurate, for instance, if an enterprise comprises a variety of production processes or products, which

may mutually influence each other. In that case, calculations on a lower level of aggregation are either inaccurate as well, or not available at all.
Consequently, it may be helpful to open the black-box and model separate process steps, or tasks, that are performed to produce a particular product. Opening the black-box reveals the existence of 'intermediate' products, see figure 5-2, in which the arrows represent mass flows and the boxes indivisible tasks.

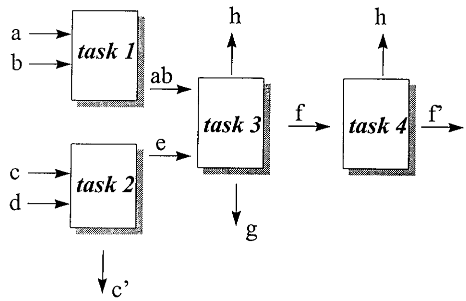


FIGURE **5-2** Modelling of process steps

An example of intermediate products are stocks, either for actual intermediates or for non-removed finished products. Stocks may occur on each level, except for the lowest aggregation level.

The other way around, if the environmental effect of products 'ab', 'e' or 'f' is considered to be unimportant (and reporting is not required), it is not necessary to fully register on this level of aggregation, and tasks 1 - 4 can be combined again. In this case, the intermediate steps are used to increase the process knowledge to formulate relationships between different flows based on physics and chemistry of the respective processes. The result for the example process in figure 5-2 is shown in figure 5-3.

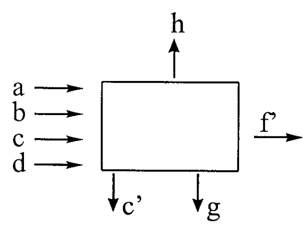


FIGURE **5-3** Process aggregation

In practice, an adequate modelling level can be chosen, dependent on the complexity of calculation or measuring and the consequences of incorrect data.

5.2.2 Aggregation of Materials

Modelling environmental effects of a production process aims to meet demands for environmental information. This is defined as a set of relevant environmental data, which enables a receiver to take environmentally-related decisions. Too highly aggregated or too detailed data, however, may turn out to be an unsound basis for decision making. In other words, environmental information requires an adequate level of detail of environmental data. In practice, several forms of aggregations are applied yet, for example in line with the classifications that are summarised in appendix C.
A recent example of the application of aggregation levels can be found in the Dutch agro-industry: the obligation to draw up mineral balances for phosphorus and nitrogen compounds. Reporting on the use of those minerals requires 'mineral-information' of all inputs and outputs. For horticulture, this may be modelled as shown in figure 5-4.

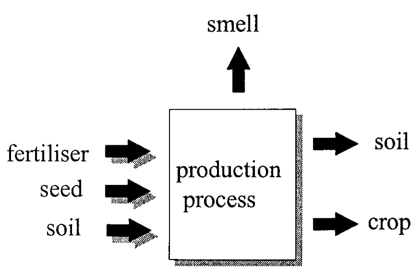


FIGURE **5-4** Black-box modelling of crop production

The first modelling step is to exclude inputs and outputs which are irrelevant for minerals bookkeeping. The second modelling step concerns the level of detail of registration for those minerals: increasing the level of detail could result in a distinction of nitrogen, phosphorus and 'other constituents' (see figure 5-5).Descending to a lower level of aggregation may also be appropriate, e.g. a further subdivision of nitrogen-containing constituents in organic (proteins, amino acids) and anorganic (NH_3^+, NO_3^-) ones. The additional effort in measuring, calculation and registration, however, can only be accepted if explicitly requested.

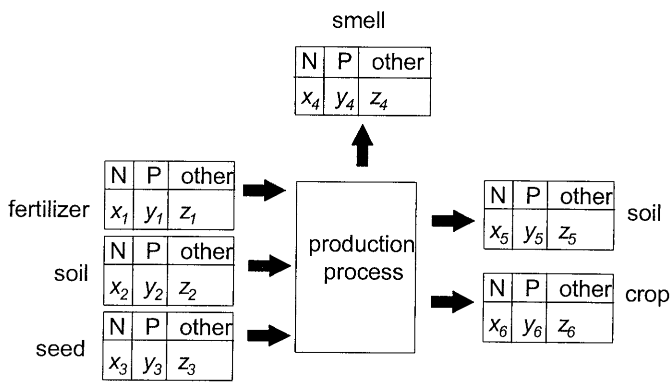


FIGURE 5-5 Mineral quantities in crop production

5.2.3 Aggregation over Time

The environmental effect of a production process can hardly be considered without taking time aspects into account. Whereas a production step at a rather low level of aggregation might be performed especially for one particular product, this is nearly impossible at the aggregation level of an enterprise. Therefore, the environmental effect of a production process is calculated over a period of time. In general, a production process will produce various types of products over a particular period of time, and for each of them, the actual resources (production means and raw materials) might differ, in a different period of time. An example production program is depicted in figure 5-6.

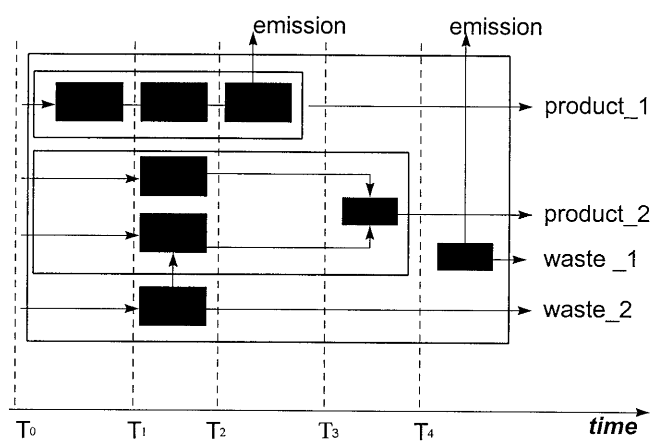


FIGURE 5-6 Aggregation over time

The choice of the length of time period may be essential, comparable with the choice of the boundaries of a production process. A typical example is the inclusion or otherwise of processes such as cleaning and maintenance, which are independent of a particular production program but are, for instance, carried out periodically. If the period of time is too short (in figure 5-6 T_0-T_3), this is comparable with the exclusion of process steps. By doing so, the overall picture might be improperly influenced. This effect, however, is undone in the long term.

5.2.4 Integration in the Enterprise

In the MIMOP approach, material flows are considered on enterprise level, thus omitting most of the chain aspects. However, this approach enables one to regard material flow in relation to general logistic principles, see figure 5-7. The inputs are raw materials, semi-finished products, discarded products and used production means meant for re-use. At the output side, a distinction is made in:

- *main* products, the original objective of the production,
- *co*-products which have a higher economic value than the input materials,
- *by*-products with a small but positive economic value and
- residual products: *waste* and *emissions* with a negative economic value.

The production of what is called here main products is a general principle of the discrete manufacturing; the concept of co- and by-products originates from the process industry. The focus of the analysis in this chapter is on a specific (group of) process(es) in a factory instead of the complete supply chain and on actual materials values instead of general or standard values, which are externally provided, e.g. by authorities. In this way, the analysis can become a basis to supply data for all kinds of environmental information systems.
MIMOP, although applied to environmental problems, is basically derived from a logistic model. This implies that the information system can be based upon already existing information systems, such as logistic systems or quality management systems. This is a major advantage. Furthermore, by means of well-known process modelling techniques, like petri-nets. it is possible to define hierarchical models, in which each transition can be a complete model itself. Finally, an overview of the MIMOP approach is depicted in figure 5-7.

Once the investment in the extension of existing information systems has been made, all kinds of environmental and logistic information can be retrieved from this basic registration. With respect to a company, this information can be applied to improve production processes in a flexible way. In the product chain, it can be used to produce correct, actual and timely data as an input for higher-level methods like LCA and MP-chains. It can also serve as a basis for the ever changing requirements of legislation, which mainly results in more and more detailed requirements for environmental annual reports.

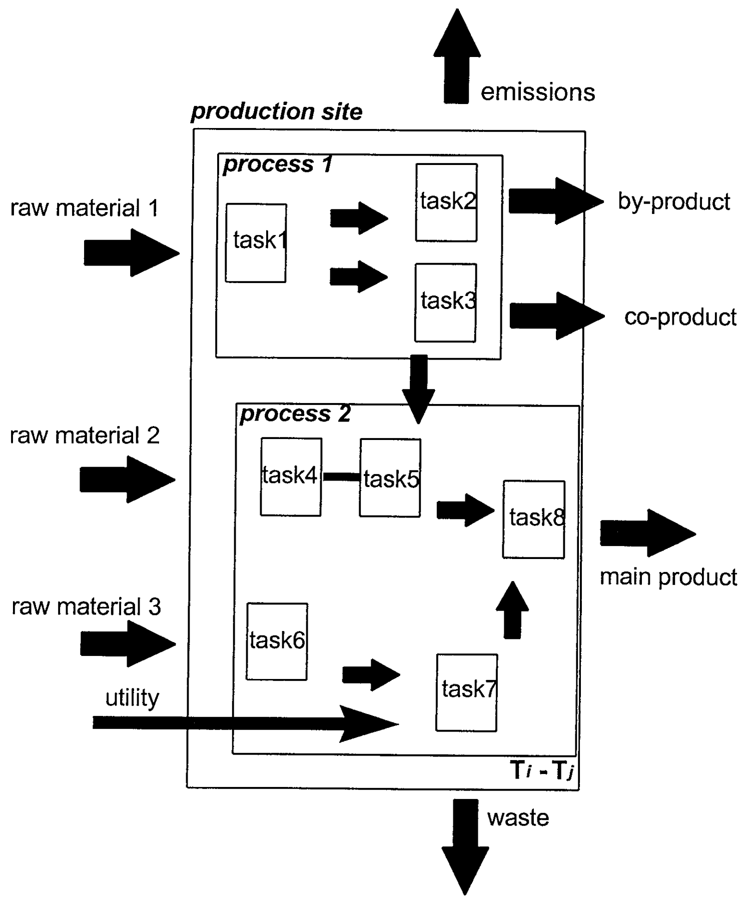


FIGURE 5-7: Multiple-input multiple-output process (MIMOP) approach

5.2.5 Conclusion

The MIMOP approach is a generally applicable environmental modelling method, which is specialised for an individual enterprise. It may be a rather detailed approach, with the inherent disadvantages of the large quantity of data to be acquired and analysed, and the limited scope with respect to the entire supply chain. However, this implies an adequate level of data aggregation at a later stage, adjusted to requirements from buyers, suppliers, legislation, government, and a satisfactory level of process aggregation to the level of a complete company. The main benefit of this modelling method is that companies can store and retrieve what is called here environmental data, particularly waste and emissions, rather easily in close co-operation with already existing business information systems. The business information system, amongst other parts the logistic and financial information system, usually has high priority and makes the implementation of environmental information systems attainable. Finally, if additionally other approaches are used, such as life cycle assessment and MP-chains, this modelling method may provide the means to guarantee the timeliness, correctness and integrity of the input of environmental data.

5.3 Case: Automotive Industry

This case study has been carried out by M.A. Langeveld (Langeveld, 1995) and M. Philipsen (Philipsen, 1996). Part of this section has already been published as a journal paper, see (Jansen *et al*, 1997). It should be noted that this work has been carried out in the same period as in which the MIMOP approach has been developed. The case study aimed at environmental reporting per period of time; gradually, it became clear that registration per operation (process approach), and hence connection with logistic information systems, is recommended.

5.3.1 Production Processes

The car manufacturer 'CARE' produces transportation means for the professional market. In the framework of the preparations for implementation of an environmental management system, the environmental co-ordinator of CARE is interested in registration methods for the environmental effects of production processes. Point of departure is a bottom-up approach, in which one production process is described according to the MIMOP approach. The selected production process applies finishing coat to different types of engines. This so-called Engine Spray Cabin is supposed to be representative for the most environmentally critical production systems of CARE. Precondition of the development of the registration method was a generic design, based on generally applicable concepts, to make the design method applicable for other production systems.

The system should periodically determine actual quantities of entering and leaving mass and energy flows, and estimate this quantities in future time periods, possibly under changed conditions of the production system. Furthermore, basic figures of environmental effects of production should be gathered to serve as a reference for future improvement.

The engines in the Engine Spray Cabin are subject to three main processes: cleaning (P_1), spraying (P_5) and drying (P_7), and two supporting processes: blending (P_2-P_4) and cleaning (P_6), as depicted in figure 5-8. It should be noted that the engine only passes through process steps P_1, P_5 and P_7. The other process steps concern utilities and waste products.

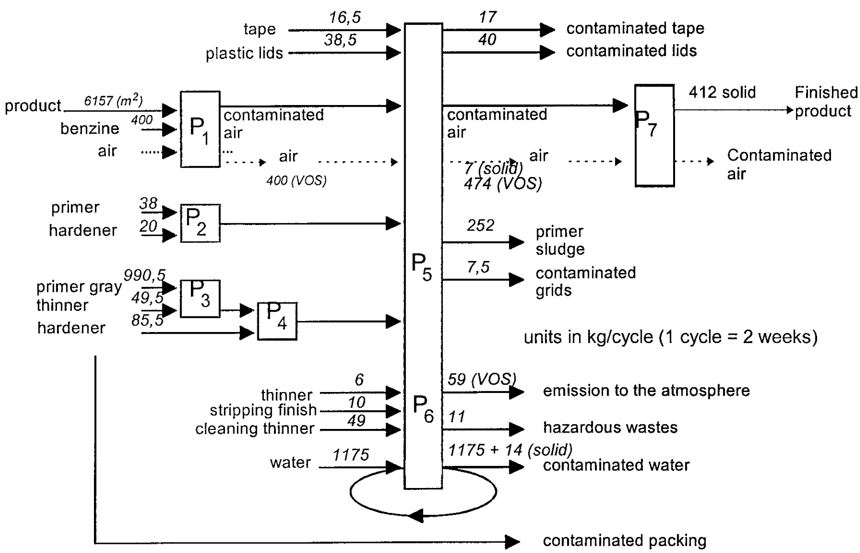


FIGURE 5-8 Materials flow related to an engine spray cabin

5.3.2 MIMOP Approach

In the production of engines, the following mass and energy flows are distinguished:

- ❑ raw materials, namely purchased materials and semi-finished products (steel, screw bolts, nuts, etc.);
- ❑ production-dependent materials; the applied quantity is proportional to the quantity of produced products (lacquers);

❑ production-independent materials; the application is not proportional to the production volume, but is related to periodical activities (cleaning agents, cooling-water).

In the framework of this study, the material and energy flows of the Spray Cabin are considered. Based on the classification above, the following types of flows are discerned:

Materials flows proportional to production level
The relevant quantity for coating is the external surface of the engine (in m^2). The type of coating depends on the engine's type. The mass balance of the materials flows which are proportional to the production level are shown in table 5-1, with the exception of the flows of air, water, and products (the engines). The quantities depend on production level and product mix, resulting in a total surface (in m^2) and a distribution in types of primer. A typical example, integrated over a year, has been presented here.

TABLE **5-1:** Mass flow proportional to production level

material (name)	*input (kg/yr)*	*on the product*	*discharges*			
			hazardous waste	*to water*	*to atmosphere*	
					solid	*volatile*
benzine	9600	-	-	-	-	9600
primer						
-base	911	216	94	6	3	592
-hardener	481	228	99	7	3	144
polish						
-base	23761	10020	4341	295	148	8957
-thinner	1200	-	-	-	-	1200
-hardener	2045	971	419	29	14	612
total	37998	11435	4953	337	168	21105

Materials flow independent of production, but proportional to time
Cleaning operations occur according to a pre-determined schedule, e.g. each two weeks, independent of the level of the production. In table 5-2, the materials balance is presented of the material flows which don't depend on production. They emerge at periodical cleaning programmes, e.g. a monthly and a yearly one.

TABLE 5-2: Mass flow independent of the production level

material (name)	*input (kg/yr)*	*on products*	*discharges*			
			hazardous waste	*to water*	*to atmosphere*	
					solid	*volatile*
thinner	145	-	130	-	-	15
stripping fluid	240	-	144	-	-	96
rinsing fluid	1170	-	-	-	-	1170
total	1555	-	274	-	-	1281

Energy flows

In this case energy flows are essentially proportional to time. The energy consumption is presented in table 5-3. In this particular case, the energy flows depend linearly on production time, with exception of the polish mixers, that are functioning continuously.

TABLE 5-3: Energy consumption

process (name)	*input (GJ/yr)*	*output*	
		heat to air	*heat to water*
additional ventilation for cleaning	58	58	-
spraying and drying	94	94	-
water-curtain	10	-	10
polish mixer	12	12	-
compressor	17	-	17
lighting	89	89	-
total	280	253	27

5.3.3 Data Model

To be able to report the environmental effects on a regular basis, the environmental co-ordinator would like to have information systems at his disposal that are able to support the processing of the previously mentioned environmental data. This information system was meant to be a prototype for internal use and to specify latently present information requirements. The system focuses in particular on the basic registration based on mass balances, and includes the operational and instrumental level of material management, scheduling, planning, manufacturing and maintenance.

The development of such information systems is based on the analysis as described in section 5.3.2. After the analysis phase, a design is made of the structure of data that should be registered in this information system ('data modelling'). Based on the data model, the functionality of the system can be designed. In appendix B, the notation system as applied in this thesis is explained.

The core of CARE's information system is the production system, a process, of which the environmental effects should be determined. The production system is considered as a set of transformation processes, based on the product to be processed –in casu the engine–, the production time and the input materials which are dependent on this product and/or production time. The result of this transformation is both the processed product and the 'environmental burden'. In figure 5-9, the main entity types of the data model and its relationships are shown.

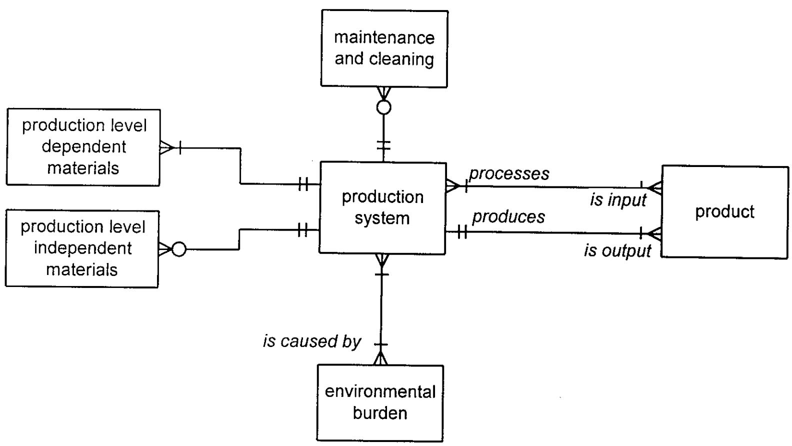


FIGURE 5-9 Data model of the environmental information system

This model represents the different flows, as were distinguished in section 5.3.1. Their effects on the environment are modelled as dependent only of the production system. There is no distinction whether the output can be used in a useful way or not. In general, not all effects on the environment will be accounted as environmental burden. When, for instance, a by-product is one of the results of the production system, this is considered as an environmental burden. It should not considered as such, however, when it will be used as input for another production system. In the Engine Spray Cabin, this may hold true for the residual heat which has been emitted, or for the used cleaning agents which can be re-used. The improved, though not implemented, data model in figure 5-10 is more close to this. In this model, the process output can be a main product, a desired by-product or an undesired by-product. The intended environmental burden of the model in figure 5-9 is represented as undesired by-product.

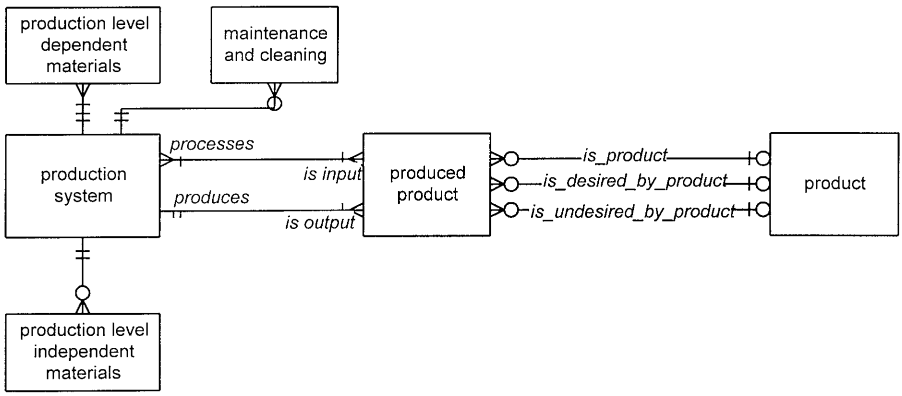


FIGURE 5-10 Proposed data model for an environmental information system

5.3.4 Case Evaluation

From this case, it became evident that mass balances play a valuable role in estimating the environmental impact of production. Complete and actual information on the grade of detail presented in tables 5-1 – 5-3, however, is often hard to obtain. It should be consciously analysed to which extent aggregation of information may be applied. In the described case, the information is on a detailed level which requires a multitude of high quality input data with respect to reliability, accuracy and consistency.

It is questionable to what extent this detailed data could contribute to an improved environmental decision-making, especially without reference to an overall picture of the entire enterprise. In this context, it is recommended that the bottom-up approach for particular production processes, e.g. the Engine Spray Cabin, is preceded by, and incorporated in, a top-down approach to provide a better understanding of the environmental effects of the enterprise. Additionally, an existing information system can be helpful if it covers both environmental and other material related issues, e.g. purchasing, scheduling, etc. In this case, the operational time (per period), the production program (number of produced units per product type per period) and the maintenance and cleaning program (frequency) may be retrieved from a logistic information system. As a result, the MIMOP approach is beneficial, provided that an adequate information policy is developed.

Finally, it should be stressed that the model is focused on a particular type of production process, in which a product, the engine, undergoes several operations and in which 'the cleaning and maintenance program' is ascribed a different role. Additionally, the production process can principally be characterised as 'discrete manufacturing', though with some important 'process oriented' transformations. This will be further elaborated in chapter 6 and 7. Concluding, to make the information system generally applicable, generalisation of the data model is required, especially with respect to product and process data. A first step has already been made in treating all outputs equally, e.g. considering waste as a (though undesired) product. In the next case study, the development of a data model is further elaborated.

5.4 Case: Flexible Packaging Industry

In the previous case study, it was concluded that the MIMOP approach is a possibility to retrieve environmental information, provided that an adequate information policy is pursued. Such a policy should include the use of existing information systems, adequate aggregation level and flexibility in product and process modelling. This section is based on a case study in which this is elaborated. It is carried out after the case in the automotive industry, and has been finished early in 1997. The involved enterprise subject to 'KWS-2000' and the Covenant 'Environmental Policy Agreement for the Printing and Packaging Industry', and is, amongst others, obliged to account for the emission of VOC's, which have been put on the 'list of prioritised materials'. This forced them to evaluate the possibilities of their Enterprise Resource Planning (ERP-) Software for this application.

5.4.1 Production Processes

The main production activity of this enterprise involves processing of aluminium foil, paper web and plastic web materials, especially for packaging purposes in food and beverage industries. Therefore, this organisation is part of both the aluminium processing industry and the packaging industry. The main products are: (coated or printed) aluminium inner liner for cigarette packages and lidding materials for dairy packaging. The following processes are performed, see figure 5-11:

- storage of raw materials and utilities;
- aluminium rolling (from 0,27mm to 6,7μm (tobacco) or ca. 40μm (dairy);
- formulation and production of inks, lacquers and adhesives;
- printing and lacquering of (thin) aluminium foils;
- storage and packaging of finished products.

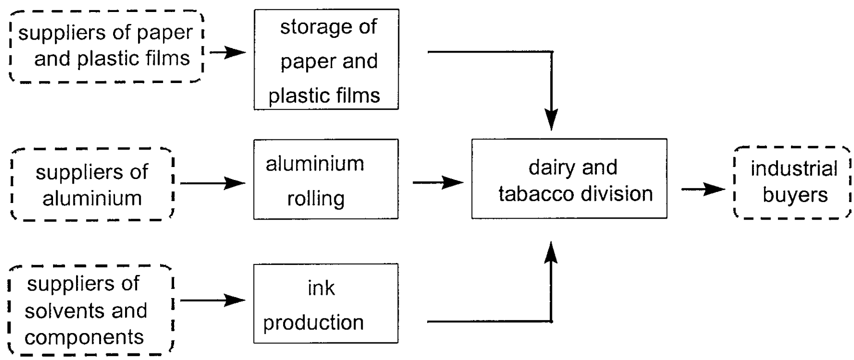


FIGURE 5-11 Production of Flexible Packaging Material

5.4.2 MIMOP Approach

Two types of registrations are of interest here: (1) the consumption of raw materials (aluminium, paper and plastic films) and (2) the accountability with respect to solvents. The current registration of raw materials is dictated by control purposes, contrary to the solvents, which are registered due to environmental requirements. Raw material consumption, however, is also important to environmental purposes because in this way, scrap production can be controlled. Fortunately, this registration can be modelled according to the MIMOP approach and is already supported by ERP-software. Therefore, the situation with respect to raw materials is described first. Then, the same line of reasoning is followed and evaluated with respect to solvents.

Raw Materials

The production of the final product for cigarette inner liner consists of three production steps, see figure 5-12. First, aluminium foil and paper are glued. For this purpose, internally supplied aluminium foil and purchased paper are supplied on cylinders and simultaneously unrolled, glued and rolled up on a

parent roll. The next step involves unrolling of the parent roll, slitting the finished product at the desired width and wirling up on (smaller) reels with customer-specific width and diameter. The waste flows consist of aluminium and paper; AL1 and PA1 due to laminating, AL2 and PA2 due to slitting.
As already mentioned, the raw material balance is merely drawn up for general control purposes. Although the quantity of raw material waste can additionally be controlled for environmental purposes, this material balance is mainly elaborated for the evaluation of the supporting information system for future application in environmental applications.

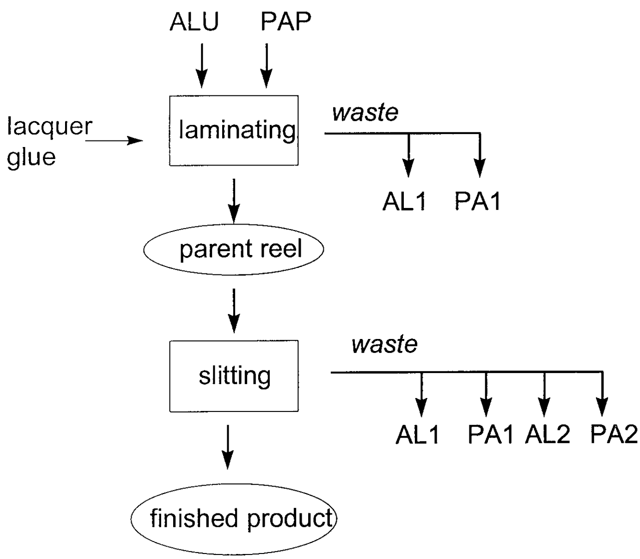


FIGURE 5-12 Production steps for inner (glue-laminated) inner liner

Solvents
With respect to the environmental effects of the production process, the use of solvents, especially volatile organic compounds (VOC's), is of importance. These are purchased, processed and finally internally supplied by the ink production unit to the refinement divisions as inks, lacquers and glue. The Covenant obliges to prove where solvents are applied, and to what extent these have been emitted to the atmosphere. The MIMOP approach enables this company to draw up a solvents balance. The first step in the solvents analysis is an overview of the materials flows in the production site.

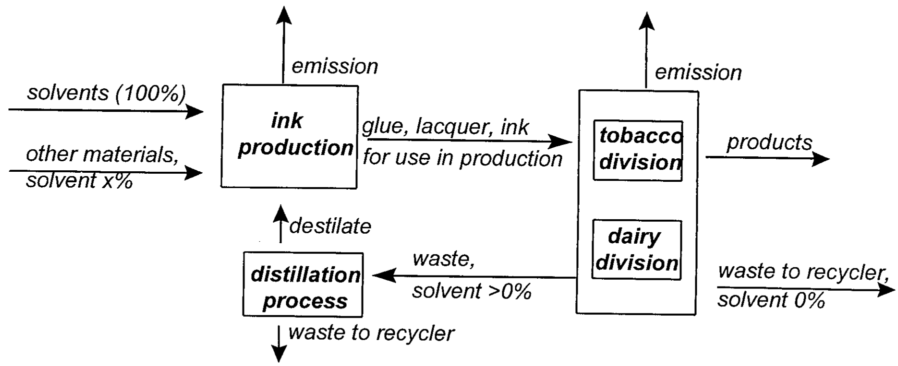


FIGURE 5-13 Solvents-containing materials flows

In principle, the following balance equation holds true for period x (all quantities are in kilogram solvent): *stock at beginning of period x + purchased quantity = stock at end of period x + sold quantity + emissions*

Application of the equation is complicated because of the distillation process. The sold quantity is either present in the main product (aluminium packaging material) or chemical waste. The solvent containing part of the chemical waste with a negative economic value, which is suitable for the distillation process, can be applied in the original recipes of lacquer, but is mainly used for cleaning purposes. The new balance equation is: *(stock of solvents + stock of distillate) at beginning of period x + purchased quantity = (stock of solvents + stock of distillate)at end of period x + sold quantity + emissions*

In the current situation, quantities in stock are measured once per year, the purchased and sold quantities are retrieved once per month.

5.4.3 ERP System

The standard ERP-software, as implemented in this enterprise, is developed for production on customer order. For that purpose, each ordered product, a production order is made. For each product, the standard product structure is generated, including the required raw materials (bill-of-materials), the process steps and resources (routing). One can deviate from the standard structure before accepting the customer order, or when preparing the customer order. This happens if it turns out that particular raw materials or resources are not available. In such a case an alternative product structure is generated, together with adjustments to the bill-of-materials or routing or both.

Raw Materials

The ERP-system of this enterprise has been extended for the application of materials balances for the raw materials aluminium, paper and plastic films. When a production order is finished, one should know how much product, co-product and waste has been produced. A co-product is defined here as (a part of) the remainder of a parent roll of customer product, a so-called extra-length. Thus, if a parent roll with width *x*, produces a customer product with width *y*, the co-product has maximum width *x-y*. Waste is either inherent in the production process (slitting, enrolling, etc.) or caused by internal rejections. The latter kind of waste passes all production steps and thus included for calculation of production times and planning schemes. Moreover, waste of this type is expensive, because many resources are applied to produce it.

The extension concerns the bill-of-materials; the standard bill-of-materials is defined as the materials requirement for a customer product and excludes recording of a set of output products, for instance the customer product, co-products and waste. Including more than one product in the bill-of-materials is implemented here by giving them a 'negative quantity per' that equals the standard yield of the by-product. The quantities for co-product and waste should be entered as negative values.

Parent		**Component**		**Quantity**
code	**description**	**code**	**description**	
r12345	5 km roll for customer *x*	a123	aluminium	5,3 km
		p124	paper	5,3 km
		g125	glue	750 dl
		c126	cylinder	1 piece
		w127	waste	- 7,6 kg
		r12346	co-product	- 5 km

The concept of 'negative bill-of-materials' is applied per production step (application, cutting and post-processing), and is used for both pre-calculation to determine the required quantities, and post-calculation to record the actual quantities. It should be stressed that the described solution is rather 'tricky' and causes side effects, for example the expectation of negative receipts of the output into stores because negative outputs are considered inputs and hence determined before production (Rutten, 1995).

Solvents

In the time that the case study was carried out, the solvents balance was drawn up manually, on a yearly basis. First, it is described how the required data was obtained manually, next the application of the method for raw materials balances is evaluated for drawing up the solvents balance.

Purchased solvents The quantity of purchased solvent-containing materials is retrieved from the ERP system by the IT-department and supplied to the environmental co-ordinator on a monthly basis. The completeness of the registration of mass flows in the ERP application is not checked. All unregistered product flows are not included in the solvents balance.

Stocks The quantities of 'solvents in stock', 'prepared solvents in stock' and 'distillate' are measured over the year. All physical units denoting quantities, e.g. litres, are converted into kilograms by using the specific gravity specified by the product documentation.

Distillation Process The solvents which are applied to the production process, but not actually used are accumulated, liquefied and distilled. The distillate is re-used in the production process, the residue is transported in the form of chemical waste to a waste collector. The quantity of distillate that is re-used for production purposes is metered in the ink production unit. The quantity for cleaning processes is monthly recorded by the production staff. The quantity of litres that is used is converted into kilograms by using the average specific gravity, which has been set at 0,85. This method introduces inaccuracy, both in cleaning processes and in average specific gravity.

Products Retention of solvents on the products (aluminium packaging materials) is neglected. The quantity is too small, which is likely since the product is used as packaging material in the food industry.

Waste Chemical waste from contaminated solvents and from the distillation process are transported to a recycler. The quantities are determined based on the monthly receipts. The solvent content of cleaning clothes are not considered as chemical waste, because these still have value and are re-used.

Emissions All unspecified mass flows at the output side of the production units are considered as emission. These include diffuse emissions and emission points like chimneys.

This enterprise is able to automatically generate raw materials balances; the question is why they follow manual procedures for calculating solvents balances. It turned out that automatic generation of a raw materials balance requires standard ERP functionality, extended by functionality for diverging bill-of-materials.

The main reason that this enterprise is not able to generate solvents balances is that the standard ERP functionality cannot support the process-oriented production of the ink production unit. The process-oriented production requires multiple output products (divergent structure) and complex process descriptions (specified in recipes). The implemented ERP system, however, is incapable to handle the necessary materials and process flexibility as required in such recipes. As a result, the implementation of an ERP system in the ink production unit would require the purchase of another system module or possibly another ERP application. The effort and cost, however, wouldn't be compensated by the possible savings or other profits.

The improvements in drawing up a solvents balance may influence this decision. Whereas control purposes didn't need automated support, calculation of the composition of output products may do so, because the actually chosen materials, the ratio in which they are applied and the actually passed production processes with related process characteristics influence the composition of output products. As a result, the ERP system should support a detailed recipe registration, including multiple (alternative) input materials, flexibility in processes and multiple output products.

5.4.4 Case Evaluation

From this case, it is concluded that the MIMOP approach may fit in ERP software. However, special attention is required for the way in which product and process structures are recorded, both for 'simple' processes, such as assembly, and for 'complex' processes, as is, e.g., depicted for ink production.

For this particular enterprise, the ERP-system merely includes purchasing, production and sales of aluminium packaging material, and doesn't cover the relevant parts of ink production, distillation and cleaning. As a consequence, the solvents balance cannot be generated in the same way as the raw materials balance. However, on principle, the ink production unit could have been supported by (process-oriented) ERP-software. If such software packages are available, the divergent structure and recipe descriptions can be used to generate solvents balances. Notwithstanding this fact, the economic feasibility is minimal for this particular enterprise in the current situation.

Although not explicitly discernible within the usual structure of production control systems, it turned out that all information on production can be related to physical flows. According to this observation, a novel approach to structuring information systems is proposed that justifies the position of physical flows in the information system and that leads to similarity on structure for the information (sub)systems. It further implies that environmental information systems should not be added as a separate module, but should be integrated in the present modules, especially the operational - logistic- information, by adding new attributes to existing entities. For that purpose, the structure of the logistic information system should be modified to by-pass the artificial difference between discrete manufacturing and process industry by universal application of multiple-input multiple-output models in all types of production. Once performed this restructuring, derivation of environmental information has become a standard task.

An at least interesting example of the 'environmental value' of environmental product labels (see chapter 3) concerns the production of inner liner for cigarette packaging. The conventional packaging material consists of a combination of aluminium foil and paper, which should be separated to make it suitable for recycling. For the German market, however, it is asked to produce so-called mono-packaging materials which are easier to recycle (Grüne Punkt). The mono-packaging is made of metallised paper. First, the paper is pre-lacquered. Next, under moderate temperature and very low vacuum, metal is evaporated and as an extremely thin metal layer (250-350 Å) applied onto the paper. At last, a final lacquer is added. This production method offers the opportunity to recycle (and re-use?) the packaging material. However, it inevitably causes an increase in use of solvents, as long as these lacquers are solvent-based. It is expected that this production method soon becomes common practice in the Netherlands, and in the European Community for a medium long period.

5.5 Conclusion

In this chapter, an environmental modelling method has been described which is specialised for several types of enterprises. This method is called the multiple-input multiple-output process (MIMOP) approach. The method starts from a black-box principle and distinguishes inputs, the transformation process and outputs. A number of extensions are suggested: (1) aggregation and decomposition of production processes, (2) aggregation of materials and (3) aggregation over time. The main advantage of such a detailed approach is that all data are based on physical flows, which might already be recorded in business information systems, such as for logistics, finance and quality. As a result, environmental data, particularly waste and emissions, can be retrieved rather easily from conventional systems.

The case studies proved that the MIMOP approach is valuable for environmental purposes, provided that an adequate data policy is applied, amongst others by an integral approach for environmental, logistic, quality and other information systems. Furthermore, it turned out that special attention is required for the registration of diverging product structures and flexible production processes in recipe descriptions. These conclusions equally apply to processes in discrete manufacturing and process industries, and moreover, require the same basic structure for the supporting information systems. As a consequence, the traditional distinction between the two kinds of information systems is no longer needed.

In the following chapter, the structure of standard ERP software packages is described and evaluated for these purposes. It aims to define which requirements ERP software should meet to be a sound basis for further extension with environmental functionality.

6. Enterprise Resource Planning and the Environment

In the previous chapter, an environmental modelling method has been developed, the MIMOP approach, which is specialised for an individual enterprise. It was concluded that this method contributes to environmental reporting, on the condition that extensive use can be made of other business information systems. Case studies revealed that especially enterprise resource planning (ERP-) software is suitable for this purpose. Therefore, structures of existing standard ERP packages are evaluated in this chapter.
First, requirements of the modelling method on the supporting information system are summarised (section 6.1). Next, the history in development and functionality of ERP software is roughly described (section 6.2). In section 6.3, existing functionality is described in more detail and evaluated for possible application on environmental reporting. This section is based on a reference data model for ERP software, as described by (de Heij, 1996). The result of this chapter is summarised in an environmental data reference model (section 6.4). This model specifies requirements on the structure of an existing business information system to be a sound basis for extension with environmental functionality.

6.1 Introduction

In the previous chapter, a method for environmental modelling based on a multiple-input multiple-output process approach has been introduced. It has been made clear that this method can be valuable provided that existing information systems are appropriate to supply detailed data with acceptable integrity. Those systems should be able to meet the following requirements:

- modelling waste and emissions as products, and thus modelling multiple inputs and multiple outputs per production process;
- modelling the composition of products, especially those components or materials that are of interest;
- availability of a mechanism to vary the level of detail of registration and reporting;
- modelling of production processes, especially process characteristics and process decomposition.

Especially, Enterprise Resource Planning (ERP) systems could be suitable for the required product and process data registration. This chapter deals with ERP- software, described from an environmental viewpoint.

6.2 Enterprise Resource Planning

This section introduces the concept of Enterprise Resource Planning (ERP). Starting in the fifties, a brief overview is presented of the evolution in standard software for logistic applications (de Heij, 1996). Next, an overview is presented of the functionality of state-of-the-art ERP software.

6.2.1 History of Logistic Software Applications

The development of logistic software started in the late fifties and early sixties with simple stock management systems. Those systems aimed to manage large numbers of items, to make forecasts on future sales, to calculate safety stock and to determine the size of purchase orders. The production was assumed to be 'stock-oriented'.
The growing capacity of computers in the early sixties made it possible to automate the calculations which used to be made manually. Usually, this software was able to explode bill-of-materials based on monthly buckets. Over the years, those applications evolved towards complete Material Requirements Planning (MRP-I), as is described by e.g. (Orlicky *et al.*). Those packages can still be characterised as stock-oriented, though they made it possible to plan on a daily basis, to trace the source of requirements and to reduce the calculation time by only recalculating changes.
In parallel, developments were taking place in the field of capacity planning and shop floor control, due to the need of make-to-order manufacturers. However, its integration with MRP packages never really took off. In the eighties, the first functional extensions of MRP packages were introduced to the market. Supplementary modules have been developed for capacity requirements planning (CRP) and rough cut capacity planning (RCCP), which finally resulted in so-called MRP-II packages (Manufacturing Resource Planning). In the same period, new functional areas, such as finance, quality control, warehouse management, process control and labour reporting were developed and integrated.

Finally, in the early nineties, standard software has become widely accepted. Examples of selection criteria of those packages are: user friendliness, international and multi-currency oriented, two-level master scheduling, integrated multi-plant approach, variant bills-of-material, product configurators, process oriented production, by/co-products, etc. Such broadly-based information systems are referred to as enterprise resource planning (ERP) software.

6.2.2 Definition and Overview of ERP- Software

In the previous subsection, it is outlined that, from a functional viewpoint, Enterprise Resource Planning (ERP-) software can be considered as an evolutionary step succeeding MRP-I and MRP-II. ERP- packages, according to the Gartner Group (Gartner, 1994) are defined as:

...whereas MRP is reactive and focuses on transactions and reporting, ERP is pro-active and provides decision support as an integral part of the entire information system.

The functional characteristics include, amongst others :–

- Integration of manufacturing and logistics with other functional areas such as finance, sales and marketing, distribution, transportation, maintenance, field service and human resources;
- Support of decentralised structures (multi-site databases), in which the primary business functions can be performed both centralised and decentralised;
- Support of flow-based manufacturing, manufacturing without work orders even in job-shop like environments;
- Support of hybrid manufacturing environments (mixed mode): combined control with and without work orders, use of bills of material and routings, as well as the 'production model';
- Possibility to plan in terms of financial units, above the level of the main production plan;
- Supply chain integration of customers (and their customers) and suppliers: supply chain management with EDI tools and Internet, links to distribution depots, public warehouses and large retailers;
- Presence of product configurators, both in the trend towards customer order controlled manufacturing, also in the (semi-) process industry.

ERP software vendors are evaluated, amongst other criteria, on their completeness of vision. It is stated (AMR, 1994) that the functional areas should be extended with a number of related aspect systems: quality assurance, safety issues and environmental management (Total Quality Management). This thesis elaborates this extension of ERP software with environmental functionality. For this purpose, first the relevant parts of existing ERP functionality are described in more detail and evaluated for support of environmental functionality.

6.3 Existing ERP Functionality

In this section, the description of existing ERP software is further detailed. For this purpose, a number of steps in the development of 'de Heij's Reference Data Model for State-independent Manufacturing Data' (de Heij, 1996) is reproduced. The applicability for an environmental information system is raised in section 6.4.

6.3.1 Material and Capacity Requirements

The traditional way of recording material requirements is the multi-level bill-of-materials, shown in figure 6-1. This is defined as (APICS, 1992):.

'a listing of all the subassemblies, intermediates, parts, and raw materials that go into a parent assembly, showing the quantity of each required to make an assembly'

In the parent-component relationship all required component items are determined, including the quantity required for the production of the parent item. As a component item itself can be a parent item, the multi-level structure is exploded until the component items are no longer manufactured items, but purchased items.

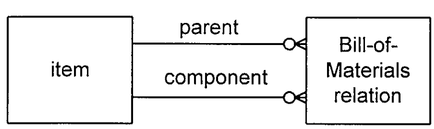


FIGURE **6-1** Multi-level bill of material (de Heij, 1996)

Next, the basic capacity requirement for the production of an item is defined. An item is produced in a sequence of one or more operations, the routing. Each operation is performed by a capacity unit (machine, personnel, etc.), which may be available for several time periods. The capacity requirement to produce an item is shown in figure 6-2. A more extensive typology for different kinds of capacities is beyond the scope of this research, but can be found in (de Heij, 1996).

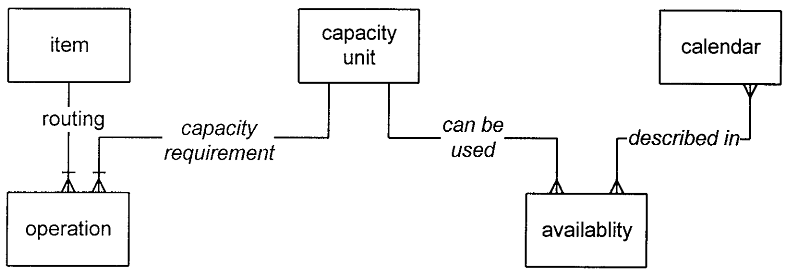


FIGURE **6-2** Capacity requirement (de Heij, 1996)

A 'routing' is defined as *'a set of information, detailing the method of manufacturing of a particular item, including the operations to be performed, their sequence, the various work centres to be involved, and the standards for set-up and run-times. It may also include information on tooling, operator skill levels, inspection operations and test requirements'*(APICS, 1992).

An 'operation' is defined *as 'a description of an activity to be performed, normally contained in a routing document that could include set-up operations, operating instructions (feeds, speeds, temperatures, pressure) and require product specifications and/or tolerances'* (APICS, 1992).

The combination of material and capacity requirement results in figure 6-3; a basic structure that can be found in many traditional MRP systems.

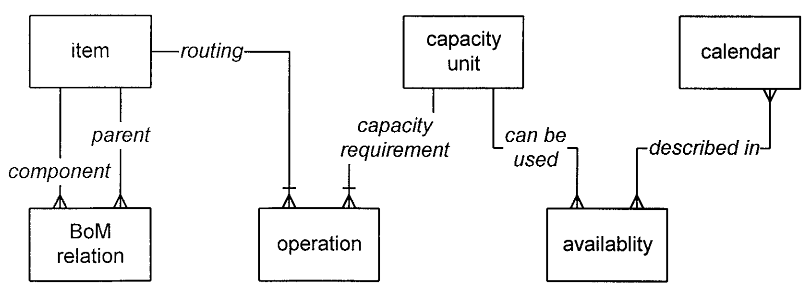


FIGURE **6-3** Simple material and capacity requirement (de Heij, 1996)

The main reason why many existing MRP-systems are unsuitable for environmental functionality is caused by the limited possibilities for the registration of product and process structures. In the following, three extensions of the basic model are described, which are generally not included in existing MRP systems, but can be found in more dedicated systems.

6.3.2 Multiple Bill-of-Materials and Routings

Several situations may require the support of multiple bill-of-materials (BoM) and routings, amongst others: different types of BoMs and routings for different purposes; alternative BoMs and routings for the production of the same item; temporary BoMs; revision of BoMs and routings; or location dependent BoMs and routings.

The recognition of multiple bill-of-materials and routings leads to extension of the basic model, as shown in figure 6-4. Based on the reason for the introduction of multiple bill-of-materials, the entity types 'bill-of-materials' and 'routing' can range from a simple identification number to a complete selection structure of bill-of-materials. In the first case, preconditions whether to use a specific bill-of-material are not included , whereas in the latter case many rules and conditions may be associated with the bill-of-materials (not shown in figure 6-4). The same range of options exists for routings. A material requirement can be used in several (alternative) routings, resulting in a n:m relation between the item types 'bill-of-materials' and 'operation'.

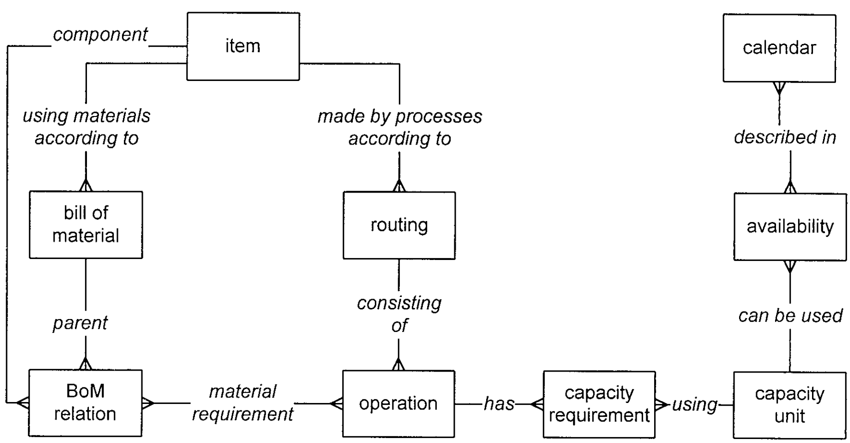


FIGURE 6-4 Multiple bill-of-materials and routings (de Heij, 1996)

Although the data model in figure 6-4 provides a good starting point for environmental functionality, it lacks structures to model compositions of waste or emissions, and the possibility for modelling multiple outputs. To this purpose, the data model is further extended in the following subsections.

6.3.3 Recipes

In chapter 5, it has been argued that an environmental - logistic information system should support the flexibility in production processes. The need for flexibility originates from the nature of the production process. That is why the (semi-) process industries make use of a 'recipe' in addition to the bill-of-materials and routings. A recipe is defined as *a statement of ingredient requirements; it may also include the processing instructions and ingredient sequencing directions* (APICS, 1992). The main differences are (van Rijn *et al*, 1993; Rutten, 1995):

- ❑ material options flexibility; different raw materials can be exchanged without changing the final product specifications.
- ❑ materials quantity flexibility; the exact quantity used of a raw material may vary between certain boundaries.
- ❑ process flexibility; the processing actions in a number of steps are not fixed but depend on the evolution of the product that should be accomplished.
- ❑ diverging product structures; a single material item results into a multitude of products according to a fixed, or sometimes variable ratio.

A recipe describes all that is necessary for the production of an item, i.e. the combination of required materials, capacities, additives and instructions. Due to the reasons mentioned, several recipes for producing a particular item may coexist, each with a specific material and capacity requirement. The entity type 'recipe' can be added to the previous data model, as shown in figure 6-5.

Differences in requirements of the (semi-) process industry and discrete manufacturing industry have mostly resulted in different structures in information systems to support the various production processes. However, a shift towards the integration of materials oriented and process oriented production information systems is natural, because many production processes inherently have both discrete and process characteristics. The data model depicted above, shows the implicit synthesis, with exception of the diverging aspect.

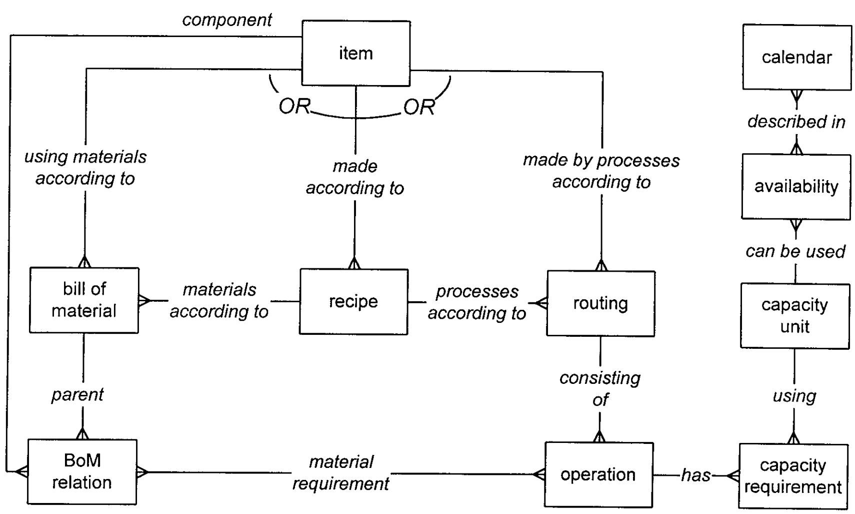


FIGURE 6-5 Complex material and capacity requirement (de Heij, 1996)

6.3.4 Divergent Structures

The product structures that are described up to now in bill-of-materials, and in many present-day ERP packages, are convergent, which means that each operation requires a number of inputs and results in only one output product. However, a large number of operations results in a set of products. In process industries, these are (partly) recognised as such, because many sub-flows are used. For discrete processes this view is not commonly accepted. Usually, the focus is on a piece of work, e.g. transformation of metal into a drill. Nevertheless, also these processes mostly result in more than the single item –a drill– that is required, in this case metal shavings. The multiple output approach can be found in software systems which are dedicated for the process industry, and makes use of so-called co- and by-products. 'Co-product' and 'by-product' are defined as follows. *Co-products* are 'all primary products that are the required planned result of the production process'. *By-products* are 'all secondary products of any importance (because of its value or the environmental requirements) that are either an apparently unwanted result of, or remain after the production process'. The following types of production processes occur (see figure 6-6).

a) basic converging product structure, e.g. (a conventional description of) the production of cars, or more accurate, the assembly of a nut and a bolt provided that those are not packaged;

b) the production process results in two more or less equivalent co-products, e.g. oil refinery;
c) in addition to the production of a primary product, one or more by-products remain after production, e.g. (an improved description of) the production of a car;
d) several equivalent products are produced, one of which is partly fed back into the production process, e.g. the production of yoghurt in which the primary product is used as a catalyst in the production process;
e) the secondary by-product is fed back into the production process, e.g. the use of catalysts.

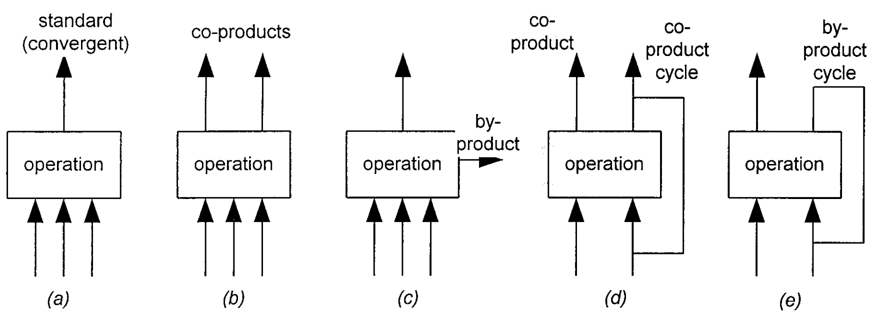


FIGURE 6-6 Diverging product structures

Co-products

In general, a production process consists of a number of operations, each of which can be the source of co- or by products. In figure 6-7 the data model is shown for co-products. It consists of the basic model, extended with multiple bill-of-materials and routings, and recipes. In addition to the previous data model, the recipe results in a 'set of co-products'. The co-product items which belong to this set are described by the item type, the actual set it results from, and the operation from which it originated.

By-products

An information system which allows description of a production process including by-products can basically be seen as simplified version of the implementation of co-products. However, the implementation of co-products in traditional MRP systems is difficult due to the nature of material requirements planning.

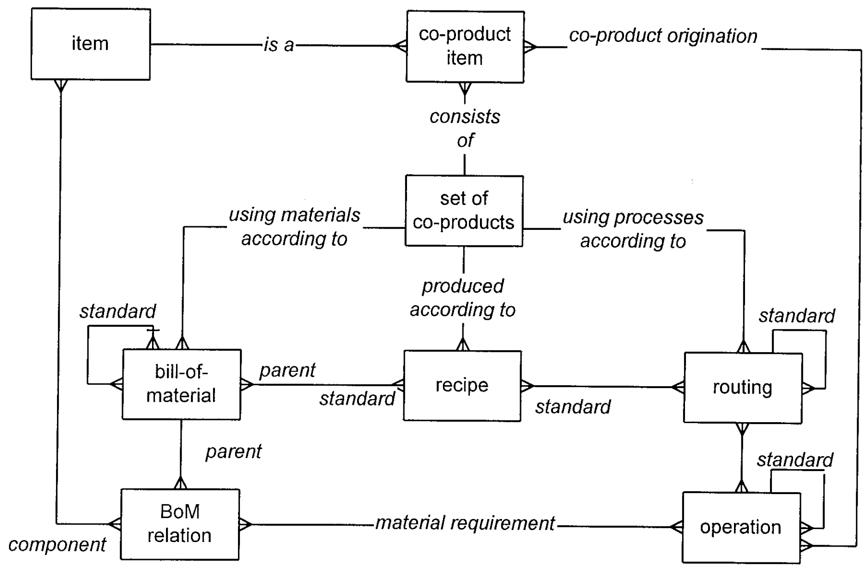


FIGURE 6-7 Co-product structure (de Heij, 1996)

MRP-I can be considered as a material co-ordination technique. Based on the registration *which* end-products should be produced at *which* time, it calculates *when* semi-finished products should be available and *when* parts and components should be ordered and supplied. This calculation technique relies, among other things, on the up-to-date registered parent-component relationships in the bill-of-materials. MRP-I calculation meets difficulty if dependencies in the bill-of-composition occur. It is argued before, that the conventional bill-of-materials is convergent, i.e. is meant to produce a single item. The introduction of divergent structures deteriorates the level of dependency and counteracts the effectiveness of the material requirements planning.

Whereas, according to the definition, co-products are 'the required planned result of the production process', by-products are 'either an apparently unwanted result of, or remain after the production process'. Therefore, material requirements planning is by definition not applicable for by-products.

Accordingly, implementation of by-products in an information system is a lot easier. In most existing MRP systems, by-products are implemented by adding a new entity type 'by-product'. The entity type 'by-product' is, contrary to 'co-product' defined by the 'bill-of-material' and 'operation'.

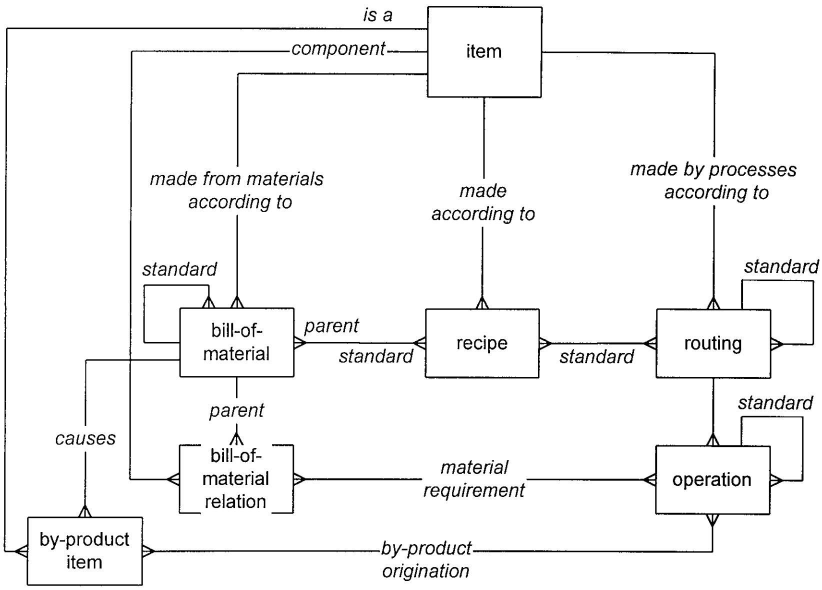


FIGURE 6-8 By-product structure (de Heij, 1996)

6.4 Environmental Reference Data Model

In the previous section, the structure of a reference data model for state-independent manufacturing data is outlined. In this section, this reference model is evaluated for applicability to environmental information systems. The result is summarised in an environmental reference data model, specifying which structure an existing ERP system should support to be a sound basis for environmental purposes.

6.4.1 Evaluation

The basic structure for registration of simple materials and capacity requirements is insufficient for environmental functionality. Although it may be possible to model compositions of products, various other requirements cannot be met. The main reason is found in the limited possibilities for modelling product and process structures. Modelling of waste and emissions, for instance, requires multiple inputs and multiple outputs and flexibility in process registration. It is concluded that standard ERP- software with only the basic functionality, as shown in figure 6-3, is unsuitable for environmental applications.

Multiple Bill-of-Materials and Routings

In many standard packages for ERP-software, the basic structure has been extended with the possibility for multiple bill-of-materials and routings. For environmental purposes, alternative bills-of-material and routings can be added which are supposed to contribute to more environmentally benign products. Furthermore, revision bill-of-materials make it possible to extend the product life, which usually results in less environmental pollution. Notwithstanding the advantages of multiple bill-of-materials and routings, the core of the problem, product and process modelling, such as in figure 6-6, has not been solved yet.

Recipes

A concept which does elaborate the modelling of products and processes is a recipe. Support for recipes in information systems not only effectively settles production control issues in (semi-) process oriented enterprises. It is also eligible for modelling environmental effects of products according to actually chosen quantities and types of raw materials. However, the mere application of recipes, which specifies production processes and material requirements of a single output product, doesn't fulfil the requirements for multiple outputs.

Divergent Structures

The call for divergent structures is not only caused by environmental purposes, though has always been inherent to process industries. ERP software, dedicated for the process industry, therefore, offers functionality to support the production of co- and by-products. The distinction between co- and by-products, however, is not suitable for environmental information systems.

Co- and by-products, as implemented in those ERP-systems differ by definition in their possibilities with respect to planning and registration of composition (as recorded in the bill-of-materials). From an environmental point-of-view, recording of the composition of by-products is indispensable and planning of by-products also might be required. Furthermore, the distinction in co- and by-products excludes more detailed registration of 'non valuable products'. This is undesired in relation to verification of completeness and correctness of the registration, as can be required by authorities. Concluding, the support for co-products would settle the problem of multiple outputs, though require improved planning functionality as described in section 6.3.4.

6.4.2 Data Model

In the previous subsection, it is concluded that existing ERP software may be based on a data structure which substantially corresponds to a structure that is essential to environmental information systems. In this subsection, the conclusions are summarised in a data model. This model, see figure 6-9, describes the structure for the registration of product and process data which is requested from ERP systems as a sound basis for the development of environmental information systems.
The core of the model is based on figure 6-7. Two extensions are added. In existing ERP-software items and capacity units are modelled as separate entities, and lack the explicit distinction between input and output items. In figure 6-9, a new entity type 'resource' is introduced. A resource can be input, output and capacity unit in a particular recipe.

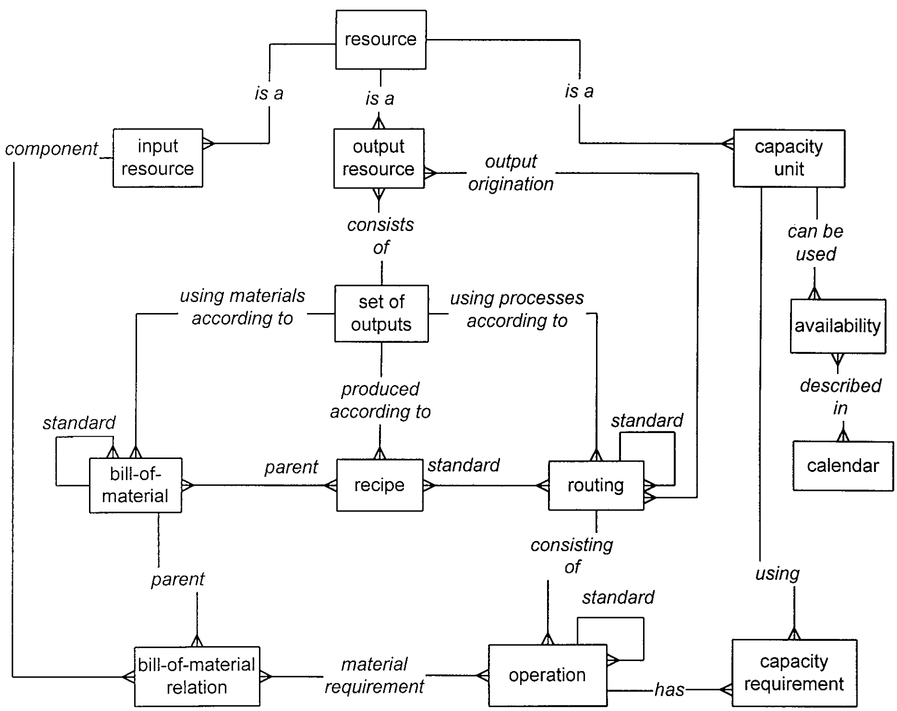


FIGURE 6-9 Reference data model for registration of product and process data

Furthermore, auxiliary materials such as packaging material, and waste and emissions are lacking. In the reference model, all inputs, outputs and production means are considered as a subtype of the entity type 'resource', see figure 6-10.

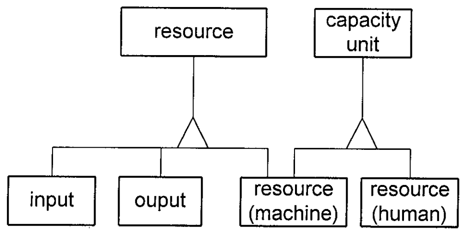


FIGURE **6-10** Subtypes of the entity type 'resource'

A resource is defined in line with the entity type 'item', as previously defined. It additionally has a composition, as is elaborated in the next section. A more detailed classification of resources is shown in figure 6-11 and figure 6-12.

6.5 Conclusion

In this chapter, state-of-the-art Enterprise Resource Planning software is described and evaluated for possible application in environmental

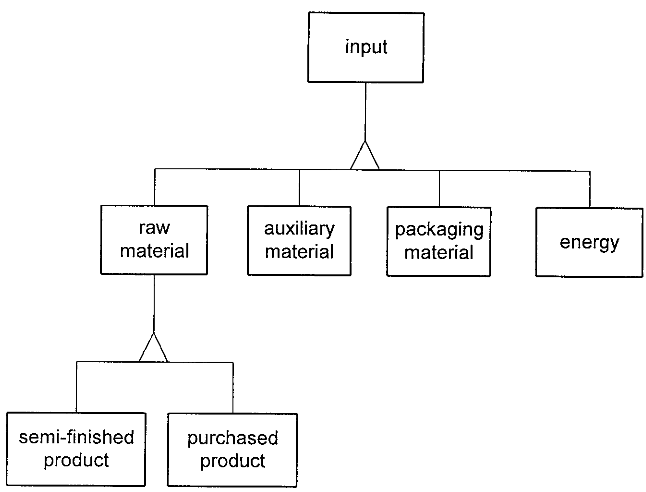


FIGURE **6-11** Subtypes of input resources

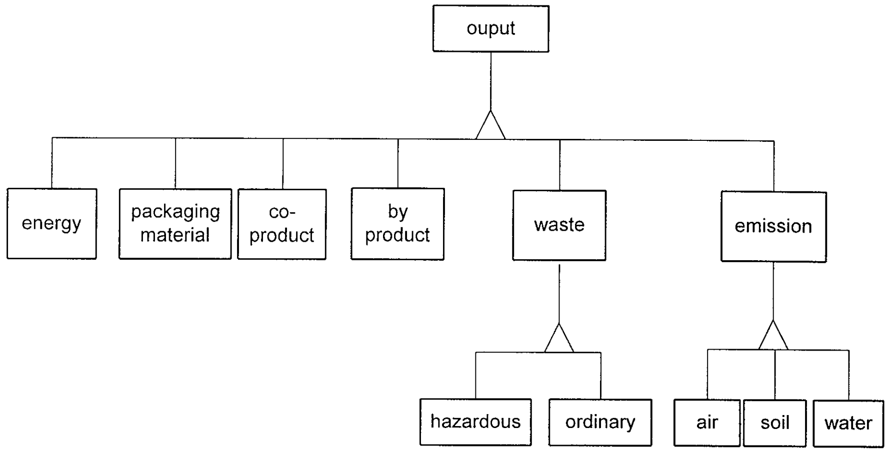


FIGURE 6-12 Subtypes of output resources

information systems. The implementation of materials and capacity requirements as can be found in traditional MRP software turned out to be unsuitable. Extensions which can be found in dedicated software packages proved to be valuable, especially with respect to the modelling of recipes and divergent product structures.

As a conclusion, it is stated that existing ERP software may be based on a data structure which substantially corresponds to a structure that should be present in environmental information systems. This especially holds true for ERP software in the process industry. It is argued before that a shift towards integration of information systems for discrete and process oriented production processes is natural, which would increase the possibilities for uses for environmental information systems. The data model in figure 6-9, namely, should be interpreted as the required structure of ERP software, to be a sound basis for environmental functionality.

7. Design of Environmental Registration Systems

In this thesis, it is aimed to meet environmental information requirements of individual enterprises. It has turned out that existing environmental applications could roughly fulfil those requirements, though, lack adequate environmental data. This deficiency may be settled by the use the multiple-input multiple-output process (MIMOP) approach. This approach is obtained from an environmental approach and can also be considered as basis of other information systems. It was concluded that MIMOP approach may serve the purpose, provided that it is applied in combination with existing information systems. In connection with that, an information system to support Enterprise Resource Planning (ERP) has been outlined and evaluated for applicability. The result is summarised in an environmental reference data model, which specifies the data structures that should be available when implementing the MIMOP approach.

In this chapter, an environmental registration system (ERS) is developed, which is based on the MIMOP approach, as described in the previous chapters. An ERS should close the data gap for existing environmental applications; it can be used to supply environmental data to already available environmental applications and to several information systems. Additionally, it will serve as a basis for an integral environmental information system, as is developed in chapter 8.

This chapter is organised as follows. The first step is to draw up materials balances (section 7.1). However, this process requires product compositions of input and output products. For this purpose, in section 7.2, the concept of 'bill-of-composition' is introduced and elaborated. In the remaining sections, this approach is refined, by the introduction of aggregation level for materials, for process steps and in time (section 7.3). Finally, it is elaborated in which way calculated and actually measured values affect the accuracy of the resulting environmental information (section 7.4).

7.1 Materials Balances

In the environmental reference data model, the structure for registration of product and process data, which is requested from ERP systems, has been described. In this section, the link between the MIMOP approach and the reference model is established. This is done by means of materials balances.

7.1.1 Definition

A materials balance for a particular production process is defined as:

> *'the mass equation of inputs and outputs of a production process, and for which the laws with respect to mass conservation apply.'*

This approach is process oriented and states that the quantity of input of a particular material equals its output quantity. However, if the process consists of a number of process steps, it is possible to accumulate input material in the form of stock. The stored materials may leave the system in the future and as a result, the materials balance for a particular period of time may include a different quantity for input and output materials. In figure 7-1, the materials balance approach for 'baking apple pie' is represented.

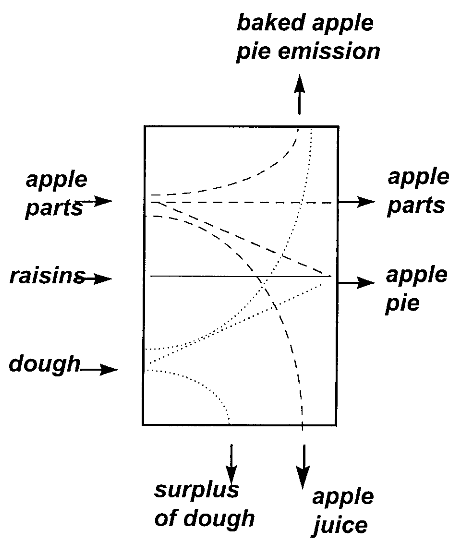


FIGURE 7-1 Materials balance for baking apple pie

In this example, the materials balance comprises all constituents of the production process; it can be considered as a *complete* materials balance for a particular aggregation level. Usually, one is not interested in all materials, because only some of these are relevant from an environmental viewpoint. Because of that, often *partial* material balances occur, especially concerning those input and output materials, which contain the critical substances, e.g. heavy metals or solvents.

Furthermore, when drawing up a materials balance of a production process, two types of process should be distinguished, dependent on the level of understanding of the transformations that take place.

1. *transparent processes*; if the process characteristics are known, the composition of output materials can be calculated, based on the actual inputs and passed production processes. The advantage of this approach is its flexibility; the total volume of data stored in the information system only depends on the quantity of input data (flows and composition) but not on output data, that are straightforwardly calculated from input and process characteristics.

2. *non-transparent processes*; if the process characteristics are insufficiently known, the composition of a manufactured item is not derived from the process, but is obtained otherwise. In that case, the composition should be recorded explicitly, within for instance particular process constraints. A typical non-transparent process is the purchasing process; the composition of purchased products may be specified by the supplier or measured when delivered. Unfortunately, many internal organisation processes may be classified as non-transparent, due to technical or economic constraints.

In case of a transparent process, the dotted lines in figure 7-1 should be sufficiently understood to calculate the composition of output materials from the composition of input materials and process characteristics.

7.1.2 Drawing up Materials Balances

The materials balance is a process oriented approach, which, in principle, may be applied to all aggregation levels, such as 'enterprise level', 'main process level' or 'process step level'. For the MIMOP approach, it is already argued that the period of time is important; this equally holds true for drawing up material balances. The algorithm for calculating a materials balance of a particular process includes the following steps:

1. determine, dependent on aggregation level of 'material', which materials should be subject to reporting;
2. gather all input items of a particular process and determine the quantity of 'material' that is supplied;

3. calculate, dependent on the process characteristics, the distribution of the input quantity over the output items.

It is important to determine on what kind of data the calculation of the materials balance should be based. Three levels of accuracy are distinguished.

Standard values The result of a non-transparent process, which is considered as 'standard process' and all input and output values are once-only defined, within e.g. particular process conditions (otherwise, see 'state-dependent values').

State-independent values The result of a transparent process, which is considered to be unique with respect to the actual 'routing' and 'input materials'. However, the values are preliminary calculated and hence, exceptions as a result of this process are not taken into account.

State-dependent values The result of a (non)transparent process, which is considered as it is actually finished. The related values are actually measured, during and at the end of the production process. Consequently, the results of such a process are not known in advance.

For 'standard processes' the calculation of the materials balance is somewhat different, because the composition of output items is once-only determined and can be retrieved any time. The quantity of material flow (kg/time) should still be determined. For obtaining 'state-independent' material balances, the moment this procedure should be followed is unimportant, because al values are preliminary calculated. State-dependent material balances, finally, are based on data measured during or at the end of the process and subsequently recorded. Finally, the output items can be considered as environmental effect, i.e. classified according to the typology, as main, co- and by-product, waste or emission. However, this should be postponed until the materials balance is used in a particular application. This issue is discussed in chapter 8, entitled 'The development of an environmental information system'.

The applicability of materials balances depends on the adequate registration of the composition of input and output products. In the following section, additional concepts are developed to register product compositions.

7.2 Bill-of-Composition

To be able to draw up a materials balance, the composition of all relevant input and output products is needed. The registration of the composition of components and products is achieved by the bill-of-composition.

7.2.1 Definition

The bill-of-materials relation is a good starting point to register the composition of products. For each product, the components are listed in a table-like structure. They are either to be purchased or manufactured. However, from an environmental point-of-view, the current division in and registration of components may be insufficient, for example if the effects of various alternatives for a particular component are unknown or if registration is required on a more detailed level.

The bill-of-materials consists of items and relations between items. In chapter 6, an item was defined as 'any unique manufactured or purchased part, material, intermediate, subassembly or product'. The right of existence for such an item originates from business requirements: an item may be ordered, kept in storage, etc. The bill-of-composition of a component, is defined accordingly, though from an environmental viewpoint. A *bill-of-composition* consists of material nodes and relations between those nodes. The right of existence for each *material node* originates, amongst others, from environmental requirements: an (internal or external) party is interested in the composition.

7.2.2 Application of the Bill-of-Composition

To optimise the use of the bill-of-composition, two types are distinguished: type 1 for purchased components, that result from a non-transparent process and for actually measured values; and type 2 for manufactured components. The least complex method to deduce the composition of a particular product is to store the values physically. This is required for state-independent values for purchased components and for products that result from a non-transparent process. Additionally, state-dependent values should be stored this way, because these cannot be derived from (state-independent) recipes.

For a complete materials balance all constituents of a component or product should be stored up to a definite level of aggregation. From an environmental viewpoint, however, partial material balances suffice which merely require registration of 'environmentally relevant constituents'. In the production of a car, for example, a number of processes make use of paints and lacquers. For the reporting on 'solvents' and 'pigments', the bill-of-composition with respect to this subset of environmental requirements, is depicted in figure 7-2.

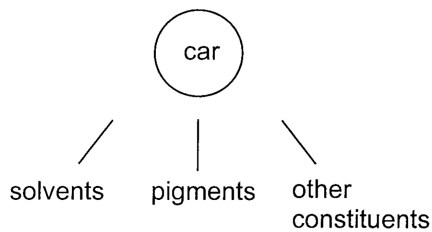


FIGURE 7-2 Bill-of-Composition for a car

Registration of the composition of products in this way, however, is rather inflexible. Therefore, a more flexible registration method may be needed if the production variety increases, as is the case because of marketing purposes.

The physical storage of the bill-of-composition implies that each combination of inputs and process conditions should be stored separately. This approach is rather rigid and due to increasing product variety probably fairly sizeable. Integration of materials balances in ERP software enables one to use calculation techniques and algorithms that are provided in the software package. For the bill-of-composition, a similar method as in the explosion of the bill-of-materials is used. This is shown in an example.

> The construction of a bicycle includes (1) assembly of a frame, two wheels and a saddle; (2) production of spokes and rims; and (3) purchase of aluminium, a frame and a saddle.
> If reporting on the use of aluminium is asked, e.g. due to governmental requirements, the quantity of aluminium in each input product should be known, either because it is physically stored (in case of rims), or because it can be calculated (in this case for spokes, wheels and bicycles).

The (state-independent) composition of an output product can be calculated, provided that sufficient product and process knowledge is available. Required data for the computation consist of product and process data. Since suchlike data is already extensively available in existing ERP-software, e.g. in the 'bill-of-material', 'routing' and 'recipe', it is naturally to integrate logistic and environmental data and applications, if not inevitable. It is also a major implication because it makes significant demands on both systems.

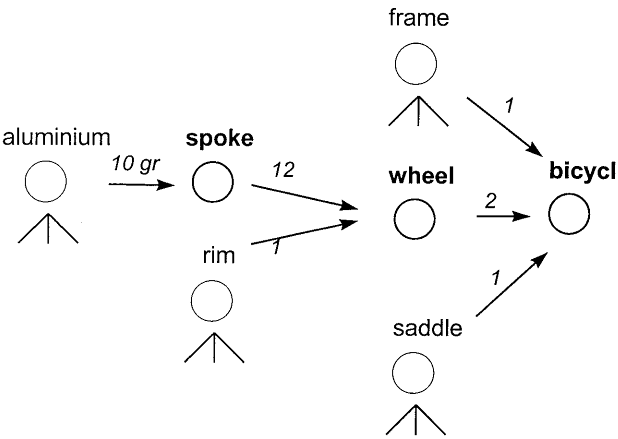


FIGURE 7-3 Bill-of-Composition based on the Bill-of-Materials

7.2.3 Data Model

The use of materials balances is a process oriented approach, based on the entity types 'routing', 'operation' and 'recipe'. The inputs and outputs are based on the entity types 'resource', 'bill-of-materials relation' and 'set of output products'. As a result, the materials balance can be retrieved from a database which is structured as specified in the environmental reference data model. This implies that extra entity types are not necessary, but only extra attributes which specify whether the bill-of-composition is calculated or recorded. It is assumed that the data on composition is included in the previously mentioned entity types. However, those were required from a business viewpoint and additional effort is needed to further detail the composition data and to store state-dependent data. This is accomplished by adding the entity type 'material', as is shown in figure 7-4.

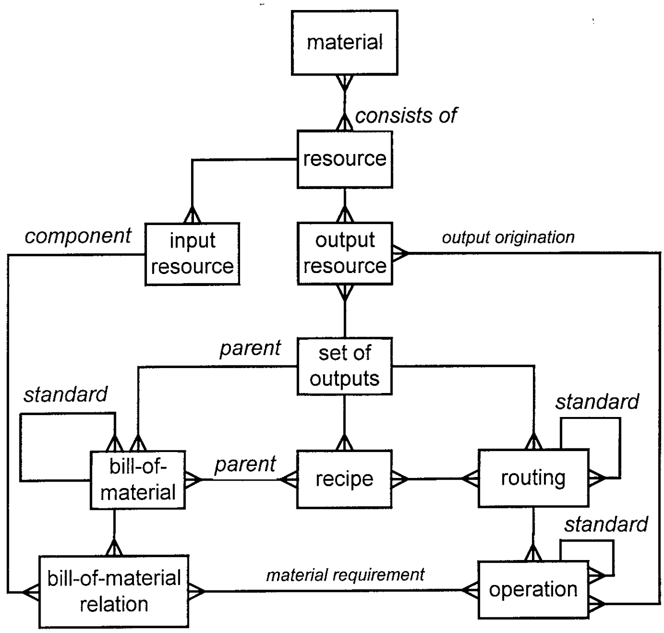


FIGURE 7-4 Product composition in the environmental reference data model

The bill-of-composition - type 1 can be read from the relation type 'consists of' and - type 2 from the entity types 'bill-of-material', 'bill-of-material relation', 'resource' and 'material' and the 'consists of' relation. Finally, an example of the production of a car shows the application of the bill-of-composition. First the bill-of-material and bill-of-material relations are specified.

TABLE 7-1: Bill-of-Materials for a car

item	item type	composition	supplier
car	manufacture	calculated	-
wheel	**purchase**	**stored**	Wheels Inc.
chassis	manufacture	calculated	-
bare chassis	manufacture	calculated	-
engine	manufacture	calculated	-
bumper	**purchase**	**stored**	Bumpy BV
brake	manufacture	calculated	-
suspension	manufacture	calculated	-
paint	**purchase**	**stored**	Paintball BV

TABLE 7-2: Bill-of-Material Relation

Parent	Component	Quantity
car	wheel	4
car	chassis	1
chassis	bare chassis	1
chassis	engine	1
chassis	brake	1
chassis	suspension	4
car	bumper	2
car	paint	5.0

From an environmental point-of-view, it may be requested, for example, to report on the use of solvents and pigments. Solvents are only applied in the car paint, which implies that this paint, a purchased item, should be further specified. In the previous example, the paint is purchased in units of a litre; the quantity of solvents and pigments is 2 kg and 0.1 kg per litre respectively. In table 7-3, the extension of the bill-of-materials relation is shown.

TABLE 7-3: Bill-of-composition

item	material	quantity
paint	solvents	2
paint	pigments	0.1

7.3 Aggregation

After the introduction of the bill-of-composition and the materials balance, one might wonder whether this approach would succeed, because of the high level of detail. The high level of detail, however, is both its strength and its weakness. To compensate the weakness, a mechanism for aggregation is introduced. Two kinds of aggregation are applied in calculating materials balances: aggregation of materials and aggregation of processes.

7.3.1 Aggregation of Materials

Aggregation of materials relates to the method and/or level of decomposition in the bill-of-composition. For example, production of cars requires a quantity of solvent; however, one could also state that it contains ethyl hydroxide and methoxy propanol, which are both solvents. Which decomposition is applicable depends on the purpose of the registration. As a consequence, the required level of reporting determines the level of registration and thus the aggregation level in the bill-of-composition.

Classification

The above described example of materials aggregation can be generalised. The aggregation levels in the material nodes can be classified, showing a decreasing level of homogeneity for environmental purposes.

- ❑ the composing objects have the same chemical composition. The objects pertain to a group with as generating characteristic either a particular (chemical) element, for example paint consists of 0.5% Pb, or a particular (chemical) combination, such as paint consisting of 45% H_2O.
- ❑ the composing objects might have a different composition but pertain to a group of objects that have another generating characteristic in common. These objects have a certain degree of resemblance with respect to a specific application, like a car consisting of 12% of steel. Although from a production point-of-view quite a number of types of steel can be distinguished, from an environmental point-of-view those types can be considered equal.
- ❑ the composing objects might have a different composition but pertain to a group of objects that have physical attributes in common: the generating characteristic is either quantitative or qualitative. An example is the percentage of bones of a pig. From an environmental viewpoint, those types are different, but technical or economic constraints complicate a more accurate approach.
- ❑ in general, the composing objects have a different materials composition, yet another characteristic in common: the generating characteristics originate from another application domain, such as safety (toxicity) or dietetics (food value).
- ❑ the composing objects pertain to the same group of parts or subassemblies.

Data Model

In chapter 2, it has been described what kind of reporting might be asked from authorities, supply chain parties and other stakeholders. In the specified materials view, three examples of such lists have been supplemented: the prioritised materials, special-attention materials and the black list (Ruwel, 1991). Each list consists of a number of categories of materials, which are structured in several aggregation levels (or groups of materials, see the classification described above). The materials or categories which are recorded in such a list, may be found in the applied resources and may be emitted to e.g. soil, water or the atmosphere. The entity type 'resource' can be exploded by means of the 'bill-of-materials relation', hence the material composition might be recorded on each level. The extension of the environmental reference data model is shown in figure 7-5.

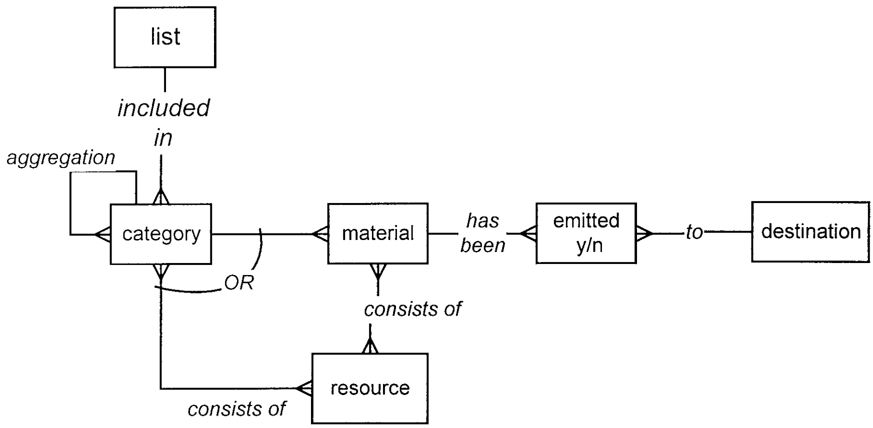


FIGURE 7-5 Materials Aggregation

Environmental reports can be drawn up based on data from each of the aggregation levels, dependent on the (internal and external) requirements. It is mentioned before that many lists are being used. Each enterprise should determine which lists apply for its particular situation. Then, in principle, the occurrence of all materials, or categories of materials, of this list should be recorded per resource. In practice, a particular category merely applies to a particular branch of industry.

This approach is not only restricted to environmental reporting, but is also applicable in related domains that require any distinction of constituent parts of a product. Especially safety requirements are based on such a distinction, supplemented by decision rules on the composition of compounds. As a consequence, several categories may coexist, which cannot necessarily be mapped onto each other and cannot be aggregated in a single category.

7.3.2 Aggregation over Time

A materials balance is meant to report on the environmental effect of a production process or group of production processes. However, production processes aren't necessarily completed when drawing up the materials balance, especially if it involves the entire 'business process'. Additionally, a process may take up a relatively (very) short period of time compared with the period of reporting, e.g. in an annual report. Generally, one should be able to define a particular length of time interval. For that purpose, in the environmental reference data model the entity type 'operation' should include start and finish times. In this way, a report covers all processes in that period, possibly supplemented with production data, e.g. the number of process instances or the quantity of output in that period. As a result, the aggregation over time implies aggregation of process steps.

7.3.3 Aggregation of Process Steps

The aggregation of process steps relates to a more detailed description of production processes. Two kinds of process aggregation are distinguished, both caused by different fields of interests in logistics and environment. In the first type, the actual division of a process in process steps is inspired by logistic decisions. However, it is not excluded that from an environmental viewpoint other material nodes arise. In the example mentioned below, the dotted boxes refer to logistic items and the grey nodes to existing semi-finished products which aren't considered as an logistic item (because those are not kept in storage, not being sold, etc.) but have some environmental impact.

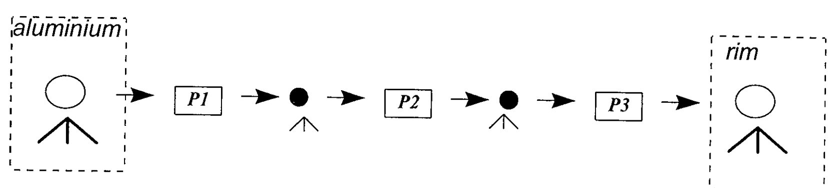


FIGURE 7-6 Aggregation of process steps - type 1

In this type of aggregation, both reporting on detailed and aggregated level is possible. For detailed reporting, additional registration is required for materials nodes which aren't a logistic item. For aggregated reporting (in the example in figure 7-6 for process P, being the aggregation of P1 - P3), the

relations between input and output materials nodes are more complex but not essentially different.
Another type of aggregation of process steps originates from the opposite: when environmental requirements are less detailed than logistic requirements on process description.

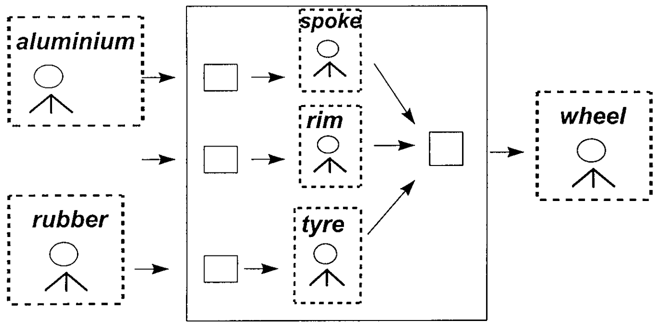


FIGURE 7-7 Aggregation of process steps - type 2

Reporting, according to this type of aggregation is possible by making use of the aggregation mechanism in ERP-applications. If the production of spokes, rims and tyres are registered as processes, the production of wheels is also a process. The process knowledge of the sub-processes can be used to determine the relations between input and output materials nodes of the aggregated process.

Data Model

In a data model (de Heij, 1996) this is described by introduction of tasks. An operation requires a number of tasks, which in turn may be applied in several operations. Corresponding with the aggregation mechanism for routing and operations, a number of tasks may be grouped into larger tasks. Additionally, operation and task sequences are added, which make use of start- and finish times of respectively operations and tasks.

7.4 State-dependent Data

In the previous sections, the materials balance of (a group of) production processes in a particular period of time has been elaborated. It is described in

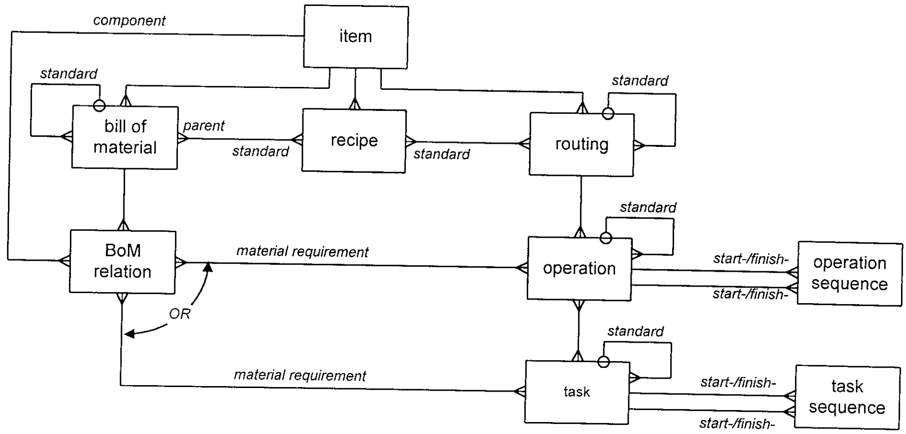


FIGURE 7-8 Process aggregation and decomposition

which way the materials balance and the composition of materials are connected. The difference between state-dependent and state-independent data is only mentioned indirectly. In this section this subject is brought to attention. Starting point is product-oriented state-(in)dependent data, subsequently the accompanying materials balance can be deduced as described before.

7.4.1 State-dependent Data in Logistic Applications

In MRP packages, the flow of materials is recorded in terms of items, which are identified by part numbers. An item uniquely identifies material, and two material occurrences with the same part number are exchangeable from a logistic point-of-view. However, for e.g. quality control, different lots for the same item - part number - are sometimes identified and recorded separately, e.g. for traceability of defects on material occurrences (Bertrand *et al*, 1990). As a result, those items are exchangeable from a logistic viewpoint, though not from a quality viewpoint.

For environmental purposes, a similar unique identification mechanism may be required because actual production processes might go differently than planned. In section 7.1, three types of product data were distinguished: standard, based on preliminary calculations and based on actually measured values. If part numbers cannot be distinguished from each other, the latter two are not significant. In the remainder of this subsection, the used concepts are defined.

Definitions

A *product family* is a set of product types. A product type belonging to such a family is referred to as a variant within this product family. A product family is usually defined based upon a standard product type. This means that the differences in the product structure within a product family will be minimal (Hegge, 1994). In this context, a *product type* is a reference with a unique reference number, called the article code, which refers to the unique combination of parameter settings for the product family to which it belongs (van Veen, 1991). A product type is specified by state independent data; this implies that two products of the same product type cannot be distinguished by identification codes.

> An example of a product family is the 'office chair'. In this example, office chairs have a two options, possibly resulting in 4 product types: with(out) arm rest and with(out) wheels. The product type 'office chair with arm rests and without wheels' is referred to by the article code 123456.

The *product*, as referred to in this thesis, is an instance of the product type as defined above, identified by a unique code, e.g. the serial number (van Veen, 1991). A product is specified by state-independent data, belonging to the product type, completed by state-dependent data, specific for this individual product. The relation between the various levels of abstraction is shown in figure 7-9.

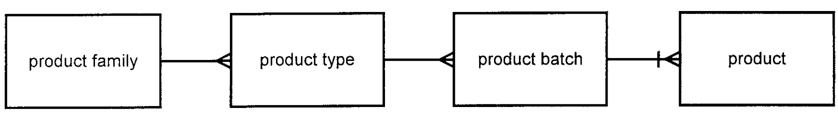


FIGURE 7-9 Abstractions of a product

State-dependent data in logistic applications is concerned with the recording of orders and materials (Bertrand *et al*, 1990). Recording state-dependent data implies that for each individual product a complete set of data should be made available. If the volume of production increases, the volume of data to be registered increases proportionally. Especially in the (semi-) process industry, those quantities are sizeable. However, those products are usually produced in production batches. A *batch* is defined by a set of generating characteristics, e.g. the used raw materials, the specific processes or machines, thus resulting in a large similarity of the individual products in such a batch.

It is assumed that the transformation of input material caused by a process and resulting in output material takes place within particular constraints, or stated differently $(I+\Delta I)(P+\Delta P)-(O+\Delta O)$ is within particular boundaries, see figure 7-10. Such similarity allows the aggregation of state-dependent data, referred to by a batch code. A batch size '1' is an individual product.

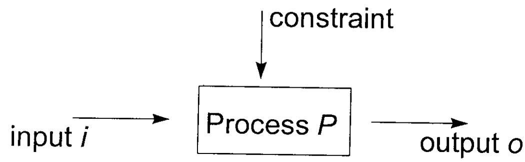


FIGURE 7-10 Context for State-dependent data

Data Model
First, the entity type 'work order' is added; each work order involves one product type ('resource'). To be able to distinguish product instances, a new entity type is defined, 'actual resource', which adds a serial number to the part number. As a result, each work order also involves one product instance and obviously, only one product instance is ordered in one work order. Furthermore, for each 'actual resource', the 'actual bill-of-materials relation' should be stored. Finally, the 'actual operation' should be registered, which links actual capacity units and work orders. The resulting environmental reference data model is shown in figure 7-11. On the next page
The data model is developed for make-to-stock production. Nevertheless, various other variants for production exist, e.g. make-to-order, or engineer-to-order, and consequently a further extended data model should be more realistic. However, this is beyond the scope of this research and reference is made to (Bertrand *et al*, 1990).

7.4.2 State-dependent Material Balances

It is argued before, that that actual production processes might go differently than planned and deviation Δ from static process data is too large. The environmental impact of a production process is modelled by materials balances; the results, the composition of output products, is stored in the accompanying bill-of-compositions. At this stage, the question is raised how

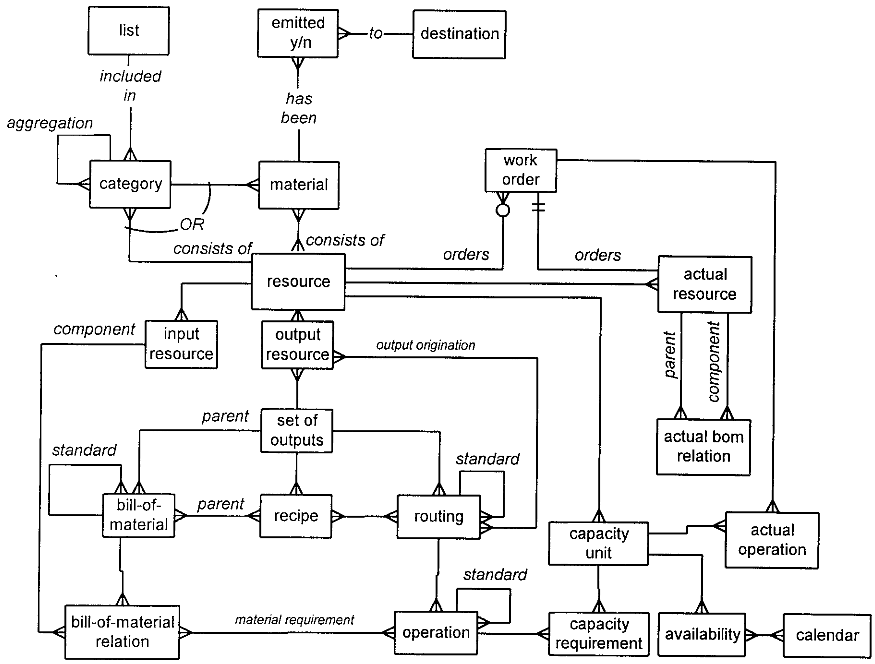


FIGURE 7-11 State dependent environmental reference data model

to register state-dependent composition data. For this purpose, the entity type 'actual bill-of-materials relation' is used, extended with a similar structure for more detailed composition data in the entity types 'actual material' and 'actual category'. The result is depicted in figure 7-12.

In the first approach, the state-dependent variant is a copy of the standard variant. However, the values in the state-dependent bill-of-composition can be adapted. The adaptations are caused by changes in the characteristics of the production process, for example the scrap/yield ratio has been increased by a machine break down. Those changes have then to be determined, which leads to the other step: the introduction of measurements, either directly or indirectly.At present, ERP- software already provides some functionality, mainly for quality assurance objectives, to obtain state-dependent values. Whereas standard values can be made available by recording those data in tables, measured data is achieved by the introduction of 'inspection orders'. Inspection orders can be applied at all stages of the production process. With respect to environmental data, a comparable concept with several inspection

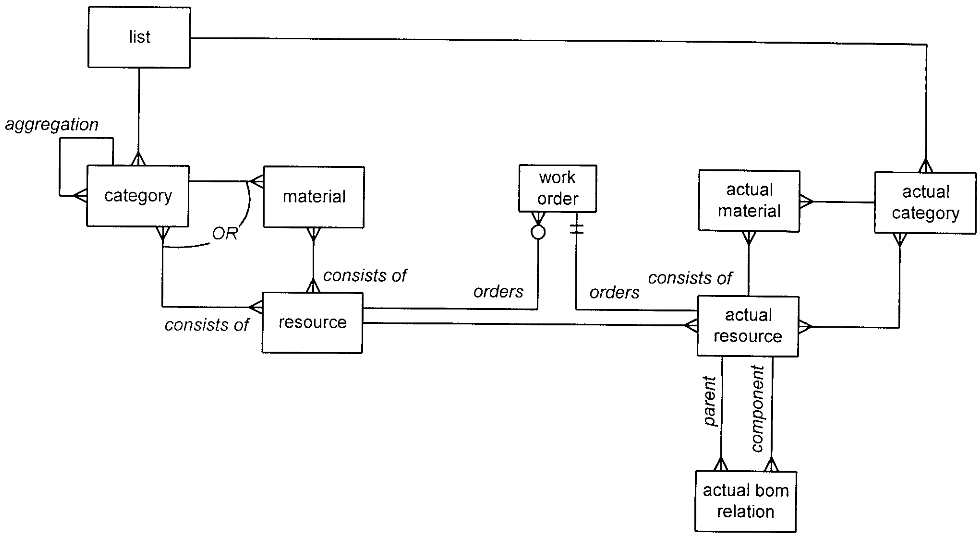


FIGURE 7-12 State-dependent product composition

orders could be followed, if necessary restricted to hazardous and/or toxic products. Additionally, standard values can be applied, based on historic measurements or calculations, simulation data or externally supplied data, and possibly supplemented by the (estimated) variance of the value. The measurements may be performed on-line or off-line, e.g. in laboratories. Traditionally, laboratory information systems are not integrated in the ERP-software, although they are valuable in the supply of state-dependent product data. Consequently, integration of these should be subject of study.

7.4.3 Data Accuracy

The introduction of state-dependent product composition data incites the notion of exactness. Apparently, the state-dependent composition could differ from the state-independent composition. Essential in such an approach is the definition of a batch. From a logistic viewpoint, a batch was defined by a set of generating characteristics, causing large similarity in the products in such a batch. Although this definition is also applicable from an environmental viewpoint, it should be noted that those sets of characteristics might differ per viewpoint. Additionally, one should agree on what might be considered as 'large similarity'. Accuracy is here defined as the lack of discrepancy between the actual value and the value registered in the information system. Discrepancy might be caused by faults and mistakes in measurements and due to usage of standard values. As a result, several levels of accuracy can be distinguished, dependent on the method of data acquisition:

- general standard values of a product family or -type; these standard values can be based on specification from authorities, overall organisations etc., for example the mineral contents of fertiliser. The standard value may be fixed, or dependent on a region, year, or any other characteristic.
- organisation dependent standard values of a product family or -type; this value can be based on estimations or simulations of the production process, such as the commonly applied raw materials or a specific piece of equipment, or can be based on measurements at regular time intervals. It is assumed that the deviation from standard process characteristic is controlled.
- preliminary calculated, product or batch specific values; this value is derived from data of actual raw materials, utilities, production processes and production means. It is assumed that the deviation from standard process characteristic is controlled.
- measured, batch and product specific values;

Standard values for a product family or -type require less effort in registration, but their accuracy is sometimes hard to determine. General standard values are applied to large groups of organisations, and therefore the probability that these values equal the actual value decreases. In addition, there is no longer an incentive for improvements.

Standard values for a specific organisation don't have this disadvantage since they can be adapted, on a yearly basis or, e.g., if the production process has been changed. Furthermore, the variance from such standard values can be estimated.

Preliminary calculated values for specific products or batches are, at first sight, more accurate. However, this might be sham accuracy. If an overall view is lacking, it is hard to check whether all flows are registered. Waste flows are usually omitted if the volume of waste doesn't influence logistic parameters such as processing time. Finally, the continuous measuring of data with sufficient exactness might not be feasible, either from a technical or economic point-of-view.

The precision can be increased by the use of computations, when relations between different data exist, like mass conservation or chemical reaction equations. A typical application is the calculation of mass balances for volatile substances like solvents. On its turn, the required input for those calculations might originate from either of the above mentioned categories.

7.5 Conclusion

In this chapter, an environmental registration system (ERS) has been described. It is developed as an extension of ERP software and it is based on the MIMOP approach. It aims to retrieve consistent environmental data, to be supplied to existing environmental information systems.
To this purpose, the materials balance has been introduced. It turned out that it can be considered as a view on the data model, and doesn't require new entity types. In addition to complete material balances in which all constituents are involved, partial material balances were defined which are restricted to a (small) subset of applied materials. In both cases, the relevant materials should be registered in the composition of products. To some extent, this may be handled in the bill-of-materials, on a more detailed level additional registration is required. The registration of product compositions in this way may be very detailed, though three aggregation mechanisms have been made available.

Materials aggregation This form of registration and reporting is already used in environmental applications, such as environmental reporting. In connection with this, a typology for aggregation levels has been defined and added to the environmental reference data model.
Process aggregation The aggregation of process steps, as applied due to business constraints, aims to decrease the level of detail onto one that is more in line with the environmental requirements. Process aggregation and decomposition mechanisms are often available in ERP software.
Aggregation over time This form of aggregation has been added because environmental reporting is not only required for a particular (aggregated) process but also over a period of time. By increasing the period of time, a number of consecutive processes may be covered. To do so, the start- en finish times of process should be measured and registered.

Finally, the accuracy of data registration is discussed. Several types of product data have been distinguished: for product types (general and organisation-dependent standard values), for product instances and batches (preliminary calculated values and measured values). A materials balance which is derived from this product data can be considered as standard, state-independent and state-dependent respectively.

The environmental reference data model that results from this approach is a basis for adequate data supply for existing environmental applications. The effect of a particular process, and its alternatives, can be used, e.g., in a life-cycle assessment. Furthermore, the extensions as developed for the ERS can be considered as an interface between already implemented ERP- and environmental information systems. The structure of the three layers is depicted in figure 7-13.

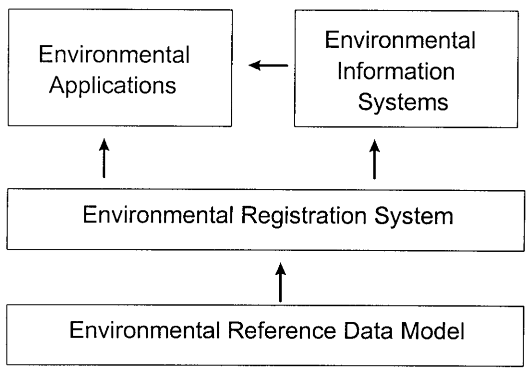


FIGURE **7-13** Layers in the development of an Environmental Information System

Finally, in part 1, it was concluded that an integral approach for environmental information systems is still not available. For this reason, the ERS will be used as a basis for an integral environmental information system. This subject is discussed in the next chapter.

8. Design of Environmental Information Systems

In chapter 4, an architecture for an environmental information system has been proposed (see figure 4.5). This architecture should resolve two issues. The first one concerns an important problem in existing environmental applications: *lack of consistent and adequate data*. This has been elaborated in the previous chapter, when developing environmental registration systems. An Environmental Registration System is based on conventional business information systems and consists of existing and new components, both with respect to data and functionality.
Another important problem, however, is *lack of integration*. Integration is desirable between (1) various environmental information systems; (2) environmental information systems and -applications; and (3) environmental information systems with other business information systems. In this chapter, an integral environmental information system for an individual enterprise is developed, that should settle those three integration issues. Extensive use is again made of possibilities which result from the fact that the Environmental Registration System is embedded in ERP-software. Furthermore, if applicable, a connection with existing applications is established. NB Environmental requirements on the entire supply chain, which have repercussions on the Environmental Information System, are discussed in chapter 9.
This chapter is organised as follows. In section 8.1, an overview is presented of the approach for this chapter. This results in five fields of interest: environmental impact in relation to production (section 8.3); purchasing (section 8.5); costs (section 8.4); quality and safety (section 8.6) and legislation (section 8.2). Based on these aspect systems, an environmental management level is described in section 8.7, which includes functionality for an environmental management system and environmental reporting, as well as connection with environmental applications, such as LCA and product labelling.

8.1 Introduction

In this introduction, it is discussed how an environmental information system can be described. First, it is outlined what is discussed in this chapter and how it relates to previous chapters. Then an approach for decomposition is presented which enables to handle complex system descriptions. This approach, the palisade model, presents a possible structure for a business information system and, consequently, a structure for an environmental information system that is based on such a system. Secondly, from the required functionality, it is deduced which components should be included in this structure.

8.1.1 System Structure

In chapter 4, a system structure for environmental information systems has been proposed. This structure should improve –

1. consistency of environmental data;
2. integration between environmental information systems;
3. integration between environmental information systems and - applications;
4. integration of environmental with other business information systems.

To achieve this, a bottom-up approach has been followed in the subsequent chapters. First, the data registration has been settled in the environmental registration system. This registration is based on core data in Enterprise Resource Planning software: product and process data. For environmental purposes, this data has been extended by material balance data. In this way, one can fulfil requirement 1 and provide a good starting point for requirement 4. This idea is shown as 'data boxes' in figure 8-1.

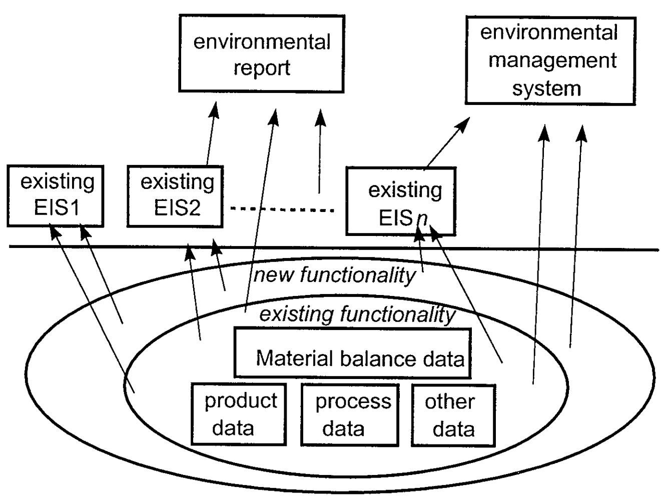
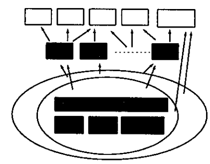


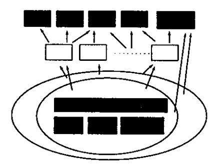
FIGURE 8-1 System Structure

In this chapter, the basis of the environmental registration system is extended to meet the other above mentioned requirements. This is achieved by describing new and conventional functionality to be executed on the extended basis registration, resulting in an integral environmental information system. This integral system is represented in the lower part of figure 8-1; it is used as:

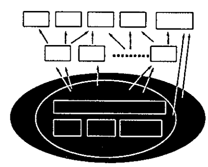
1. A means to supply consistent environmental data to conventional environmental information systems. In chapter 4, it has been argued that those systems are merely strategic or tactical and lack operational data. Those data can now be retrieved from the integral system as shown in the figure alongside; this is not further elaborated here.

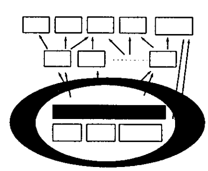


2. A means to supply consistent environmental data to (conventional) environmental applications. In chapter 4, it has been concluded that environmental information systems and -applications are hardly geared to one another. In this chapter, the link between those is elaborated. This especially concerns the upper part of the environmental information architecture, as depicted alongside.



3. An independent environmental information system. In fact, this is the integral system as referred to in the lower part of figure 8-1. This is the core of this chapter, for which integration with environmental applications and with other business information systems can be considered as preconditions.





4. The environmental part of an integral business information system, as a result of integration of data and functionality of conventional business information systems.

Summarising, in this chapter it is elaborated which existing and new functionality should be available for an integral environmental information system. For this purpose, the components of such a system are distinguished and detailed. The whole set of components can be considered as the

environmental information system. As regards environmental applications, each application can be considered as a view on a number of components.
In the remainder of this section, the components are distinguished. Next, starting from section 8.2, those components are described. Finally, in section 8.7, the bottom-up approach is concluded by defining several environmental applications as a subset of the environmental information system.

8.1.2 Palisade Model

In this stage, it is necessary to specify how functionality of an integral (environmental) information system can be described. In terms of the previous subsection, one should define how the functionality of the layers, as referred to in figure 8-1, can be described. This structure should offer a mechanism to decrease the complexity of the model. Such an approach is the palisade model, which originates from the fact that different users consider different parts of their common world. Two types can be distinguished in this context.
An *aspect system* may involve all business functions of an organisation, but is restricted to a particular view or aspect. A *subsystem*, contrarily, covers only one business function, but doesn't exclude a particular view (Bemelmans, 1987). The palisade model, applied to ERP-software, is shown in figure 8-2.

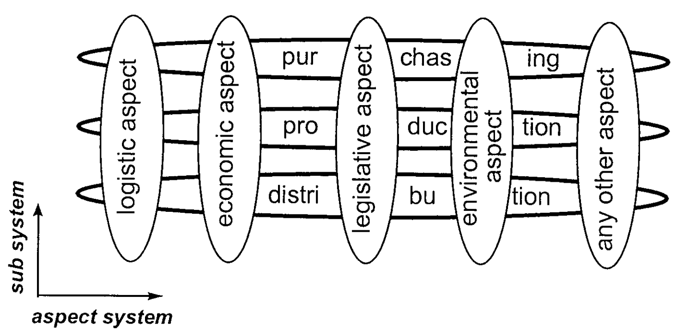
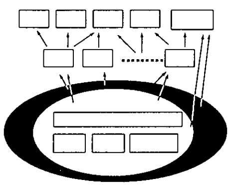


FIGURE 8-2 Palisade model: subsystems versus aspect systems

Those definitions are merely a theoretical starting point, since a particular business object usually belongs to a number of aspect systems. An example is the 'packaging business object', which can be considered from a logistic point-of-view (which distribution item, at which location, with defined quality and costs), a legislative point-of-view (due to the packaging agreements) and an environmental perspective (once-only items cause more waste than re-usable ones).

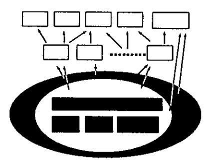
8.1.3 Functionality

In this subsection, the palisade model is applied for the development of an integral environmental information system. In this way, five aspect systems are distinguished.

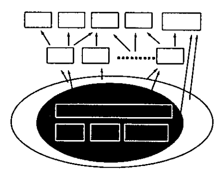


The *legislative aspect* system can be considered as (directly and indirectly) directive for the application of the environmental information system. It is an important source of prerequisites which are applicable for this particular enterprise. This part of the system is, contrary to other aspect systems, not transaction oriented and merely concerns new functionality (the outside layer in the figure at the left hand side).

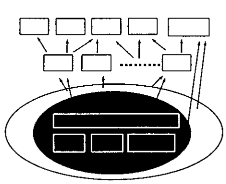
The *environmental-production* aspect system with respect to production and distribution is described. This concerns both existing and new functionality on data registered in the Environmental Registration System, as shown alongside.



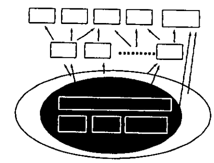
Additionally, *environmental-economic* aspects should be taken into account. Due to increasing environmental costs (e.g. costs for dumping waste) and investments (e.g. for sustainable substitutions), benefits of another environmental policy may be evaluated against its costs. This mainly concerns existing functionality on existing and new data (the inner layer at right).



Subsequently, two supporting aspect systems are discussed. An important role is played by *quality and safety* aspects. This is, a.o., shown by a demand for combined assurance systems from a management perspective, but also from efficiency perspective, because useful functionality may already be available (inner layer, see alongside).



This also holds true for the environmental view on purchasing. However, it is argued that, at present, state-of-the-art business information systems not sufficiently support purchasing yet. In this context, it is argued that environmentally oriented purchasing can be considered as a specialisation of conventional purchasing.



Based on the above mentioned aspect systems, *environmental management functionality* is developed. It covers the information system for environmental management systems, according to ISO-14001 and related ones. It focuses on support for the audit cycle, registration and monitoring of environmental effects and (annual) reports. Furthermore, it is shown that the required data could support other applications, such as LCA or product labelling.

8.1.4 Overview

Summarising, an environmental information system can be described as an environmental view on the sub- and aspect systems of ERP-software. The above described functionality of an environmental information system can obtained by elaborating the following views, see figure 8-3.

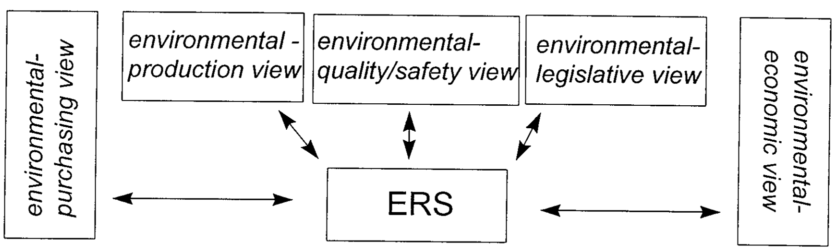


FIGURE 8-3 Views on an Environmental Information System

- *Environmental-legislative view* The environmental–legislative part contains a set of databases with the licences, obligations (e.g. lists with registered substances), agreements and guidelines (section 8.2). Interfaces are perceptible with, amongst others, the safety and quality part.
- *Environmental-production view* The environmental-production view covers information on use of energy and raw materials, waste and emissions: basic functionality for reporting, irrespective of requirements for a particular objective. This view is elaborated in section 8.3.

- *Environmental-economic view* The environmental–economic view is related to environmental costs of products and production. Problems to be tackled are, for example, definition of environmental and energy costs and allocation of those on a particular product or in a particular production order, see section 8.4.
- *Integration with Quality and Safety view* The quality and safety view includes the definition of hazardous product characteristics, the processing of measurements and laboratory data, related to inspections on the product or process, and to
trace lots in the plant. Such data, combined with safety data, enables the organisation to deal with product responsibility (section 8.6).
- *Integration with Purchasing view* In this part, the purchasing process is elaborated (section 8.5). Other logistic aspects are discussed in section 8.3 (production) and chapter 9 (supply chain concepts, such as re-use, recycling and disassembly).
- *Management level* At the management level, the functionality of the aspect systems is used for the purpose of Environmental Management Systems, Environmental Reporting, Life-cycle Assessments or Product Labelling (see ISO-14000 series). Each of these applications requires one or more aspect systems.

8.2 Legislative view

The legislative view (see figure 8-3) provides the domain scope for items to be discerned in the environmental and business information system. It contains databases with licences, agreements and guidelines which may concern all subsystems of the business information system. This view may be used relatively independent of other parts of the system. Nevertheless, the lists with registered materials that result from legislative obligations (see figure 7-5) provide up-to-date information for the calculation of product composition and material balances. In this way, it can be considered as a specification of the preconditions for design of an environmental information system. Furthermore, interfaces with other aspect systems are perceptible, amongst others, the environmental-production view and the quality and safety view.
In chapter 2, several kinds of communication between enterprise and authorities have been distinguished: structural and incidental information flows, detailed product and process data for goal-oriented regulations and aggregated data as part of self-regulation. It has been argued that those flows

are based on information that are, in several ways, derived from materials balances, as is described in section 8.3. These balances are made up of information that is obtained by means of formal or informal environmental audits. A data model of the relation between audits and regulations is shown in figure 8-4.

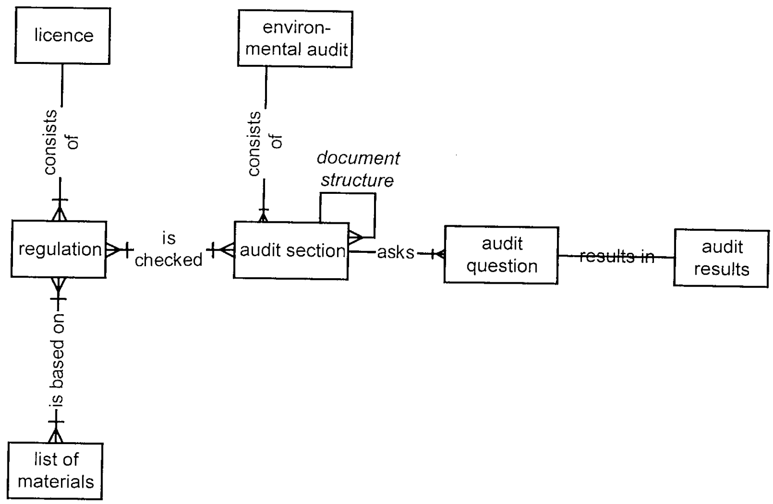


FIGURE 8-4 Relation between audits and regulations

From the database with licences, a set of regulations can be derived. The related text fields refer to a particular part of the auditing procedure. An example is the regulation concerning solvent emission, which states that some emission level of x kg/year should not be exceeded. The corresponding audit section includes a question 'are the emission quantities determined by this and this date?'. An environmental audit may be part of a certified (environmental management) system, but may also be carried out independently. For certified systems, the audit should be carried out by a third party. However, for internal purposes this may be an internal department as well. The audit results may be internally used and communicated to others, a.o. authorities.

Data obtained by audits are also relevant for other aspect systems. Nevertheless, it should be taken into account that additional information might be required. This may concern once-only information, e.g. submission of an request for particular investments, or information on nuisances with a partially subjective character, e.g. a complaint book. This information could still be related to physically based information, for example to assess the relation between 'emission of solvents', 'number of complaints' and particular weather conditions.

Finally, from the database with registered hazardous and/or toxic substances, there is an explicit relation with the safety system, especially the risk and safety data. The database is maintained in the legislative part, the data is accessed from the safety aspect system, comparable with the composition data for the environmental aspect system.

8.3 Production View

An obvious requirement concerning environmental systems, is the quantification of environmental effects due to production processes and products. However, *the* environmental effect itself is still not yet defined. Since the impact depends on many specific parameters, like 'location', it is argued here, that *the* impact doesn't exist. Environmental impact as applied in this research, is considered to be an interpretation of this analysis; therefore only process analyses are presented. At a later stage, the (inter-)subjective interpretation has to be added, e.g. for reporting on 'waste', in fact on 'what a particular person or body considers as waste'. In such a way, the translation from materials flows into environmental impact has been made explicit, and consequently the criteria for the interpretation can be evaluated.

A typical example of a disagreement on the definition of waste material is discarded computer equipment. In Europe, each country, and in the Netherlands, each Province is allowed to enact their own laws on 'waste materials'. These laws, however, might shut the door for a computer manufacturer to refurbish discarded equipment.

A Material Recovery Business Unit aims to re-use products and components, dismantling up to 60 different fractions and recycling of materials. The, for this purpose necessary, inter-provincial and international transportation of waste materials has turned out to be almost impossible due to inconsistency in laws (prohibition to cross borders) and different interpretations of 'waste', ranging from 'product after first use' to 'product that cannot be used anymore'. In practice, material recovery is frequently considered as waste processing, a branch of industry which is subject to rather strict transportation laws. It can be concluded that a product or material as such cannot be considered as 'useful' or 'worthless', though it depends on the entire life-cycle.

First, some examples show the limitations of attempts to standardise the interpretation. Next, a two-step approach is proposed, based on the distinction of analysis and interpretation.

8.3.1 Difficulties in Allocation

Several complications may arise to determine the composition of output materials, and to classify these as useful product or useless waste. In the following, this problem is illustrated.

Distinction between co- and by-product

Production of meat includes, amongst others production steps, fattening of cattle. Fattening has a number of side effects, including the 'production' of manure. In Western Europe, this is usually considered a negative effect and thus manure is treated as a by-product, because the current contribution of nutrients in soil is already (too) high. Contrarily, for mineral-poor soils in, for example, the Sahara, manure production would be a positive side effect, and thus manure was a co-product, if not the primary objective of cattle breeding. Actually, the same held true in Pleistocene regions in Western Europe before artificial fertiliser was available.

As a conclusion, qualification of a particular output product as 'product' or 'waste' is ambiguous. As a mater of fact, the opposite also holds true: the production of vegetables, which extracts minerals from the soil, is recommended in Europe, and dissuaded in Africa. Furthermore, chain effects occur. First, the feed and fodder consists of ingredients that are considered as waste, if it should not be used to feed animals. And secondly, this production results in meat, which has to be substituted for other food stuffs, with accompanying impacts.

Outsourcing

Another limitation comes up in, for example, painting of cars. The painting process additionally requires daily cleaning of machine parts, which should be allocated to the produced cars of that particular day. Let the effect of the cleaning process per car be an amount of wastewater x. To reduce this, the car manufacturer could improve the cleaning process, but he might also decide to sell the remainders of the cleaning process as a (by-)product, to contract a cleaning service, or even to outsource the complete painting process. Only the first option guarantees an actual improvement, and chain effects such as outsourcing should be treated separately.

Mixed flows

In the same case, the environmental effect of the paint shop is dependent on the number of cars to be painted (production dependency) and the quantity of used (or required) cleaning products (time dependency). In the latter case, the impact can be allocated proportionally to production. In general, such facilities deal with different products, creating different production characteristics. As a result, the allocation with respect to these products is usually ambiguous or unknown and allocation for mixed flows therefore arbitrary. Furthermore, chain effects as described above, will occur. The lower the level of detail, the more likely these effects will turn up.

8.3.2 Two-step Approach

The main conclusion to be drawn from section 8.3.1 is the distinction between the objective analysis and the more subjective interpretation. This results in the following steps.

1. *Analysis:* Determine the input and output composition of products or components, based on the materials balances concept. Which materials are taken into account is triggered by stake-holders, due to which the volume of registration can be reduced.
2. *Interpretation:* Assign the composition of each output product to the defined classes, e.g. main product, by-product, co-product, waste and emission; and aggregate the values of the compositions per class, up to the desired level of reporting. In the following, various state-independent and state-dependent aggregation levels for reporting are specified.

An example of this separation can be obtained from the case study in the flexible packaging industry (chapter 5). After the cleaning process of resources, the used cleaning clothes are transported to a waste recycler, because they absorbed lacquer and thinner. In case of once-only cleaning clothes these are discarded as waste. In case of re-usable ones, these are processed resulting in low-value solvent and recycled cleaning clothes.

Interpretation of the process analysis results in quantification of pre-defined output streams, e.g. in a prescribed format, e.g. by authorities. However, in general, the level of detail in the process analysis differs from the required level for reporting. The following levels can be discerned:

- ❑ Reporting environmental effects of an *organisation* within a definite time period; for example an aggregation of effects of all customer orders in the period under consideration. However, this might be too detailed from a practical viewpoint. Therefore, if data are difficult to obtain, other aggregations can be applied, such as aggregation of (state independent) impact of all produced products or executed processes.

- Reporting environmental effects of a specific (group of) production *process(es)* in the period under consideration. These can be considered both dependent and independent on specific inputs and outputs, including dependencies in mixed flows.
- Reporting environmental effects of a specific (group of) *product*(s). These could be determined for a specific phase of the life cycle, over a complete life cycle or in a particular period of time. This impact might depend on specific inputs, processes and resources (state dependent instead of state independent).
- Reporting environmental effects of a specific (group of) *resource*(s). Comparable with the previous level, those impacts relate to either a specific product life-cycle phase, a complete life cycle or a period of time. Also distinction between state dependent and independent applies, as a result of particular production plans.
- Finally, reporting environmental effects of a *customer order,* being an aggregation of the environmental effect of products for a customer order (state-dependent data).

8.4 Economic View

An economic view on environmental issues should first provide an overview of existing fields in business applications (section 8.4.1). In these fields, especially the definition of environmental costs turns out to be significant (section 8.4.2). Finally, consequences for the environmental reference data model are summarised (section 8.4.3).

8.4.1 Overview

The most traditional economic aspect in business applications is *financial accounting,* that automatically supports the delivery of annual reports. It reports on the historic financial events and is a means for external communication (towards shareholders, treasury etc.). An extension of financial accounting is *financial management,* which involves a more future oriented system. It covers the financial decision support based on balances, profit- and loss account, etc. and results in, amongst others, cash management tools, or treasury management. Financial accounting and financial management are both based on the qualification of 'environmental' of particular costs. A financial annual report may, for instance, mention the expenditures due to internal and external environmental obligations. Accordingly, it may support such future decisions.

A third kind of economic tool is the *management accounting*, which supports management decisions, such as order acceptance, make-or-buy decisions, or investment decisions. Environmental management accounting should support environmental management in answering questions such as 'does the enterprise meet the requirements as set by legislation, customers and society', or 'which products or production processes contribute to which part of the pollution, and to what extent'. Though such questions are hardly related to economic aspects, the economic consequences of such decisions should be evaluated.

In this section, especially the subject of environmental costs is elaborated. It is shown that calculation of environmental costs is merely an allocation problem than a different kind of calculation. Environmental costs enter into all three economic fields. However, especially in environmental management accounting they are extensively applied.

8.4.2 Environmental Costs

Environmental costs may be related to particular product types or to a production process in a certain period. These costs can be preliminary calculated (state-independent) or post calculated (state-dependent), e.g. for particular orders, respectively for an enterprise in a period x. However, the allocation of costs to environmental and non-environmental costs might be ambiguous, dependent on the used definition of environmental costs. To gain insight in environmental costs, the following definition is introduced (CBS, 1991): *environmental costs are defined as the additional cost for an organisation, compared to the situation in which this organisation didn't consider the reduction of environmental impact and in which environmental taxes are excluded*.

A weakness of this definition is that external costs, costs at expense of society, are not included. Though external costs play a key role in preventing environmental damage, this factor is not further elaborated at this stage. At present, any improved definition is arbitrary; in view of the scope of this thesis, the authorities' measures should suffice.

Based on the development of a quality cost system (Nakamura, 199?), the environmental costs are made operational by the distinction of prevention costs and calamity costs. *Prevention costs* result from the organisation's care for the external environment, by listing, controlling and reducing its impact. *Calamity costs* result from a negative effect of business activities, despite of prevention. A typical example are costs to take measures to get rid of chemical waste or the costs of environmental taxes. The distinction of prevention and calamity costs empowers an organisation to control environmental costs.

It still remains difficult to label costs especially as environmental costs. One complication is caused by the financial benefits that may be achieved. A simple case is the profit caused by selling or re-using what should formerly be considered as waste. Investments for preventive activities will be recovered sooner, if such profits are included. This also holds true for costs, e.g. taxes, that are not made due to prevention activities. Such profits are taken into account as negative costs. More complicated is the deduction of investments that had been made regardless of environmental considerations, like replacement investments for a piping system or a new refinery with reduced SO_2-emission and less workforce.

A second complication in defining the environmental costs arises if those costs have to be assigned to a specific product (type), the so-called allocation. This occurs if strategic decisions for products are made which are (partly) based on environmental costs. The allocation problem presents itself if the production process yields multiple desired outputs (divergent process); in that case, it is arbitrary to assign the environmental costs to a particular output. Nevertheless, the allocation problem is well-known, e.g. in the field of Activity Based Costing, though is not completely solved in cost accounting.

8.4.3 Data Requirements

In ERP- software, considerable functionality for cost accounting is available. This module calculates cost prices for 'items', based on bill-of-material data, recipe data, routings and cost price changes for raw materials, labour costs etc. In the previous section, it has been argued that environmental costs should be defined and allocated carefully, but then can be considered as costs to be assigned to a particular cost entry. Hence, the environmental costs can be calculated, comparable with these other cost prices. For that purpose, the environmental reference data model suffices, but accompanying calculation algorithms should be added.

Calamity costs can be calculated by cumulating the costs for the item types 'waste' and 'emission' and for particular production and/or removal costs.

Prevention costs, e.g. for replacement investments, are not covered in ERP-software and require additional functionality.

8.4.4 Conclusion

When agreement is reached on the definition and allocation of environmental calamity costs, calculation of those costs can be carried out in line with conventional cost calculations in ERP-software. If the environmental information system is based on such a system, environmental costs of products and processes can be calculated. This information can be used in financial annual reports and for financial management purposes. With respect to environmental management accounting, the environmental costs are a basis for further decision making.

8.5 Integration with Purchasing

Environmentally oriented purchasing is considered merely from the manufacturer's viewpoint. In this subsection, the general purchasing process is depicted, with an emphasis on environmental information systems.

8.5.1 Purchasing

A functional definition of 'purchasing' can be found in (van Weele, 1994). He defines purchasing as 'the procurement from external sources of all goods and services that are necessary to run a business, for maintenance and for management under the best possible conditions for the organisation'. He classifies production steps in (1) *initial purchasing*, at a tactical level, including specification of requirements, selection of suppliers and contracting, and (2) *ordering*, at operational level, including ordering of goods and services, monitoring progress, quality and financial aspects, and follow-up, evaluation and vendor rating. In figure 8-5, the succession of purchasing steps is shown.
Each material that is purchased passes these phases, though the importance of each phase may differ in the level of detail, dependent on the type of product and the role of this product in a business process. In (de Heij, 1996), a number of purchasing groups are distinguished: raw materials, additives, semi-

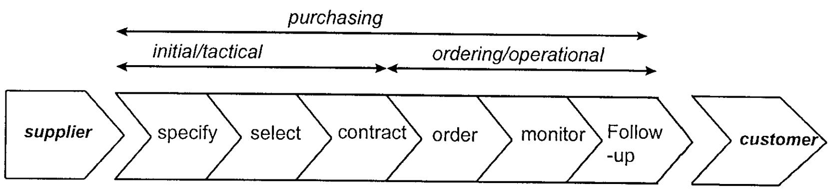


FIGURE 8-5 Overview of purchasing activities (van Weele, 1994)

finished products, components, finished products, investment goods, indirect goods and services. For those purchasing groups, especially the operational level of purchasing ('ordering') is implemented in state-of-the-art ERP software (de Heij, 1996).

8.5.2 Environmentally Oriented Purchasing

From an environmental viewpoint, desired products should meet a similar set of requirements in comparison with a purely business-oriented viewpoint. Those requirements still include price, quality of products and processes and logistic aspects such as delivery conditions. However, these are evaluated for environmentally relevant purposes, which may manifest themselves when specifying a product or when selecting a supplier. Those activities amount to adaptation of general quality requirements in a more sustainable direction: specifying additional requirements, finding suppliers which meet those requirements and evaluation of (traditional and) new criteria. The following requirement levels may be distinguished:

- supplier requirements, e.g. the supplier makes use of a, possibly certified, environmental management system such as ISO-14000;
- organisation requirements, e.g. the supplier belongs to a corporation that meets certain requirements or takes part in a supply chain initiative, such as a label for beef;
- product-supplier requirements, e.g. this particular product of this supplier meets requirement *x*, such as non-chlorous paper;
- product-supplier-process requirements, e.g. this product of this supplier is manufactured in a particularly specified process, as is known, for example, for free-range eggs or 'Max Havelaar' coffee; and
- product-supplier-process-resource requirements, e.g. this product of this supplier is manufactured in a particularly specified process with a particularly specified resource.

8.5.3 Data Requirements

The above described requirements for environmentally oriented purchasing are mainly raised in initial purchasing. Existing ERP software, however, barely provides support for initial purchasing (Van Stekelenborg, 1997). For this reason, a dedicated data model for a.o. source selection is proposed in the same publication. Starting point are products and activities that are subject of a purchasing process. Responsibility to supply products and carry out activities is modelled through contractual relations between organisations. In addition, it may be required that relations are modelled in more detail. A product may consist of components (bill-of-materials relation), activities may be composed of sub activities (process decomposition) and organisations may be structured in departments. Likewise, smaller operations can be modelled, as well as tools and production equipment that is used in production. The matching data model is shown in figure 8-6. In fact, external organisations can be modelled in the same way as an internal organisation. As a result, this allows for the definition of customers of the potential supplier.

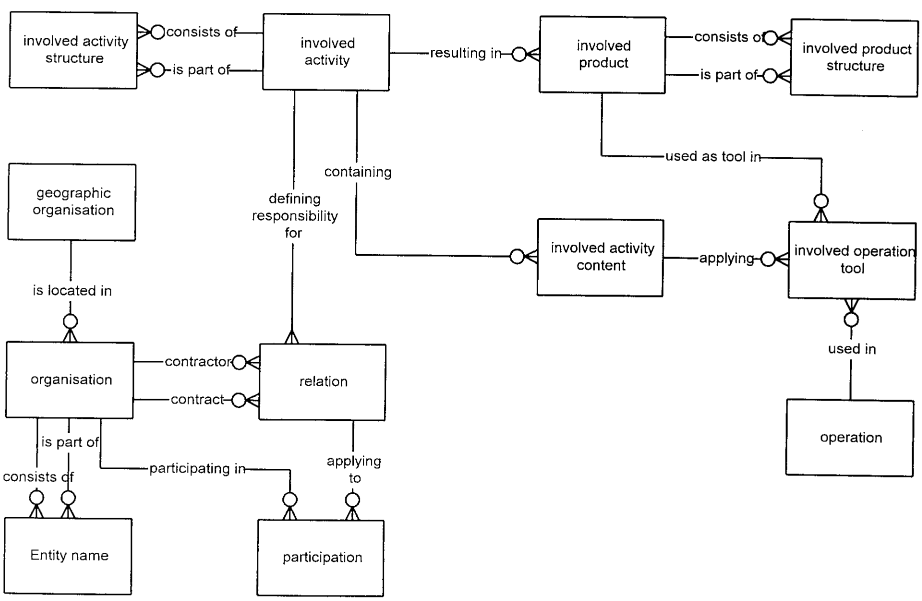


FIGURE 8-6 Modelling potential sources (taken from Van Stekelenborg, 1997)

Modelling Support of Diversity

The purchasing activity may strongly vary according to products and their features. Products may be selected on different criteria for different product classes, so-called product specific features. Furthermore, each feature has a number of (product type dependent) options, which may be a basis for selection. An example is shown in table 8-1.

TABLE 8-1: Features and options for selecting products

Product type	*Product subtype*	*Feature*	*Options*
vehicle	bike	length	2,0; 2,5
		max velocity	20; 30; 40
	car	length	4,0; 4,5
		max velocity	80; 120; 180; 200
office equipment	table	life span	10; 12; 15
		price	<100, 100-150, >200
	chair	life span	25, 30
		price	<10, 10-30, >30

Besides the class of 'products', many other classes may come up when specifying requirements. As a result, generalisation is required. For initial purchasing, this concerns the entity types in figure 8-6 ('organisation', 'relation', 'activity', 'product', 'operation', 'tool'). A mechanism, based on (Hegge, 1996), that allows the generic definition of objects is provided by Van Stekelenborg (1997). The data structure that models this mechanism is represented in figure 8-7.
The example in table 8-1 can be considered as a possible population of this data model. A 'generic source' contains a number of 'source specialties', e.g. (vehicle, bike) or (product, office equipment), but also (process, maintenance) and is described by 'features'. Furthermore, the applicability of a 'source specialty' is defined by 'options', which belong to a particular 'feature'.

Modelling Environmentally Oriented Purchasing

Thanks to the high level of abstraction of the model in figure 8-7, addition of environmental aspects to initial purchasing software is not a major operation. Adjustments are merely required on the attribute level, which should be extended with environmentally relevant features. In figure 8-6, this especially holds true for the entity types 'feature' and 'option' and may include the criteria as summarised on page 146. A disadvantage, however, is that a particular structure in purchasing requirements is not available. Due to this, it is possible to create a wide variety of unstructured purchasing conditions. In

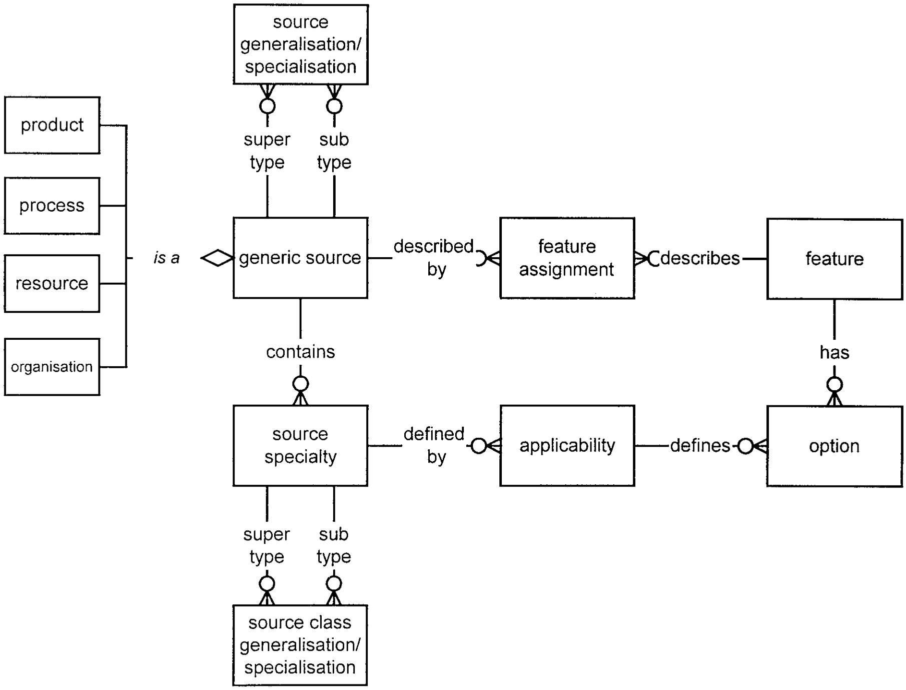


FIGURE 8-7 Modelling features and options

general terms, this can be settled by a classification hierarchy for 'features', see figure 8-8. From an environmental viewpoint, a generic source may include the supplier organisation, processes, products and production means. Features and feature classes include the environmental effects as specified in the lists of hazardous and toxic materials. However, it is argued before that further detailing and prescribing of features is highly organisation and region specific, and should be refrained from on a generic level.

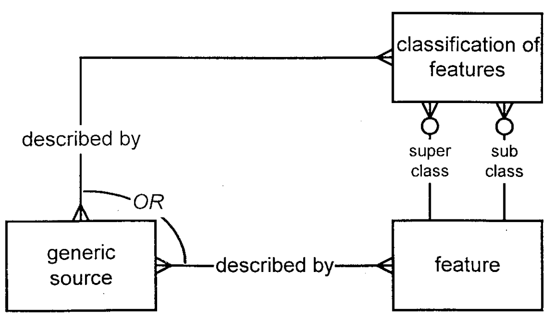


FIGURE 8-8 Classification of features

8.5.4 Conclusion

In many ERP systems, functionality is accommodated for operational purchasing processes (ordering). Environmentally oriented purchasing, however, merely concerns initial purchasing. Dedicated software for this purpose is not commercially available, though a data structure for initial purchasing is proposed by van Stekelenborg. This structure also allows the modelling of environmental features and options. Finally, a classification for features can be added to structure all kinds of requirements.

8.6 Integration with Quality and Safety

In the environmental - quality model, the product and process characteristics with respect to environmental issues are specified. From this viewpoint, a number of topics are covered: quality data, safety data and laboratory data.

8.6.1 Quality Definition

One of the main problems in specifying quality is caused by the different views, and thus different definitions. An overview is provided by (Bassie et al, 1995). A first idea is expressed in the transcedental view: quality is absolute and can't be analysed. Statements concerning quality can therefore only be made by comparing different objects. In practice, however, this definition encounters several obstacles. More operational is a product based definition: quality depends on the quantities in which certain measurable characteristics are present. Tendency of quantities towards such a characteristic means higher quality. For 'users' this is accentuated to 'fit-for-use' (Juran, 1979), and for manufacturers to 'conformance-to-requirements' (Crosby, 1979). In this research, this definition is taken as starting-point and particularised as *the combination of product and manufacturing based quality: both the product and the production process meet specified requirements.*

8.6.2 Quality Management

Another source of confusion is the application of 'quality' on different levels in the organisation, namely as quality control level (the lowest level), quality management level and quality assurance level, as is depicted in figure 8-9. The same concepts have already been discussed in chapter 2, particularised for 'the environment'. It is often advocated that 'quality', 'safety' and 'environment' should be integrated in so-called integral or combined systems; this applies for the assurance and management level.

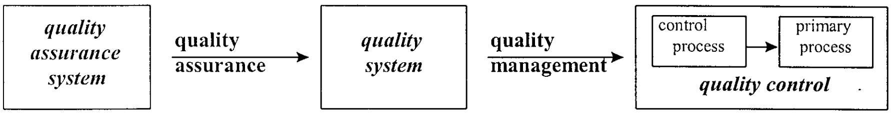


FIGURE 8-9 Levels of quality assurance (taken from Bassie et al, 1995)

A research project on Quality Assurance Software Application Requirements (QUASAR) proposes a reference model for the *quality control* level (Bassie, 1995). This model consists of three dimensions: the object of control, the steps in the control process and the implementation.

Object of control The model can be applied on products, production processes and resources. For the products, for example three types are identified: raw materials, semi-finished products and end-products. Processes may include product design, purchase, production and sales. Finally, resources covers machines, tools, employees and measuring instruments.

Control steps For each of the objects, five control steps are distinguished:

1. Identification of the quality characteristics. Since quality has been defined as conformance to particular requirements, those should be specified.
2. Specification of standard values and unity for those characteristics. For each quality characteristic, a standard value is specified; together the description of the quality requirement.
3. Specification of measurement methods for each quality characteristic: how and when should a measured value be obtained.
4. Storage of measured values. To be able to analyse and verify results at a later stage, it should be defined how those values are stored.
5. Verification of those results. The outcome of the measurements are compared with the specified norms, resulting in a conclusion on the quality of the object.

Implementation level Finally, for application in (ERP) information systems, three architectural layers are distinguished: state-independent data, state-dependent data and decision support (Bertrand *et al*, 1990). For each of the implementation levels, the control steps can be supported , which has been depicted in figure 8-10. Example populations of this data model are represented in Table 2 and Table 3.

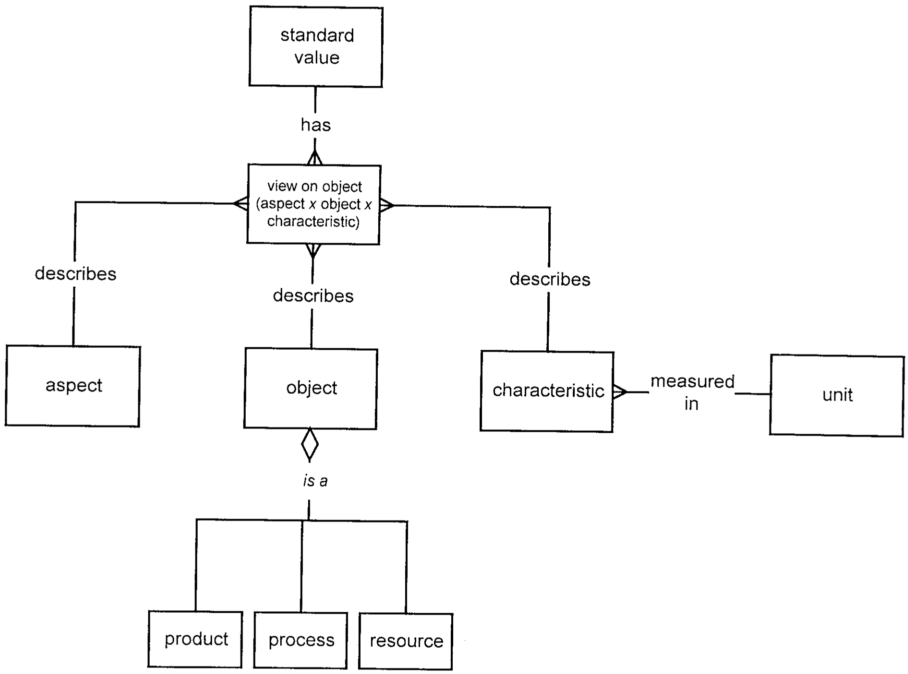


FIGURE 8-10 Data model for quality

From an environmental viewpoint, this data model is very well applicable by extending the set of characteristics. Additionally, some of those characteristics can be considered as safety properties and are usually further detailed in the safety system. Following the terminology in figure 8-9, the control processes for 'quality', 'environment' and 'safety' are different, though these are based on the same product and process data. This enables a similar approach for management of the control processes and, as a result, integration of the accompanying assurance systems. This is also relevant in the context of automated support, because support for quality information may already be available, e.g. in the form of 'inspection orders' which are used to collect actually measured data. Finally, with regard to actual measurements, specification and storage of those might be carried out in a laboratory, which is supported by a laboratory information system.

TABLE 2 View on an Object

id	object	aspect	characteristic
0011	apple	taste	hardness
0012	apple	taste	acidity
0021	apple	image	colour
0022	apple	image	size
0111	car	image	speed
0121	car	environment	petrol consumption
1110	apple harvest	product quality	speed
1210	apple packing	environment	recycled
1310	painting	environment	solvent use
1311	painting	endurance	hardness
211	road worker	safety	colour

TABLE 3 Characteristics

id	characteristic	unit
1	hardness	N/m^2
2	acidity	pH
3	speed	km/h
4	recycled	yes; no

8.6.3 Safety data

An important topic in environmental management is materials control. The materials database, actually a view on the logistic 'items database', is a key concept in both safety and environmental applications. This database consists of all materials that enter and leave the boundaries of the organisation. For safety reasons, dedicated registrations for particular products, Material Safety Data Sheets (MSDS) are developed to control (specified) hazardous flows. The legally bound information distribution by means of MSDS thus is a subset of the materials database. Additional requirements of registration include the possible effects of a material, so-called 'risk' data and the accompanying measures to prevent calamities, so-called 'safety' data.

Data Requirements

It is argued that the data model of figure 8-10 can be applied for quality and environmental purposes, as well as for safety reasons. For the latter, the entity type 'subject' concerns a product 'item', and the entity type 'aspect' the safety issues. MSDS data should involve a listing of the risks that may be caused and of the regulations for handling a particular item.

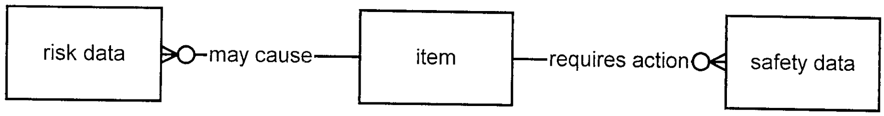


FIGURE **8-11** Safety Data Model

MSDS sheets can also be generated for manufactured items. Based on the process characteristics, specified in the 'recipe', a particular combination of materials results in a new material or product item for which another MSDS might apply.

8.6.4 Conclusion

In this section, it has been described that the quality and safety aspect systems are closely related with the environmental aspect system. For each of those, the control of primary processes is different. Based on the model of (Bassie, 1995), this control can make use of the same kind of data. For this purpose, three dimensions have been defined and subsequently represented in a data model. This involves the subject of control, e.g. products or processes, the control steps and the implementation level.
Due to this, the management of this control level can be dealt with in a similar way and quality assurance, respectively environmental and safety assurance can be integrated in so-called 'integral' or 'combined' assurance systems. Finally, a safety system requires generation of MSDS sheets. Those can be realised by a view on a common database, extended with risk and safety data.

8.7 Environmental Management Level

An *environmental management system* is, defined in the terms of figure 8-9, a dedicated assurance system. Application of such a system in an enterprise results in an environmental program, with organisation specific policies, action plans and implementation. Subsequently, effects of a new plan should be measured, monitored and reported, after which deficiencies are eliminated and a revision of the plan may take place. In this section, the main parts of an environmental management system are elaborated in view of the previously designed environmental information system. For this purpose, three subjects are raised: automated support for audit cycles (section 8.7.1); automated support for measuring and monitoring (section 8.7.2); and environmental reporting (section 8.7.3).

The information which has been collected for the EMS can also be used by other environmental applications, e.g., *environmental reporting* may also be used for annual reports, as is also discussed in section 8.7.3. Measuring may be used for product information in the form of *product labelling* or *life-cycle analysis*. This is discussed in a separate subsection (section 8.7.4).

8.7.1 Support for the Audit Cycle

Passing through the steps of an audit cycle involves scheduling of the activities in the audit cycle, based on particular start or finish times and the assignment of personnel to those activities. Basically, this requires scheduling of activities and (human) resources, which may be applied in ERP-software as work-flow management.

Work-flow Management

The goal of work-flow management is to manage the flow of work in an organisation in such a way that work is done at the right time by the proper person. Work-flow management includes control of documents in an organisation, means to execute specific tasks, and co-ordination, planning, control and communication of work in relation to employees. Control of work can be realised by splitting it up in activities. The design of an organisation is not taken into account, as well as the way in which individual tasks are executed.

In principle, work-flow management is independent of automated tools that might support work-flow management in an organisation. However, in large scale environments it is inefficient or even unfeasible without such tools.

Data Requirements

The core of a work-flow system is the decomposition of activities in smaller tasks. This functionality has already been described in the environmental reference data model, see chapter 7. Additionally, it is possible to register which employee is responsible for a particular task, based on the task type.

This is recorded independent of an actual task to be carried out. For that purpose, state-dependent data is added: a group of specific tasks, a 'specific order', requires a case-manager who is responsible for the way the task is carried out. The case manager is employed at a department, which also provides an employee to carry out this task. The above is depicted in figure 8-12.

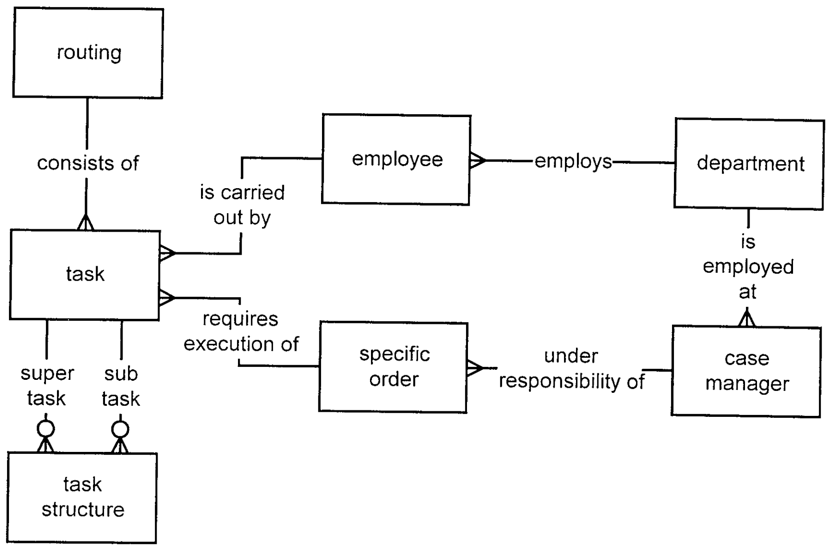


FIGURE 8-12 Data model for a work-flow system, based on (van den Berg and Kusters, 1996).

It is recognised that this model can be optimised and extended as a result of specific requirements. However, those extensions are not dependent on the environmental domain and thus beyond the scope of this research.
Furthermore, this part of the system is independent of an environmental information system; in fact it is frequently applied for logistic, or quality improvement.

8.7.2 Measuring and Monitoring

An EMS makes use of a number of environmental aspect systems: production, quality and safety, and legislation (see figure 8-13). In the legislative view, it is determined which issues should, at least, be taken into account, such as use of solvents, or applied quantity of cadmium. This can be supplemented by other issues that are important for a particular enterprise. This results in a list of environmental issues under study[5]. Environmental effects of those issues are retrieved from the production view and, if necessary, supplemented by quality and safety data.

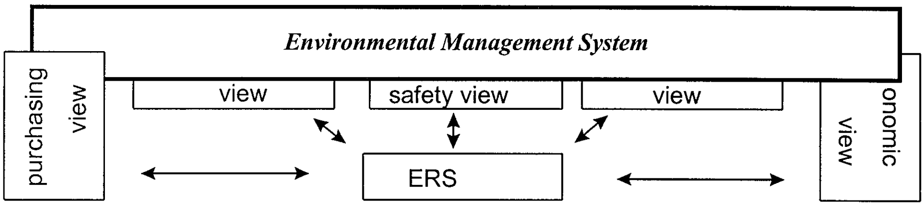


FIGURE 8-13 Environmental Management System in an Environmental Information System

Mirroring actual situations

In the environmental program of an EMS, it can be specified which environmental subjects are raised in a particular period. Usually, this involves improvements to products and processes with the intention to reduce a particular environmental effect. It has been argued in section 8.3, that this can be deduced from the composition of resources and the material balance of a production process (Environmental Registration System and environmental aspect system). For this purpose, it should be determined which materials are relevant for the effect under consideration and which processes are of importance. For these processes, it should be decided to which extent the composition of input and output flows should be actually measured (state-dependent data), and which data should be retrieved otherwise (state-independent data). When this policy is ready, the requested data can be registered in the environmental registration system. The progress can be monitored per period of time.

Forecasting future situations

So far, the registration of actual or estimated environmental effects of production has been discussed. Implicitly, this registration is made of processes which already have taken place. Another application can be found in the area of planning and simulation. Since state-independent data can be made available in advance, before the actual production takes place, this data can also be used to estimate the consequences of a decision, e.g. to purchase a batch of raw materials with specification *x*, price *y*. By calculation of the expected

[5] In an earlier phase, this list should have been translated into the Environmental Registration System, as a result of which only relevant materials are registered.

environmental impact, a deliberation can be made whether the price y justifies the environmental impact and the costs this might cause, e.g. by exceeding emission ceilings. Possible precaution measures could be to purchase another raw material, to adjust production process or to change investment decisions. Planning and simulation can be based on capacity requirements planning for production orders. Usually, capacity requirements planning is carried out for capacity and liquidity checks, but can be extended to visualise environmental consequences of a production plan and to evaluate to what degree admitted production impacts per time period has been used.

8.7.3 Environmental Reporting

Environmental reports are widely used, frequently as part of an Environmental Management System or for annual reports. For both, it is important to register consistent data, which can be obtained from the Environmental Registration System, in combination with an environmental-production aspect system. The roles of quality, safety and legislation can be compared with those for measuring and monitoring. Purchasing aspects may be included as a means to justify earlier decisions to choose for a particular product or supplier. Finally, economic aspects may be included, amongst others costs and benefits of environmental improvements, possibly allocated for particular products or processes.

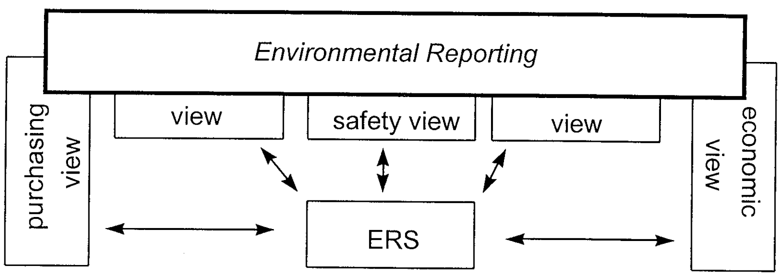


FIGURE 8-14 Environmental reporting in an Environmental Information System

Which data is relevant for a particular enterprise is branch and region or location specific, and therefore not further specified here. For reporting in an environmental management system, it may be specified in the legislative aspect system or management system itself. For environmental annual reports, this is not specified at all (yet).

The most simple variant of an environmental report consists of one or two paragraphs in the financial annual report. The most comprehensive variant is an independent report which may consist of the following items.

- representation of data on environmental effects of an enterprise, possibly further specified for significant products and processes, environmental cost data, relation with quality and safety issues and the way in which environmental regulations are fulfilled;
- Placing the above intended data in context with relevant business figures, history data and benchmarking information of comparable processes and enterprises.
- Evaluation of the environmental management system and discussion on the progress of the environmental program.

8.7.4 Environmental Product Information

Environmental product information is discussed here in two variants. *Product labels* may concern various kinds of product characteristics, as registered in a combined assurance system. *Life-cycle assessment,* in general, includes (part of) an entire supply chain, though is confined to typical environmental effects.

Product labelling

Product labelling is a means to communicate characteristics of a product. These (intrinsic and/or extrinsic) characteristics are based on properties of production processes as recorded in the production view, possibly supplemented by quality and safety data. Furthermore, purchasing policies may be taken into account, as well as information recorded for the purpose of regulations and audits. The latter may result in a certified product label. An overview is shown in figure 8-15.

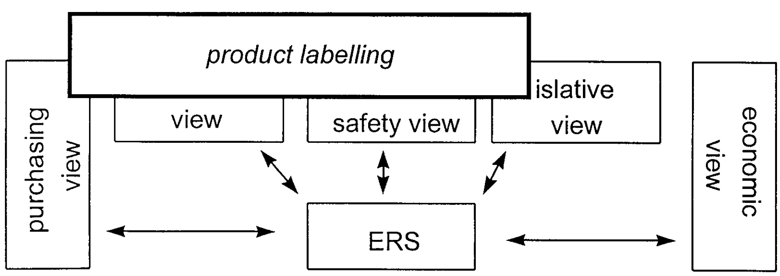


FIGURE 8-15 Environmental labelling in an Environmental Information System

Product labels may also be based on a number of production steps carried out by different enterprises. In that case, supply chain information should be added. This subject is raised in section 9.3.

Life-cycle Assessment

A life-cycle assessment is a cradle-to-grave approach for a particular product type. As a result, the assessment covers several life-cycle phases, including consumption and waste processing Consequently, several enterprises are involved and should supply environmental data. In this subsection, data supply for one part in such a chain has been outlined. This data is mainly based on data from the Environmental Registration System and production view, see figure 8-16.

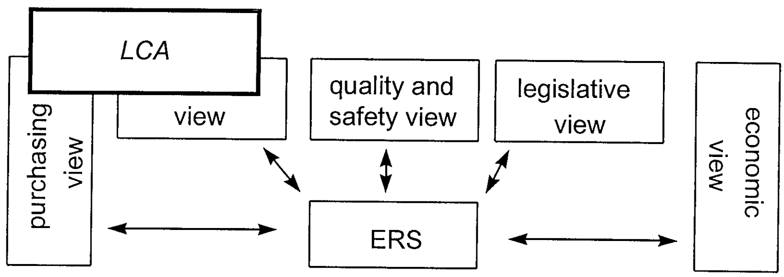


FIGURE 8-16 Life-cycle Analysis and Environmental Information Systems

8.8 Conclusion

In this chapter, a method has been described for modelling of ERP-systems. It distinguishes subsystems and aspect systems and for each combination, a software component can be designed. In this thesis, the environmental aspect system is elaborated. It is detailed for the subsystems production and purchasing and for the overlap with the economic, legislative, quality and safety aspect systems.

The *legislative* aspect system, turns out to be rather loosely coupled with the other aspect systems. It is mainly provides the domain scope for items to be discerned in an environmental information system. It supports storage of (environmental) licences and regulations, and the derived audit structure. It supports the registration of composition data for items in such a way that it specifies which materials should or could be of importance.

For *production*, it is described on which levels an environmental effect can be considered. For processes, an environmental effect can be calculated for a

single process step or an aggregation of those, often onto the level of the entire enterprise. For products, an effect can be calculated for a single end-product, and for a particular customer order. Finally, the effect of production means can be assessed. Dependent on the registered data, the effect may be state-independent (preliminary calculated) or state-dependent (actually measured), and is considered over a particular period of time.
In the cross-section with the *economic* aspect system, especially environmental costs are important. It turned out that these costs aren't really different from other costs, as far as the calculation is concerned. However, it is difficult to determine which costs should be considered as environmental costs and how these costs should be allocated on a particular product group.
For *purchasing*, it turned out that automated support is merely available for the operational level, which involves the ordering process. Environmentally oriented purchasing, however, especially concerns initial purchasing: the selection of products and suppliers. Initial purchasing is not implemented in ERP systems yet, though a design has already been made in (van Stekelenborg, 1997). This design proves to be sufficiently generic for the implementation of environmentally oriented purchasing.
The *quality* and *safety* aspect systems, finally, turn out to be closely related to the environmental aspect system. For each of those, the control of primary processes is different, though based on the same kind of data. Due to this, the management of this control level can be dealt with in a similar way and quality assurance, respectively environmental and safety assurance can be integrated. In practice, this is often called an 'integral' or 'combined' assurance system. Additionally, as an example, a safety system requires generation of MSDS sheets. Those can be realised by a view on the same database, extended with risk and safety data.

Finally, in the environmental management system, three issues are discussed that may be covered by an environmental information system. First, the support of the *audit cycle* is described. It turned out that it especially depends upon the management of the work flow: scheduling of activities based on due dates and the assignment of personnel to those activities. This can be covered by existing work-flow management systems, which are based on process decomposition. Because the environmental reference data model is also based on process decomposition, this model can be extended in line with work-flow management systems.
For the *registration* and *monitoring* of environmental effects, as may be required in an environmental management system or for other internal

objectives, the environmental registration has paid its rewards. Additionally, extension of this approach supports decisions by planning of future environmental effects, based on state-independent data of planned input resources and production processes.
Finally, the role of *registration* is illustrated. At present, environmental reports are already being made, though adequate and consistent data may not always be available. An ERP system, extended with an environmental registration system and environmental information system could provide such data. Additionally, it makes it possible to add business and benchmarking data, by which environmental data are put in a context.

Summarising, in this chapter three environmental applications have been described: environmental management systems, environmental (annual) reports and an integral environmental information system. It can be concluded that the layered structure as proposed in the previous chapters offers sufficient flexibility to meet internal environmental requirements, as specified in part 1, those from authorities and from within the supply chain respectively. Its main contribution is based in the integration with already implemented information systems, especially Enterprise Resource Planning software. This integration enables a higher level of data integrity.
In the next chapter, this line is continued for requirements on the supply chain as a whole.

9. Environmental Information in Supply Chains

In part 1, it has been specified which environmental applications should be available for individual enterprises. In the first place, it has been concluded that environmental applications are present in enterprises, but these are incomplete and lack consistent environmental data. For this purpose, an environmental registration system has been developed. Secondly, it turned out that the existing environmental applications and information systems can hardly be integrated into a coherent whole. Because of this, an integral environmental information system has been designed to fulfil requirements of an individual enterprise, caused by internal demands and those from supply chain parties. However, this approach is limited due to the high dependency on the choice of system boundaries.

This chapter focuses on environmentally oriented applications beyond the scope of an individual enterprise, on supply chain level. It turns out that the concept for environmental information systems as outlined in the previous chapters is not right away applicable. For an individual enterprise, the border of what is included and excluded in a chain analysis is physically or legally defined. However, this doesn't hold true for supply chains and an additional delineation method is required. In section 9.2, it is outlined that a guarantee mechanism in so-called information decoupling points (IDP) enables definition of decoupled networks. Through this mechanism, it is guaranteed that that links in the chain before the IDP don't have to be included in a chain analysis.

It turns out that this concept is not specific for environmental applications, though can also be applied for, e.g., quality purposes. However, these approaches presume that local, usually more detailed data is available.

Subsequently, some important environmental -supply chain- applications illustrate the applicability of IDP's and decoupled networks: product responsibility, including tracking and tracing (section 9.3), product certification (section 9.4) and reverse logistics (section 9.5).

9.1 Introduction

In the previous chapter, environmental requirements of an individual enterprise have been elaborated. It has been shown that this approach is very limited from two viewpoints. First, environmental pollution often contributes to effects beyond the scope of an individual enterprise and hence these cannot

be considered detached from effects of such enterprises. Secondly, the choice of system boundaries of an enterprise becomes of vital importance. Introduction of subcontracting of particular process steps reduces the number of enterprise activities and thus actual pollution generated. Ultimately, a virtual enterprise, which merely exists by management of outsourcing of all process steps, wouldn't cause any environmental effect at all, without changing actual production processes and thus actual pollution generated.
Nevertheless, enterprise internal registration of environmental effects is still necessary for more detailed information, principally concerning responsibility of an enterprise itself, e.g. for support of permissions and accountability. Exactly because of this, it also serves as a sound basis for adequate and consistent environmental information exchange.
For the outside world, a supply chain is considered as a single entity. In this chapter, it is outlined in which way management concepts for a supply chain can again be translated in requirements on individual enterprises. In this chapter, the environmental registration, -information and -management systems are considered as preliminary work for environmental applications that fulfil requirements for the supply chain as a whole.

Environmental requirements on supply chains

The main triggers for environmental consciousness in supply chains are not really different from those on enterprise level and are mainly imposed by economic and legislative aspects. There is a growing consciousness in enterprises that the customer's customer is also their customer (Kornelius, 1994). Moreover, the ever more severe regulations increasingly dominate social and ethical incentives. In industry, especially economic reasons are mentioned. *End-consumers* ask for environmentally benign products. Related to this, competitive advantage is important, because the *environmental image* may repel suppliers and customers. Additionally, *viability* of the supply chain may be endangered due to exhaustion or prohibition of raw materials, boycotts of products and lack of continuity of enterprises in the chain. *Legislative* incentives, at last, may cause, voluntary or compulsory, adapted approaches for products and processes, e.g. product take back or recycling.

Environmental information in supply chains

Environmental requirements on enterprises and on supply chains don't really differ. Furthermore, an enterprise is a (more or less arbitrary) group of production processes, which in principle may be extended over the entire product life-cycle. Nevertheless, environmental information in supply chains differs from enterprise internal information flows. The main reason is that it takes more effort to delineate supply chains, contrary to physical enterprises, which are delineated by definition.

In this chapter, it is elaborated how the delineation problem in supply chains can be handled for the purpose of environmental information. It will be shown that this concept can be generalised and applied to other aspects as well, such as for quality or safety issues. Finally, this concept is illustrated for three particular environmental chain applications: product responsibility, product certification and reverse logistics.

9.2 Supply Chains

The foregoing chapters focused on production processes within a particular enterprise. In principle, such an enterprise may include all phases of a product life-cycle. Nevertheless, more frequently those production processes are distributed over several enterprises. In this section, it is elaborated which differences should be taken into account.

9.2.1 Supply Chain Structures

A supply chain is a network of two or more enterprises, which are, each for itself, not a constituent of one of the other enterprises or which are separated by market forces. Additionally, each of those enterprises adds value to the creation of the same product or service, or an unequivocal group of products or services. This implies that a supply chain has the following characteristics.

- ❑ the chain consists of a set of independent enterprises;
- ❑ the interaction or co-operation is not only incidental;
- ❑ the chain is either product- or service oriented;
- ❑ the co-ordination between enterprises is (partly) based on market forces.

Sub-structures in Supply Chains

In practice, a number of chain structures occur: linear, shared resources, converging, diverging and network structures, see figure 9-1–figure 9-4. Those structures resemble with those which are found within an enterprise and can been described by the MIMOP approach.

The least complex structure is what is intuitively considered as a chain: output of the predecessor is the only input of the successor (figure 9-1).

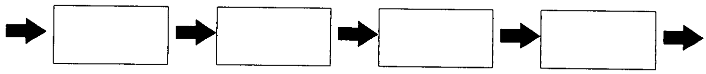


FIGURE 9-1 Linear chain

In a supply chain of several different product/market combinations, a common resource might occur. In such a shared capacity unit, product flows could mutually influence one another, see figure 9-2.

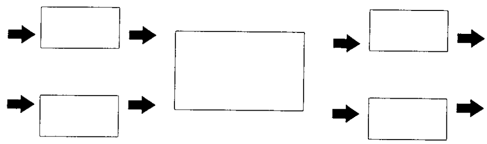


FIGURE 9-2 Chain with shared resources

In converging and diverging supply chains, a similar situation exists, see figure 9-3. The difference is, however, that if this chain covers only one product /market combination, co-ordination with other products is not necessary.

FIGURE 9-3 Converging respectively diverging chain

If converging and diverging structures simultaneously occur, a so-called chain network arises. Complex networks are caused by increasing interaction in parts of the chain, e.g. in agriculture and food industry. Ordinarily, one particular branch of a network chain will be emphasised, the others supporting the main branch (see figure 9-4).
A supply chain is thus composed of links, representing enterprises. From a supply chain perspective, especially the issues that go beyond such an enterprise are important: products, by-products, flows of money and information. In other words, the interaction between links is essential, *in* the chain with suppliers and buyers, and *outwards* to authorities. To handle to information load, two chain modelling concepts are discussed here. The first concept involves delineation of a chain in a so-called decoupled network. The second concept concerns efficient information exchange by means of minimal models.

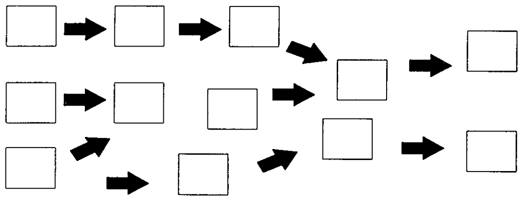


FIGURE **9-4** Chain network

9.2.2 Decoupled Networks

Modelling a supply chain, however, is arbitrary, because *the* start and *the* end are not unambiguously defined. A dairy chain, for example, consists of breeding and raising cattle, milking cows and collecting milk. However, this chain could be extended with the production and supply of feed, or with the processing, packaging and distribution of milk. Roughly speaking, 'start' is defined as the physical extraction phase, in which *materials are withdrawn* from the environment. Accordingly, 'end' is defined as the phase in which *materials are returned* in the environment.

Two notes should be taken into account. First, still several 'starts' and 'ends' can be found. This may be due to use of alternatives, e.g. several types of feed and several suppliers per type can be distinguished. Additionally, except for the main chain, several supporting chains exist, e.g. those which supply means for the production or transportation phase, or supply means to produce those on their turn. Furthermore, cycles may occur. Especially in agriculture, many examples can be found, such as the cycle in milk production (- growing grass - feeding cows - fertilising grass - etc., of which milk can be considered a by-product). The ultimate result can no longer be considered as a chain, but should be characterised a network of enterprises. This network is based on precedence relations which are dependent on the aim of registration.
Secondly, such an extensive chain network is hardly manageable. The large quantity of enterprises makes it unwieldy. However, many branches are relatively unimportant in relation to the objective of modelling, such as a particular production method of production means. Furthermore, when going back as far as the extraction phase, information is increasingly difficult to obtain, and if available creates a pile of information. Finally, when a particular product is sold, it is not firmly prescribed how and when it will be returned to the environment. As a result, the pure definition of a conceptual supply chain

turns out to be a chain network with many undefined starts and ends. In the following, it is outlined how an information decoupling point handles those loose ends and contributes to information management in such a chain network.

Information Decoupling Point

The concept of an information decoupling point (IDP) resembles the logistic concept of the customer order decoupling point (CODP), a.o. described in (Hoekstra and Romme, 1992).

A CODP determines which part of the main production process is driven by customer orders and which part of the main production process is driven by a schedule which is ultimately based on demand forecasts. The CODP concept is important for the type of production control. *Customer order driven manufacturing,* beyond the CODP, aims to improve delivery time performance, whereas forecast driven manufacturing can be considered as *make-to-stock,* aiming to balance cost and flexibility of the stock. The foregoing is represented in figure 9-5 for two Production Units (PU) before the CODP.

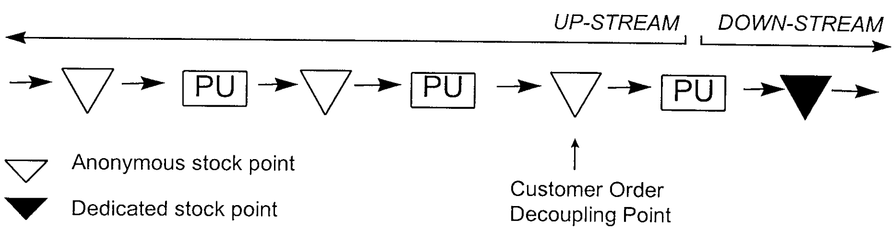


FIGURE 9-5 CODP in a goods flow

An *information decoupling point* determines in which part of a supply chain product properties are described in detail and where this detailed data is aggregated. Up to the IDP, the available upstream data is attached to the product; after the IDP only the new, downstream data is attached and exchanged. In the IDP, a name is assigned to a set of generating characteristics, e.g. environmentally benign or animal friendly. This name serves as a kind of a tag, that can be referred to down-stream in the supply chain. This has been depicted in figure 9-6. A refinement of such a mapping on a binary tag can be achieved if the set of generating characteristics is extended and mapped onto a (small) set of characteristics. Examples can be found in the production of paper, which may be 'recycled', 'chlorous-free', or 'wood-free'.

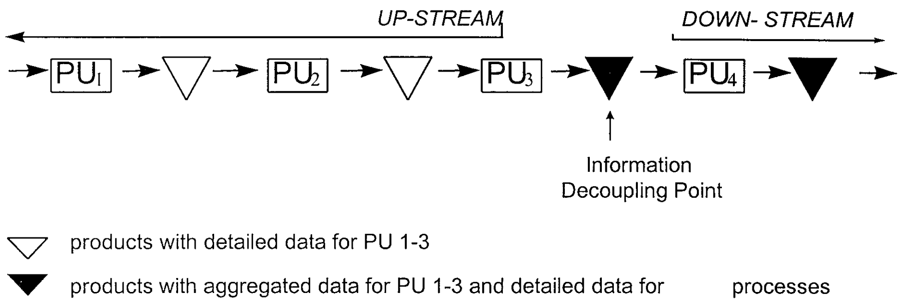


FIGURE 9-6 IDP in the goods flow

A major advantage of an IDP is that, although detailed data won't be exchanged, these will still remain accessible by means of the identification code. As a result, these data can be traced back. The idea of an IDP is applicable for both state-independent and state-dependent product data. Especially in case of mistakes or suspense, such individual product data is valuable to recall products and to identify causes. This usually doesn't hold true for a Customer Order Decoupling Point, where merely the stock level is increased and data on preceding life-cycle phases are lost.

An IDP may also be defined for various other aspects, such as logistics or product quality. Those IDP's resemble in the sense that it results in a group of similar products with regard to a particular aspect. In logistics, all products with article number '12345' are identical. For product quality, all products with batch code '12346-83Y01' are (considered to be) the same. This concept also holds true for environmentally friendliness, animal friendliness, etc. A CODP may correspond with a logistic and/or quality IDP. In such cases, lot traceability is possible by means of the article and/or batch code.

Finally, IDP's for different aspects not necessarily coincide. In each IDP, a heap of data converges, and is collected and stored. To be able to assign a particular environmental or quality value to a product, an adequate selection of different kinds of IDP's is required.

In figure 9-7, an example for an environmentally friendly retail-store is depicted. Such a store gathers environmentally oriented product information from the farmers and wholesalers it is affiliated with, to be able to guarantee the (environmental) product quality to its customers. The customer on its turn is usually satisfied if purchased products are labelled by this environmentally friendly store, and the confidence that he could trace back the product history if necessary. In this case, the reach of the mapping consists of one attribute.

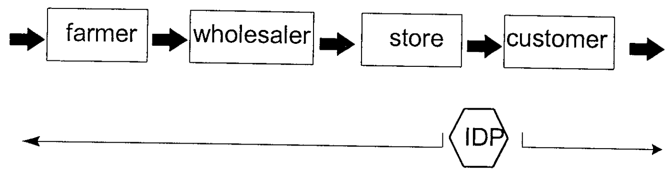


FIGURE 9-7 IDP in the food supply chain

Decoupled Networks
As a starting point, it can be concluded that a network of processes within an enterprise and within a supply chain can be considered in a similar way. However, it has turned out that in supply chains there is no fine distinction between the 'inside' and 'outside' of the entity that is modelled. For that purpose, additional criteria should be specified to be able to draw a line. Those criteria, with respect to a particular aspect, can be made explicit by definition of IDP's. In the IDP, it is specified in which way the delineation has been made and which guarantees can be count on. Such a guarantee may be supported by, for example, product certificates. The result is a group of enterprises which have been decoupled from its neighbours: a Decoupled Network, see figure 9-8.

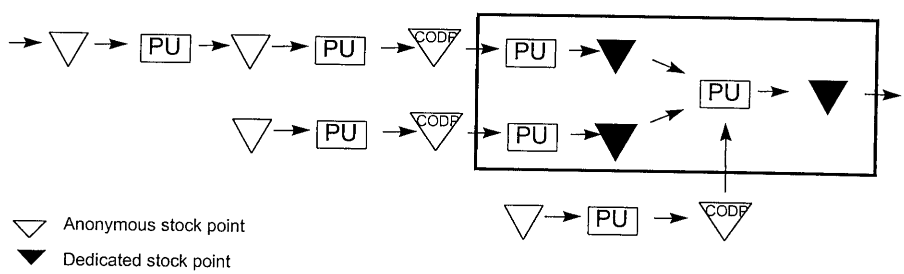


FIGURE 9-8 Decoupled Network

9.2.3 Information Exchange in Supply Chains

In chapter 8, design of an environmental information system has been described from the viewpoint of an individual enterprise. However, in supply chains, an enterprise should communicate with its direct suppliers and buyers, authorities and other stakeholders. This communication includes production processes and product information, as far as the view of this individual enterprise reaches. This idea is represented in figure 9-9 by a window.

Modelling of a supply chain implies linking of involved windows. Furthermore, communication flows might be extended towards a hierarchical level that exceeds individual enterprises and governs a so-called extended enterprise, responsible for a particular product-market combination, e.g. environmentally friendly produced bread. Such a body is called the chain manager. Chain information is also important to provide authorities with environmental information. If such information is available, an additional flow towards authorities is relevant (dotted line).

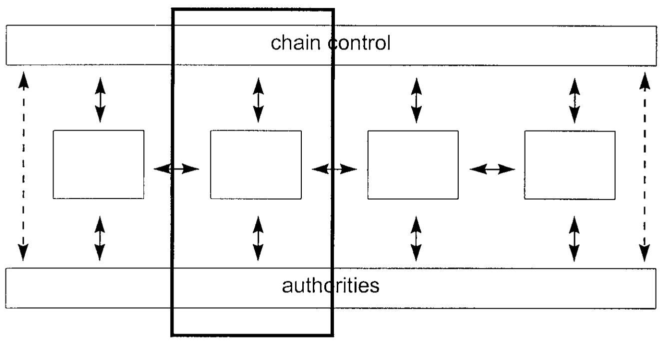


FIGURE 9-9 Supply chain modelling and window linking

The function of chain control is not necessarily performed by an independent third party, but could also be performed by one of the chain links, usually the supply chain leader.

Information flows in supply chains

Two kinds of environmental effects have been distinguished up to now: environmental effects caused by enterprises (process oriented) and by complete supply chains (product oriented). This section focuses on information exchange between processes and enterprises in a supply chain, assuming that sufficient local information is available.

Parallel with product flows, two types of information are discerned: *transaction-oriented data* and *product information*, including product quality, environmental impact etc. (forward coupling of state-dependent data), see figure 9-10. In the opposite direction, *product specifications* are submitted, such as price, quality, packaging material and unit, production process (backward coupling of state-independent data).

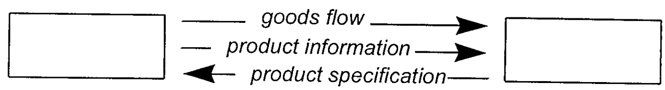


FIGURE 9-10 Forward and backward coupling

Supply chain management makes demands on specification of products 'which requirements should this product meet?' and specification of production processes 'in which way and within which terms should this product be produced?'. It is important how far this backward coupling reaches and in which way. For example, requirements of a retailer may influence processes on an auction or even at farmer's. Another example concerns backward coupling, which may be based on explicit orders but also on specification of preconditions for possible demands. In the latter case, required specifications should be communicated in the supply chain, possibly with respect to type and value range, of state-independent, not transaction oriented data, see section 9.4.

Another important aspect of supply chain information involves product responsibility, which is elaborated in section 9.3. Product responsibility requests product identification, the possibility to discern a product from another, which is achieved if product and information flows can be coupled.

Information that may be exchanged in a supply chain is based on the enterprise's behaviour. This behaviour, from an environmental viewpoint, has been discussed in the previous chapters. Nevertheless, it is not desirable to exchange all available data. Usually, a supplier is not eager to provide unnecessary insight whereas a customer shouldn't be overloaded with data. Therefore, the level of detail is an important criterion in information exchange. Additionally, the number of supplier-customer relations should be taken into account. Each enterprise is part of several supply networks and is confronted with a proportional number of interfaces. For this reason, there is an increasing need for standardisation of such interfaces.

Minimal Model

Behaviour of (enterprise) processes can effectively and efficiently be described in a so-called *minimal model* (Beers and Beulens). In a minimal model, behaviour of an enterprise or production process is described for a particular period of time. It is influenced by particular constraints and control data, related to the input and output product flow. For modelling of an environmental aspect system, this in particular involves constraints imposed by authorities and supply chain parties as described in part 1. The resulting behaviour is recorded in reports, based on the environmental information system. A minimal model implies that chain models can effectively be described by their interfaces. An interface may regard data on the input and output, on constraint and control data and on output reports, as represented in figure 9-11.

For modelling environmental behaviour, it should be recognised that especially the output and report flows may be divergent. Consequences of such multiple outputs have been discussed in chapter 8. With respect to multiple reports, two types can be distinguished. In case of forward coupling, it especially concerns product information for customers. In case of backward coupling, this merely involves product specifications for suppliers.

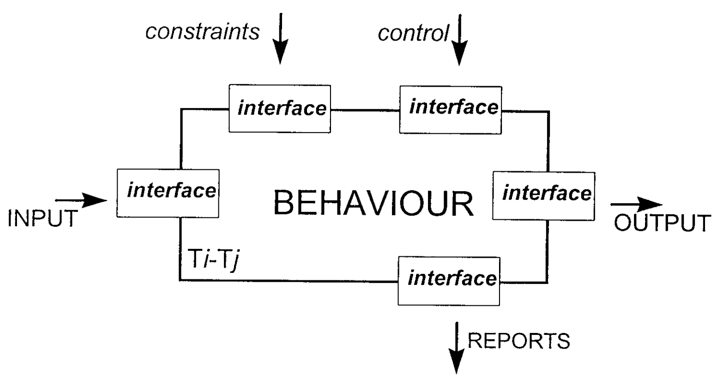


FIGURE 9-11 Minimal Model for reporting

Both forward and backward coupling not necessarily take place between two 'successive' enterprises in a goods flow, but these may skip some. This also holds true for the goods flow itself, namely with respect to enterprises that merely create added value by addition of information or a simple logistic function, e.g. an auction or wholesaler. As a consequence, the goods flow and the related information flow may run independently to some extent.

Finally, information exchange usually takes place between autonomous enterprises. However, system boundaries might gradually evolve due to far-reaching chain integration or conversely due to outsourcing. Strictly, the modelled behaviour is based on processes instead of enterprises; as a result, the basic structure of a supply chain model is not influenced by shifts in the chain.

9.2.4 Conclusion

Modelling a supply chain implies that all enterprises which add value to a particular product (group) should be included. Usually, this results in a complex network structure, built up from linear, convergent and divergent chains, which additionally may share particular resources. In such a network structure, it is arbitrary to define *the* start and end. For this purpose, so-called decoupled networks are distinguished, delimited by information decoupling points (IDPs). In such an IDP, it is specified which criteria are met with respect to a particular aspect. Consequently, a decoupled network is defined for a particular aspect, e.g. environmental protection or safety conditions.
Modelling information flows in (decoupled) supply networks comes down to coupling of behaviour models of enterprises. For this purpose, the behaviour of an enterprise can be described in a minimal model, which merely defines interfaces instead of entire business process. A minimal model is defined with respect to a particular period of time. Two types of coupling should be distinguished: forward and backward coupling, which concerns both goods and information flows.
For software development, supply chain modelling requires at least sufficient understanding of the structure of the decoupled network. From this, implementation results in elaborating relevant interfaces of minimal models for participating enterprises. However, the degree of co-operation or integration between enterprises may add additional requirements. Often agreements on political and technical issues should be satisfied, but these may be supplemented by logistic, quality, environmental and other constraints. In the following sections some of those additional constraints are further elaborated.

9.3 Product Responsibility

In general, several enterprises are involved in a product life-cycle and hence in registration of goods flows. To guarantee that supplied products meet customer requirements, registration is necessary. This holds true for production data those that cannot be measured on a final product (intrinsic values) and that can hardly be measured due to technical or economical restrictions (extrinsic values). As a result, coupling of products and accompanying data may be required.

One application, *product tracing*, originates by exception handling: if a product on the market appears to be 'bad quality' or different from an (implicit) specification; the responsible supplier (production batch, used production means, etc.) should be traced. A well-known example is salmonella infection which is communicated by chicken; once this infection in a particular product has been determined, the source has to be traced back to enable the farmer-supplier to take protective measures.

Another application originates from the fact that the product is considered to be valuable or risky: a supplier has to be able to *track products* that left the enterprise. For this purpose, continuous registration of products and customers is required. Examples are parcel post for which a third party is responsible, or products that are specified in the opium laws, which oblige authorised owners to keep a balanced bookkeeping for opiates. Also the follow-up of the salmonella infection requires tracking; once the infected group of chickens has been determined, all products should be withdrawn from the market. To be able to track and trace products, two questions should be answered: 'how can products be identified' and 'where and how should data be registered'.

9.3.1 Product Identification

Coupling of a product with its accompanying data requires unique identification of this product. Two levels are distinguished: product types and individual products/batches. In addition, it is shown that in some cases identification may not be possible or desired.

Identification of product types

Usually, an enterprise has its own enterprise information system and makes use of its own internal article codes. When goods are supplied, a store-keeper immediately translates the externally delivered product codes into his own system. Communicating product codes over a number of links in supply chains is therefore a source of misunderstanding, especially when those codes often change, e.g. due to engineering changes. To handle this problem, a system is needed which can be used by any enterprise to translate their internal product code into a universal product code. The internal code can still be used internally, but only the universal code will be exchanged.

In Europe, an organisation has built such a coding system, the European Article Numbering (EAN). This coding system is compatible with the Universal Product Code (UPC) that is used in the USA and enables a store-keeper to couple the goods flow and data flow automatically. The EAN coding system distinguishes the following units: articles (consumer units and packages), trade and order units, supplementary information, locations, shipments units and deposit tickets. The EAN codes are attached to the product types at the source (decentralised). The code is composed as follows:

	system code		connection nr.					article nr.					control
location	13	12	11	10	9	8	7	6	5	4	3	2	1
example code	8	7	5	2	3	2	7	6	1	8	1	0	6

The system code identifies the EAN code distributor; the connection number identifies the enterprise that is responsible for the product, usually the manufacturer or the owner of a hall-mark. The article reference number is decentralised attached by the owner of the connection.

Using the same article codes enables an enterprise to exchange data automatically, so-called Electronic Data Interchange (EDI). Apart from general benefits of EDI, some additional effects are important. First, planning and prognosis data can be retrieved from suppliers and customers to improve their internal production and logistics. Secondly, shorter delivery times can be achieved by preliminary ordering and supply level control, giving the supplier a clear insight in the market.

Identification of products and batches

Drawback of the EAN-13 article code is that it is attached to a product type, and as a result, all products of that type are considered to be equal and therefore indistinguishable. In practice, however, it might be required to distinguish individual products, for example in food industry, where expiration dates are input for delivery and stock optimisation. Other examples that can not be modelled in EAN-13 are serial numbers, forward codes and weight indications. To solve these problems, an Application Identifier (AI) can be added, by means of an EAN-128 code, added to EAN-13. The AI standard defines data blocks, each block starting with an identifier of 2-4 characters for the meaning, format and length of the field. A number of common identifiers are predefined and new identifiers can be claimed. Note that EAN-128 is only applicable for trade units, whereas EAN-13 is also applied to consumer units. Benefits of EAN-128 for manufacturers are in internal logistics: product registration and pallet structure (which articles, quantities, batches and tenability). The main benefits in distribution are in sorting, routing, tracking and tracing.

Aggregation of products in batches is allowed provided that products in a batch are considered to be identical. In this context, identical means that there is no distinction between products *relative to a specific criterion*, in other words, those products have a particular generating characteristic in common. In chicken production, for example, chickens are considered to be identical if they have the same genetic characteristics and are kept and fed under the same circumstances, which is usually the case for each barn. Therefore, a barn is treated as batch. On the other hand, this doesn't hold true for production of beef. Each cow in a herd is considered to be different, because they differ significantly in genetic material and weight. In both cases, the criterion is that animals are considered to be equal or not, depending on quality, shape and composition, in the opinion of the buyer.

Difficulties in identification

Coupling of goods flow and data flow may be complicated by disturbances in supply chains. The location of a disturbance can be considered as a (forced) information decoupling point: information which has been attached to a product before it passed the IDP, is detached and only new information is further communicated. The EAN coding system is useful in distinguishing specific products or batches, but unique coding of products and batches, however, is not always applicable due to economical and/or technical restrictions. An example of the first restriction occurs in diverging chains, e.g. a meat chain. When pigs are supplied for slaughter, they can be uniquely identified by their identification number; further processing of the carcass only takes place after quality and health inspection of the organs. Once the carcass has passed the tests, the head, including identification tag, is removed, leaving the remainder anonymous. The products of such a production process are boxes with ham, cutlet, etc. which have the generating characteristic 'passed the test'. If additional tests would reveal abuses, identification of the source is hardly possible.

Other identification problems occur when a particular product cannot be recognised at a different place or time in the supply chain, due to changes in name, number or composition. For example, computers are sold with a unique serial number, which has been translated into an internal code to be used within the company. After some time, one decides to change the configuration. Even if the owner registers the changes, the original supplier is not informed and wouldn't recognise this product, e.g. when it is returned for re-use or maintenance purposes.

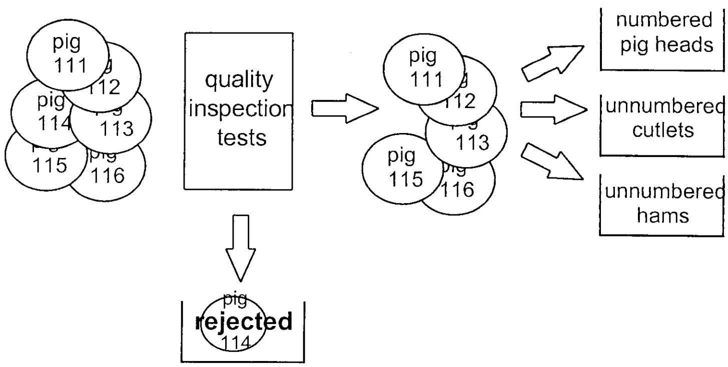


FIGURE 9-12 Supply chain for pork production

Finally, another difficulty might be that identification is not feasible. This is mostly related to the necessary level of detail, by which a high level of detail results in high costs. Especially products with low value and risk, which are produced in large quantities are not suitable for unique identification; decreasing the level of detail leads to a better cost/benefit balance.

9.3.2 Location for Registration

Possibilities for tracking and tracing of products depend on registration of relevant data with respect to this product. In the previous subsection, identification of individual products has been described, in the following the location of data registration is elaborated. The effectiveness and efficiency of a particular location depends on the applications that will use the data in a later stage. One way of data storage might be applicable for one objective and too expensive, or unsuitable for another. Requirements relate to the quality, integrity and topicality of data, the performance and reaction speed. First, an overview of alternative solutions is presented.

Central registration

Central data storage implies that all links in a chain have one common location to store product data, either in the chain or at a third party. In a chain, it is possible to store the data (1) at the first party, usually the manufacturer which enables tracking; (2) at the last party, usually the customer which enables tracing; and (3) at any information decoupling point. In each alternative, identification of goods and coupling with product data is not trivial. An example of data storage at an IDP is production of slaughter chicken for the German market. German legislation obliges chicken slaughters to trace which increaser supplied which chicken to which fattener and which breeder supplied it initially. Registration by the manufacturer is advantageous when recalling products from the market. A supplier of baby food has been able to trace back a quantity of contaminated baby food to a subcontractor of his meat supplier. Still, he was not able to recall the entire tainted batch because he didn't know which customers where using it, and he had too recall the products of the full production day.

Alternatively, data can be stored at a third party, either a chain manager or an independent enterprise. The concept of a chain manager is effective provided that it is a powerful party. In many cases, however, the power in the chain is distributed between several parties and central data storage would unbalance the power in the chain. Introduction of an overall or inspection enterprise would bring help, e.g. the Dutch National Cattle Syndicate which is responsible for registration of birth, death and business transactions of cattle.

The main benefit of a central registration concept is that tracking and tracing could relatively smoothly be implemented, due to the possibilities for controlling and checking data integrity. Nevertheless, in the opinion of chain parties the concept might be unsatisfactory due to political consequences, for central data storage empowers one party to use the collected data strategically, thus wielding relatively too much power on the chain.

Distributed registration

In case of decentralised data storage, product data is stored at the location where it has been produced. Decentralisation precludes excessive concentration of power in the chain, yet the same difficulty in identification of products is encountered. In addition, when data has been registered at several locations, identification might be frustrated by application of different, incompatible concepts. To enable tracking and tracing, a central chain management with respect to standards for information management is necessary.

Implementing distributed data storage increases opportunities for communication problems. It possibly reduces data quality and integrity, especially if many small parties are involved, which are relatively unreliable with respect to data management.

On the contrary, preservation of power in the supply chain largely increases willingness and thus feasibility of the system. Furthermore, it enables parties to implement their system independently and offers liberty to adjust it to other enterprise internal management systems, such as a production control system. As a result, it can be concluded that those parties should share a common generic data model to facilitate the data exchange.

Attached to a product

Contrary to data storage at a particular location, registration can be maintained on the individual product itself. A well-known example is the covering document that goes with shipments, a consignment note or waybill. Newly applied alternatives are a covering, attached or inserted micro chip. In pigs, for example, a chip can be inserted just behind the ear. It is used for identification and history data such as on feed and medicine. In production of engines, a chip is attached to record the bill-of-materials, the version and release data. Later on, this data might be extended with engineering changes. Based on suchlike information, disassembly and re-use of parts can take place more effectively. Generally, coupling between a product and its accompanying data is trivial; on the other hand, tracking and tracing require additional effort. Tracking data is not possible, unless additional databases in the chain are set-up. For tracing, it is required that each link follows a standardised format in registration, at least including geographic data of its enterprise.

9.3.3 Conclusion

To meet requirements of dynamic behaviour of the business environment, two types of registration are distinguished: product independent data, connected to a product type or product code, and product dependent data, connected to a batch of products. The way this data should be registered (local, central, attached to a product) depends on the desired communication in the supply chain and political aspects. There are several viewpoints whether to register data, amongst others for tracking and tracing purposes. Especially storing detailed product history data for future tracking requirements is rather expensive, and the reasons to do so very much depend on the strategic aims. Summarising, depending on the specific circumstances an enterprise has to face, the following aspects should be balanced:

aims and scope of individual enterprises;
aims for the supply chain as a whole;
level of aggregation of product types, batches and individual products;
location of registration, with respect to the goals and political impact.

Furthermore, the level of data aggregation might reduce the volume and complexity of data registration. In the next section, this is further elaborated from the viewpoint of product certification.

9.4 Product Certification

Product certification is a means to guarantee a particular level of product quality. In this context, registration of a product is concerned to its quality and characteristics. Such a guarantee can be based on measuring actual parameter values of those characteristics *on the end product* or by describing the *product history* represented in particular attributes. However, measurements on end products might be very complex, or even impossible, if the quality is determined by attributes that can not be measured on the end product because this characteristic isn't intrinsically present in the product, e.g. whether or not a product is environmentally benign produced. In the following, the focus is on the registration of product history data. First, the situation within a single enterprise is summarised, then the supply chain aspects are introduced.

9.4.1 Registration in a single enterprise

Registration in individual enterprises has been elaborated in chapter 8. It has been argued that production data of a single enterprise may be related to products and processes. For *products*, two types of registration are distinguished: state-independent and state-dependent product data. For *processes*, several aggregation levels have been discerned, ranging from a small production step up to the entire enterprise level. Also for processes, a similar distinction between pre- and post calculated values is applicable.

Processes may, or should, meet particular requirements; for this purpose such a process can be certified. For environmental requirements, choice of system boundaries highly influences the outcome of 'environmental performance'. For a useful application of process certification, additional overall context information is indispensable.

Also products can be certified, as far as a particular enterprise is concerned. Nevertheless, products are frequently further processed as component or constituent in other products, by which an earlier result my be reduce or even undone due to sub-optimisation. A typical example is the use of raw materials which are considered as 'environmentally benign' when being used in production. The resulting products, however, may turn out to be low-quality, as a result of which these should be replaced more frequently. This also holds true for life-cycle phases after a product has been discarded, if refurbished products are outdated due to technological improvements. Consequently, the environmental effects of a product should be seen in the context of the entire life-cycle.

9.4.2 Registration of product life-cycle data

Usually, a product life-cycle takes up a number of enterprises, e.g. in case of the meat supply chains as described before. For this purpose, registrations of individual enterprises should be coupled. This kind of data can also be aggregated, and possibly used for certification, for example for products or services as considered in cradle-to-grave approaches. Certificates may involve accountability for production rules as specified in the certificate, e.g. the ISO approach (such as ISO-9000 or ISO-14000) or assurance that those production rules meet (standard) requirements, for example the quality mark for McDonald's hamburgers. Certificates can be used to aggregate information, that is collected within an enterprise and that should be communicated within the supply chain. Dependent on the application, this communication may take place on different levels of aggregation.

Aggregation levels

Several levels of data interchange can be distinguished. These levels differ in aggregation level and are built on each other. The following levels are discerned:

1. certification of the supplier yes/no;
2. criteria on which a certificate has been designed;
3. extent to which criteria are met.

On the *first* level, the only requirement is that the supplier is certified, and the communication is a simple 'yes' or 'no'. In the hamburger chain, this would imply that all meat suppliers are allowed, provided that they have a certified EMS. On the *second* level, the supplier has to be certified as well; the communication, however, is extended by the criterion on which the certificate is based, e.g. for an ISO-14000 certificate, it is specified that the use of 'herbicides' or 'heavy metals' is restricted. On the *third* level, the supplier additionally specifies the collected values for the desired characteristics: the volume of production has used x ton of herbicides a year.

Finally, product certification can be combined with product responsibility. Products or batches are treated individually, and product characteristics can be coupled to unique products. It has been argued that this type of registration for individual product or batch level is labour-intensive and expensive, and hence allotted for products with a high risk factor. For product quality, examples can be found in aerospace and defence industry, for product safety, examples can be found in food industry. With respect to pure environmental characteristics the foregoing doesn't apply.

9.4.3 Conclusion

Previously, it has been argued that detailed environmental data may be available, though frequently lack an overall view, which may lead to sub-optimisation. Additionally, overall views may gain insight in environmental effects on a broad level, though often lack consistent and adequate data to be able to draw strong conclusions. In this section, it is shown that a combination of those two approaches, supplemented by application of communication levels, contributes to a better overall insight and more environmentally benign products.

On a strategic, analysis level, environmental models should be founded on a life-cycle approach. Input data for this model, however, should be based on locally registered process data. For this purpose, criteria for chain parties should be made explicit with respect to process properties. Supply chain parties, on their turn, should demonstrate that they meet those requirements.

9.5 Reverse Logistics

In this section, two subjects in the field of reverse logistics are raised. First, the role of recycling, and product acquisition from recycled components and materials is elaborated (section 9.5.1). Next, this is specialised for a particular type of product, namely packaging material (section 9.5.2).

In this thesis, it was aimed to provide manufacturers with means to fulfil their internal and external environmental requirements. On a strategic level, this involved especially (environmentally benign) product design; on tactical and operational level mainly (environmentally benign) production. Here, the focus is on the latter. Nevertheless, it is recognised that, considered from a product-life cycle view, the phases following production contribute to a large extent to the environmental effect of a product. In this section, this is taken into account, though again the consequences from a production viewpoint are elaborated.

9.5.1 Product Acquisition from Waste Streams

Roughly, four product life-cycle phases can be distinguished after the production phase: use, collection, recovery and (re-)distribution, see figure 9-13. Especially product recovery may be a matter of concern for manufacturers. The main reasons for product recovery are in essence similar to other environmental incentives. Pro-active enterprises see new markets and possibilities for cost reduction; reactive enterprises may be confronted with forced product take-back. Furthermore, product take-back is an extra service for customers and is associated with added value for a product/service combination or a 'green' image.

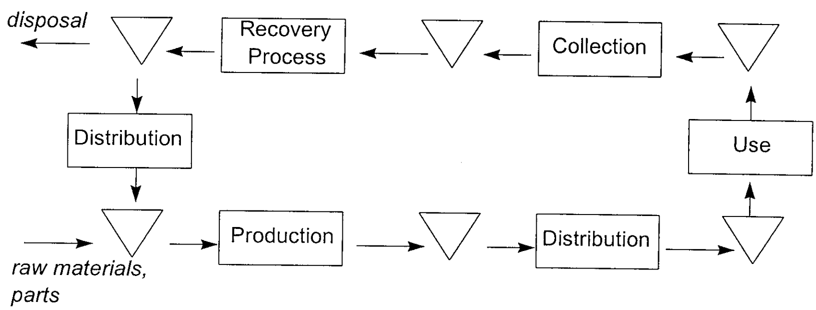


FIGURE 9-13 Product Life-cycle

Product recovery may result in different types of output. A product or component can be considered *as new*, with exactly the same characteristics as when first manufactured. Additionally, products and components may be *upgraded* by replacing parts or be used as *lower quality* products, components and materials. This output variation is based on different types of product recovery processes. The following steps in such a process can be distinguished (Caanen, 1996), see figure 9-14.

Preparation

When a used product has been delivered, it should first be decided whether this product, its components, or its materials may add value to the product

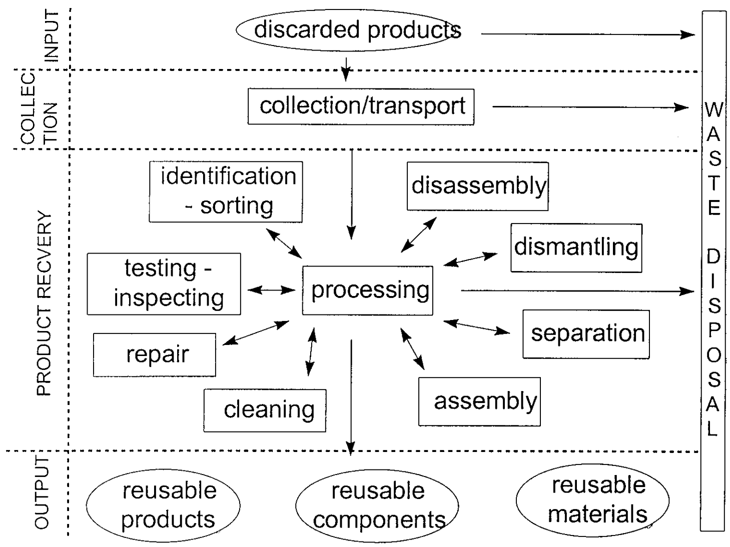


FIGURE **9-14** Product recovery options

recovery process. At first instance, a rough assessment is based which includes *identification* of the product and *sorting* valuable and non-valuable products in view of the objective of refurbishing. This process is usually repeated a number of times, when additional process steps, amongst others *cleaning*, have been carried out.

Separation

Complex products usually consist of many parts, grouped in so-called components or subassemblies. Those components are physically connected, of which such a connection may be irreversible (a weld) or reversible (a nut and bolt). Two types of separation processes of a product in its components are distinguished: non-destructive separation, or *disassembly*, and destructive separation, or *dismantling*. If some of the components should be re-used, it is required that these remain undamaged. Furthermore, is should be stressed that usually not all disassembly steps add value to a product (contrary to assembly), though these may be required in regulations or necessary for further processing. In general, a limited assembly depth will be realised. In (Lambert, 1997), criteria for optimal disassembly depth are elaborated.

When a product has been disassembled and dismantled, the resulting flow of materials is split into two or more flows of components. This process of *separation* is based on criteria for further processing of these components. Separation may be based on intrinsic or extrinsic material characteristics.

Extrinsic characteristics are, for example, size and shape; a separation technique for this distinction is, for instance, filtering. Frequently, intrinsic characteristics are important, e.g. to recover valuable materials. For this purpose, chemical and physical techniques are widely applied in ore processing.

Recovery

Product flows which have been made available by separation should usually be *refurbished* or *repaired* and material flows be *upgraded* before these can be re-used. The nature of such processes is mechanic (repair) or chemical (for example to increase the purity of a material). This process is concluded by *testing and inspection*. Generally, the obtained secondary material flows have a lower quality of a virgin product flow, which may pose restrictions for re-use. The above holds true for 'material/parts recycling' and for 'component/product recycling', provided that this component has not been disassembled. In case recycled components consist of recovered materials, or recycled products consist of recovered components and/or recovered materials, *assembly* is required. Also this process is concluded by testing and inspection. Finally, the recovered material can be re-used. This may be in a high-quality, equal-quality of low-quality application.

An example is the Mercedes Benz plant in Berlin –Materials and Parts Recycling (MTR)– which is concentrated on reconditioning engines and subassemblies for Mercedes Benz customers. The products are offered as standard service parts for at least 10-20 years after new sales, for approximately 80% of the price of a new one and with 'as new' guarantee. They are as much as possible composed of used parts. Engines are remanufactured in a cost efficient way.

In figure 9-15, an overview of the recovery process is presented. All supplied engines are roughly identified and stored (supply-driven), however, these are only recovered if a particular engine type is demanded (demand-driven). In this way, a very large stock is available which reduces the likeliness that a particular part cannot be recovered.

It should be taken into account that engines of a particular type not necessarily consist of the same subassemblies due to engineering changes. This may cause dependencies between parts, which complicates planning of the recovery process. When an engine is (manually) disassembled, parts are identified, small parts are kept in storage, and large parts are immediately further processed. In the assembly process, the large parts are assembled supplemented by recovered small parts and, if necessary, third party supply. After a quality check, the recovered engine is transported to the customer.

Logistic aspects

Logistics in the context of product recovery is defined as 'providing the right quantities of the right products at the right time at the right place against lowest costs, *including* disposal of technically reusable but economically not feasible reusable items' (Caanen *et al*, 1996). This involves decisions, such as where and how to collect discarded products, what can be obtained from a product and for what purpose, and when and how residual materials can be disposed.

Several parties may take part in a reversed chain: waste collectors, product recovering enterprises, waste processors and distributors. In general, waste collectors and waste processors are especially equipped for its purpose. However, other functionality may also be carried out by so-called Original Equipment Manufacturers. Comparable with other production processes, a customer order decoupling point can be identified, e.g. make-to-stock or assemble-to-order. Different is uncertainty in supply (used products), with respect to timeliness, correct type and version and adequate quality.

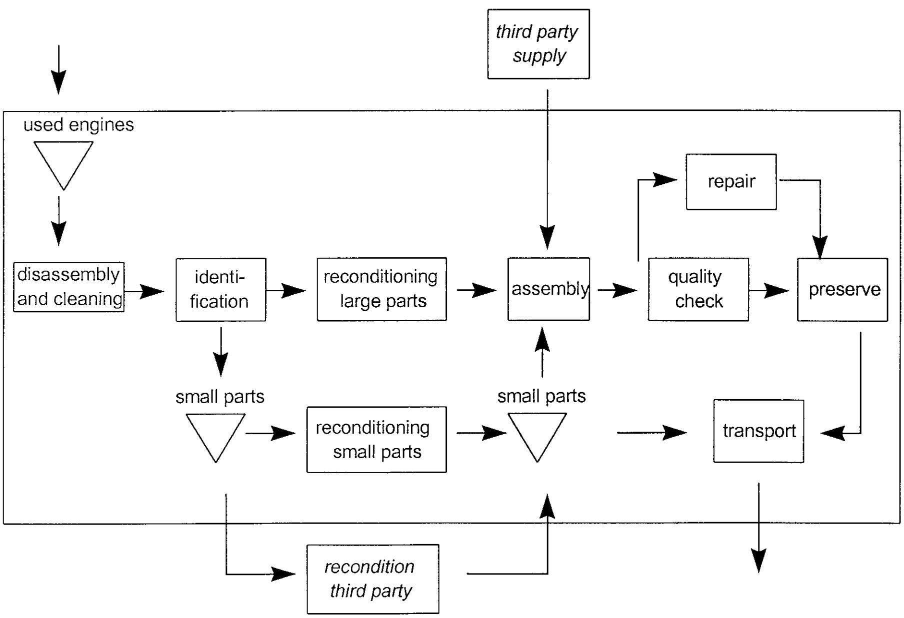


FIGURE 9-15 Materials and Parts Recycling Mercedes Benz Berlin

IT support for recovery processes as described above can only partly be covered by ERP software. There should be an emphasis on identification of products, components and materials.

Furthermore, bills-of-materials require special attention. Used products which are supplied may originally be produced according to several bills-of-materials. Each of those bills-of-material should be available when recovering a product or component, thus resulting in a number of so-called variant bills-of-materials. Furthermore, it should be stressed that parts of a particular component not necessarily can be re-used in other components. This functionality is usually not available in ERP-packages and requires considerable extensions.

Environmental aspects

One of the objectives for product recovery is to reduce environmental impact of products, considered in view of an entire product life-cycle. At first glance, product recovery results in a reduction of raw material consumption. However, additional aspects should be taken into account. A significant environmental effect may be caused by additional processes that are required for recycling: collection, dismantling, cleaning etc. require energy and possibly other environmentally polluting materials. Furthermore, use of recovered products may cause a different environmental effect than for new products, even if it is 'as new'. This may be due to technical improvements of the product, e.g. the recovery of car engines; an engine from 1980, recovered 'as new', is still less economical (due to fuel consumption) than its 1997 alternative.

Applied methods to determine environmental effects of a product are life-cycle assessment (LCA), design for the environment (DFE) and design for disassembly. The latter can be considered as an approach, which especially aims to reduce effort in terms of materials and energy, when it has already been decided to re-use a product. In DFE, environmental effects of various alternatives are counted, including alternatives for product recovery and based on a particular product life time.

In such analyses, it is difficult to decide on the 'best' solution for two reasons. First, multi-criteria analysis and decision making is difficult by nature. It is hard, if not impossible, to objectively make a trade-off between the difference in energy use, raw material consumption, waste and emission flows. Secondly, the analysis is based on assumptions: processes are supposed to be carried out under particular circumstances, but may turn out to run differently in practice. This also holds true for the product life-time. Additionally, it is supposed that a product will pass through particular phases, e.g. recovery, which not necessarily will take place.

In each approach, a supply chain is considered as a single entity. However, in practice, the chain is composed of individual enterprises. In chapter 8, it has been argued in which way environmental information systems for an individual enterprise may contribute to life-cycle approaches. This equally holds true for product recovery processes.

Conclusion

Frequently, it is assumed that product acquisition from waste streams contributes to a reduction of environmental effects. In the foregoing, it has been argued that, on supply chain level, this is not necessarily true. Furthermore, to assess environmental effects of individual enterprises, it has been shown that the line for environmental information systems, can be continued.

9.5.2 Distribution Means

Packaging, and more specifically packaging material and distribution means, manifests itself in the well-known consumer packaging, but also in a number of production dependent processes: unit packaging, collection packaging, transportation packaging, packaging means and as product carrier (Boodts, 1995). The importance of packaging re-use originates from:

1. initiatives from authorities: legislation;
2. economic motives: increasing costs;
3. image and competition: environmental consciousness;
4. supply chain integration: attractiveness of standardisation;
5. new technology: bar coding and EDI.

The most relevant, mutually interrelated, characteristics of packaging can be found in:

the application of different kinds of packaging;
the nature: standard or specific;
the life-cycle: chain aspects and the influence on the primary processes;
the possibility for re-use.

In (Boodts, 1995) a data and process model has been developed, which induces extension of a large number of business processes of an ERP system (sales, purchasing, production, storage, distribution, control, finance, etc.). From an environmental viewpoint, Boodt's second assumption is of

importance. *At all packaging levels, the packaging is considered to be an item, as described in the basic system, with some adjustments.*
The most important consequence of this assumption is that existing functionality for items, like planning and control, are already available. The item types in figure 9-16 are subtypes in the product typology of section 6.4; accordingly, packaging material is treated as input product and applied in routings and recipes and the like.
As stated before, packaging plays a role in the environmental communication with authorities and supply chain parties. The communication includes the type and quantity of used packaging materials, but also the information content, the label, of the product. The information content of the product, such as the production characteristics, is derived from the other modules.

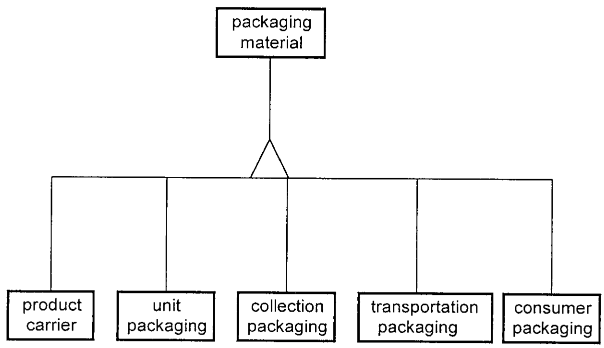


FIGURE 9-16 Packaging material considered as an item

9.6 Conclusion

This chapter focuses on environmentally oriented applications beyond the scope of an individual enterprise, on supply chain level. It considers the supply chain as a single entity and includes especially product responsibility, product certification and reverse logistics. It is shown that these are not specific for *environmental* applications, though can also be applied for, e.g., quality purposes. However, these approached presume that local, usually more detailed data is available. For environmental applications this concerns information systems for enterprise internal registration, information and management, as specified in the previous chapters.
Incentives for environmental supply chain applications are comparable with incentives in individual enterprises: customer requirements, environmental

image of the supply chain, viability of the supply chain and its parties and legislative obligations.

First, several subtypes of supply chains are identified: linear, converging, diverging and network chains. For all these chains, *the* begin and end of a chain cannot be defined unambiguously. For this purpose, so-called information decoupling points (IDPs) are defined. An IDP enables delineation of parts of the supply chain and results in a decoupled network.

Supply chain modelling, subsequently, is based on modelling of interfaces between enterprises in a supply chain. An interface may concern product information and specification and can be described according to the minimal model approach.

One of the constraints in a minimal model may be related to product responsibility, as a means to guarantee that products meet particular customer requirements. Two application types are mentioned: product tracing and product tracking.

Another constraint may be caused by product certification. Whereas process certification is restricted to a particular enterprise, product certification usually concerns several enterprises. To be able to guarantee that a produced product meets the requirements for certification, such constraints is exchanged and should influence the system's behaviour. Furthermore, the information which guarantees that a product meets the requirements is communicated in the output interface.

Finally, the role of reverse logistics has been discussed. It is elaborated which steps should be carried out to be able to re-use products or to produce products which consist of used materials or components. In the context of this thesis, it has been concluded that this not necessarily implies that this results in more environmentally benign products and production processes, though this should be proved by, e.g. LCA.

10. Conclusions and Discussion

The main objectives of this study were: (1) to give an overview of environmental information requirements from the viewpoint of manufacturers; (2) to give an overview of existing environmental applications that meet those requirements; and (3) to develop an environmental information system to fulfil environmental information requirements as stated in the overview, making use of already existing environmental applications and conventional business information systems.
In this chapter, first the general conclusion is presented. Subsequently, the methodology and significance of the research is discussed. Finally, some specific conclusions and their implications are discussed in more detail, including consequences for environmental modelling, extensions of enterprise resource planning software and supply chain modelling.

10.1 General conclusion

This research focuses on environmental information for business purposes, especially on data integrity. In this thesis, the resemblance, rather than the difference with other business information and information systems is taken as point of departure.
Conventional environmental information systems are hardly integrated with other business information systems. It has turned out that lack of integration has resulted in an inefficient and ineffective environmental information policy and in inconsistent environmental information.
For application in the context of this study, existing environmental modelling methods are combined, which has resulted in the Multiple-Input Multiple-Output Process (MIMOP) approach. It is concluded that the larger part of environmental data can be modelled by this approach. Furthermore, it is concluded that this approach is suitable for integration with modelling approaches which are frequently used for the benefit of other business information systems, especially Enterprise Resource Planning systems.

Integration between environmental- and ERP information systems takes place on several levels. The most important is the registration level, which enables non-redundant data registration. It is shown that the environmental reference data model can be specified as a view on an ERP reference data model.
Furthermore, this property enables functional integration. It has turned out that environmental applications are frequently based on conventional functionality applied on new data or on new functionality (on conventional and new data).
Finally, some attention has been paid to environmental information in supply chains. It is argued that, from an environmental viewpoint, enterprise boundaries should be subject of discussion, for example in case of outsourcing of activities. However, if the fixed enterprise boundaries are abandoned, it has turned out that delineation of the object of modelling is difficult. For this purpose, so-called decoupled networks are defined. In such a network, environmental information can be modelled based on locally available environmental information systems.

10.2 Methodology

The research aimed to improve the efficiency of environmental information policy of enterprises, and to increase the level of data integrity of environmental information from the viewpoint of enterprises. At first sight, one should start at a high level to study environmental effects. However, it quickly became apparent that this approach requires environmental information from individual enterprises, information which frequently turned out to be unavailable or inconsistent. For that reason, first a detailed and local approach is elaborated.
As a consequence, this thesis focuses on efficient environmental information registration, and less on particular environmental functionality and environmental applications. For that reason, conventional systems and tools have been taken as point of departure. Another consequence of the applied approach is that environmental information systems beyond the scope of an individual enterprise has remained underexposed. Some attention has been paid to supply chain modelling, however no attention has been paid to consequences of environmental effects of, amongst others, product use.

Within the scope of this study, another shortcoming should be mentioned, namely the limited number of case studies in the validation phase of the research. Whereas many cases are available to validate the translation of the modelled data into environmental information, only two cases show the translation of the model in information systems. Furthermore, it would have been valuable if a prototype had been implemented. The prototype could have shown omissions on a more detailed level and could have been used for evaluation and improvement in practice. This research doesn't claim to provide a 'plug and play' system. Nevertheless, it shows that environmental information, and environmental information systems, can benefit from already available (business) information and information systems.

10.3 Existing situation

Requirements

Environmental requirements on an individual enterprise are, to a large extent, formulated by authorities, supply chain parties and the enterprise itself. Those requirements show large similarity, and merely differ in level of aggregation. Research has turned out that these data are largely based on process and product data, on different aggregation levels. This view provides an opportunity for integration with business information systems that already register those data partly.

Environmental Information Systems

Many environmental applications are already available, e.g. Environmental Management System, Life-Cycle Assessment, environmental labels, etc. As an overall picture, it can be concluded these applications roughly meet environmental demands of individual enterprises on strategic and tactical level. Practical application, however, depends on the underlying operational level. Research on already available environmental applications revealed that these could be supported by a collection of conventional environmental information systems. However, it has turned out that there is a gap between operational and strategic/tactical level and that these information systems don't meet the information requirements of the mentioned environmental applications. The weakness is based on:

(1) lack of integration between environmental information systems and environmental applications.
(2) lack of integration of the necessary environmental information systems;

(3) lack of integration of environmental information systems with other business information systems;

A survey on existing environmental modelling methods led to a similar picture, which revealed that existing methods equally lack adequate environmental data specialised for enterprises.
It is concluded that a need exists for an integral environmental information approach from the viewpoint of manufacturers, particularly on operational level. Such an integral approach includes environmental applications, enterprise information systems and their mutual co-operation.

10.4 Environmental Modelling

Existing environmental modelling methods are not suitable for individual enterprises. Many data are required to meet information requirements of those methods. Usually this information is not completely, or not at all, available, which causes discrepancies in the integrity and accuracy of information and which makes conclusions rather weak. Therefore, it is concluded that also an adjusted environmental information modelling method is needed for individual enterprises.

MIMOP approach
Registrations with regard to the goods flow can be used to retrieve environmental information; it turned out that environmental information systems are based on data which are related to products, processes and production means. These data are in essence not different from registered data in other business information systems.
The MIMOP approach is based on this idea and can be considered as a combination of existing environmental modelling methods. The main advantage of this method is that all data are based on physical flows, which might already be recorded in existing business information systems. This method is rather detailed, though it additionally provides means for aggregation with respect to processes, products/materials and over time, which largely reduces such drawbacks.

Consequences
In the MIMOP approach, for the time being no attention has been paid to registration of environmental information which is not directly related to the

goods flow. This implies that, for example, soil inspections or complaint registration are not included. Further research should reveal whether it is desirable and possible to include such functionality.
Furthermore, no special attention has been paid to modelling and registration of energy flows. In a first approach, energy is modelled as a constituent of a product. However, when implementing this approach in an ERP system, it may face difficulties, e.g. in measuring. Further research should show whether this approach remains applicable in other systems with more emphasis on energy registration.

10.5 Integral environmental information systems

In this study, an environmental information system which has been developed in line with the MIMOP approach, can be considered as an extension of an enterprise resource planning system, with respect to registered data and functionality. In an overall view, existing functionality is available for existing and new data, as well as new functionality is available for existing and new data. The whole is a means to support (existing) environmental applications directly and via (existing, conventional) environmental information systems.
It aims to retrieve consistent environmental data, to be supplied to existing environmental information systems. To this purpose, the materials balance has been introduced. It turned out that it can be considered as a view on the data model, and doesn't require new entity types. The relevant materials should be registered in the composition of products. To some extent, this may be handled in the bill-of-materials, on a more detailed level additional registration is required. The registration of product compositions in this way may be very detailed, though three aggregation mechanisms have been made available.

Materials aggregation
This form of registration and reporting is already used in environmental applications, such as environmental reporting. In connection with this, a typology for aggregation levels has been defined and added to the environmental reference data model.

Process aggregation
The aggregation of process steps, as applied due to business constraints, aims to decrease the level of detail onto one that is more in line with the

environmental requirements. Process aggregation and decomposition mechanisms are often available in ERP software.

Aggregation over time
This form of aggregation has been added because environmental reporting is not only required for a particular (aggregated) process but also over a period of time. By increasing the period of time, a number of consecutive processes may be covered. To do so, the start- en finish times of process should be measured and registered.

This approach has resulted in an environmental reference data model (ERDM). The ERDM is a basis for adequate data supply for existing environmental applications. It can be used as a means for selecting a business information system with an adequate data structure from an environmental viewpoint. The extensions of the ERDM, as developed for the environmental registration system, can be considered as an interface between already implemented ERP- and environmental information systems.

Consequences
Starting point for the development of environmental information systems is a reference data model for Enterprise Resource Planning software. This data model should be considered as an overview of possibly available functionality in ERP systems. In practice, commercially available software packages merely cover a subset of this functionality. When developing an environmental information system, it should be examined whether all required data structures are available. This especially holds true for an important precondition of environmental information systems: the 'diverging aspect'.
Many ERP systems are designed for discrete manufacturing processes, e.g. for the automotive industry. This implies that such ERP systems are based on (convergent) bills-of-materials. From an environmental viewpoint, however, such a process is divergent because waste and emissions remain. This requires considerable adjustments. Adjustments with respect to divergency may cause less impact for ERP systems designed for process industries, because those systems already support divergent production planning based on (divergent) recipes.
In this study, it is argued that coexistence of different kinds of software packages for discrete manufacturing and process industries is not desirable. and a shift towards integration of information systems for discrete manufacturing and process industries seems to be natural. An important

reason is that many business processes have both discrete and process oriented characteristics. From an environmental viewpoint, however, virtually all processes are divergent, because waste and emissions remain.

10.6 Environmental information in supply chains

The study of environmental information and information systems particularly in a single enterprise is limited for two reasons. First, environmental effects usually ignore enterprise boundaries. Secondly, environmental effects concern processes which may, or after some time may not, be carried out in a particular enterprise.

Beyond the scope of an individual enterprise, on supply chain level, it turns out that the concept for environmental information systems as outlined before is not directly applicable. For an individual enterprise, the boundary of what is included and excluded in a chain analysis is, though arbitrary from an environmental viewpoint, physically or legally defined. However, this doesn't hold true for supply chains and therefore an additional method for delineation is required. It is outlined that a guarantee mechanism in so-called information decoupling points (IDP) enables definition of decoupled networks. Through this mechanism, it is guaranteed that that enterprises in the chain before such an IDP don't have to be included in a chain analysis.

Consequences

In this thesis, it is argued that delineation by means of IDPs is not specific for environmental applications, though can also be applied for, e.g., quality or safety purposes. Further research should reveal the consequences of a particular locations of an IDP, shifts of the location of an IDP in the supply chain and application of several kinds of IDPs in a supply chain.

Finally, it can be concluded that this research doesn't claim to provide a 'plug and play' system. Nevertheless, it shows that environmental information, and environmental information systems, can benefit from already available information and information systems.

APPENDICES

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B: Conventions for Data Modelling

Terminology

Data Structure
A model of a set of data that describes the actual structure of this set. This (logical) structure is independent of both the way in which it is used by different applications, as well as the software and hardware techniques that are used to store, project, retrieve, access this set. The term data model is considered to be a synonym.

Entity
A 'thing' for which data is collected and recorded, such as objects, persons, abstract concepts or events, because it is relevant for an organisation.

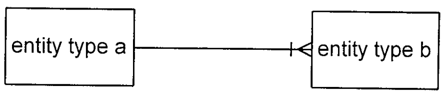
Entity Type
A set of entities that display the same behaviour and characteristics within a certain level of abstraction.

Relationship Type
A logical association between to entity types.

Notation

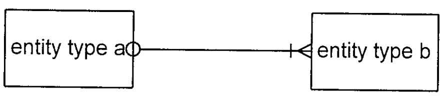
mandatory 1:1 relationship type
an **'a'** is related to one **'b'**; and vice versa

optional 1:1 relationship type
an **'a'** may be related to a **'b'**; and a **'b'** is related to one **'a'**

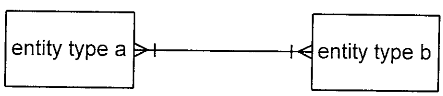


mandatory 1:n relationship type
an **'a'** is related to one or more entities **'b'**; and a **'b'** is related to one **'a'**

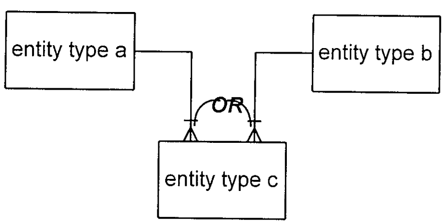
mandatory 1:n relationship type
an **'a'** is related to zero or more entities **'b'**; and a **'b'** is related to one **'a'**



optional 0:n relationship type
an **'a'** is related to one or more entities **'b'**; a **'b'** may be related to a **'a'**



n:m relationship type
an **'a'** is related to one or more entities **'b'** and vice versa



exclusive relationship type ('OR')
a **'c'** is related to either one or more entities **'a'** or to one or more entities **'b'** but not both

C-I: List of prioritised materials

I Acidifying and fertilising materials

- ammonia
- phosphate
- nitrate
- nitrogenous oxides
- sulphur dioxide

II Metals

- arsenic
- cadmium
- chromium
- copper
- mercury
- lead
- zinc

III Organic compounds

a) non-halogens

- petroleum
- (gaseous) hydrocarbons
- benzene
- ethene
- phenol
- formaldehyde
- toluene
- propylene oxide
- ethylene oxide
- polycyclic aromatic hydrocarbons
- styrene

b) halogen aromates

- chlorides
- chlorobenzene

- chlorophenol
- dioxines
- PCB and PCT

c) other halogen compounds
- chlorofluorhydrocarbons
- 1,2- dichloroethane
- hexachlorocyclohexane
- methylbromide
- tetrachloroethene
- tetrachloromethane
- 1,1,1-trichloroethane
- trichloroethene
- trichloromethane
- vinylchloride

IV **other materials**
- asbestos
- fluorides
- carbon monoxide
- ozone
- dust (fine)
- dust (coarse)
- sulphur hydrogen

C-II- List of materials that require special attention

(source: Staatscourant 199, October 12, 1990)

halogen aromatic hydrocarbons

1. chlorobenzene
2. chlorophenol
3. chlorotoluene
4. chloroaniline
5. chloronitrobenzene
6. hexachloride
7. polychlorobiphenyl and -triphenyl

aromatic hydrocarbons

9. benzene
10. toluene
11. styrene
12. polycyclic aromatic hydrocarbons

halogen non-aromatic hydrocarbons

13. dichloromethane
14. trichloromethane
15. tetrachloromethane
16. 1,2- dichloroethane
17. 1,1,1-trichloroethane
18. trichloroethene
19. tetrachloroethene
20. vinylchloride
21. methylbromide
22. chlorofluor hydrocarbons
23. hexachlorobutadiene
24. hexachlorocyclohexane

non-aromatic hydrocarbons

25. ethene
26. gaseous hydrocarbons

heavy metals

27. mercury and compounds
28. chromium compounds
29. cadmium and compounds
30. lead and compounds
31. arsenic and compounds
32. antimone and compounds

33.copper and compounds
34.zinc and compounds
35.nickel and compounds

rare earth
37.lanthanium
38.cerium
39.neodymium
40.gadolinium

phtalate esters
41.dibutylphtalate
42.diethylphtalate
43.diisobutylphtalate
44.phtalate acid anhydride
45.benzylbutylphtalate
46.butyl(2-ethylhexyl)phtalate
47.butylglycolbutylphtalate
48.di(2-ethylhexyl)phtalate
49.dimethoxy ethylphatlate
50.di(2-butoxyethyl)phtalate
51.dioctylphtalate
52.dimethylphtalate
53.dihexylphtalate
54.diheptylphtalate
55.di(n-hexyl, n-octyl, n-decyl) phtalate
56.diisodecylphtalate
57.diisooctylphtalate
58.dimethylcyclohexylphtalate

acidifying and fertilising materials
59.phosphate
60.nitrate
61.ammonia compounds
62.sulphur oxide
63.nitrogen oxide
64.tritium

radio-active materials
65.carbon-radioactive isotopes
66.radon-radioactive isotopes
67.radium-radioactive isotopes
68.iodine-radioactive isotopes
69.polonium-radioactive isotopes

70.lead-radioactive isotopes
71.cesium-radioactive isotopes
72.strontium-radioactive isotopes
73.xenon-radioactive isotopes
74.argon-radioactive isotopes

herbicides

washing active materials
98.ethylenediaminotetraacetate (EDTA)
99.nitriloacetic acid (NTA)
100.anionic surface reactive substances
101.cationic surface reactive substances
102.non-ionic surface reactive substances
103.whiteners
104. washing active impurities
105.washing active bleaching agents
106.sulphates for filling in detergents

fire-delaying materials
107.polybrominebifenyles (PBB)
108.polybrominebifenyl oxide (PBBO)
109.tetrabrominebiphenole-A(TPPB-A)
110.hexabrominecyclodecaan
111.1,2-bi(tribrominephenoxy)ethane

other materials/material groups
112.2-hydroxy-2-methylpropane nitryle
113.acroleine
114.acrylonitril
115.phenol
116.formaldehyde
117.ethylene oxide
118.propylene oxide
119.fluoride
120.asbestos
121.sulphur hydrogen
122.carbon disulphide
123.carbon monoxide
124.ozone
125.dust (fine and coarse)
126.petroleum

C-III List of black materials

(source: Tweede Kamer, vergaderjaar 1985-1986, 19204 nrs 1-2)

materials	soil	water	air	remarks
I heavy metals, notaloides and compounds				
arsenic	x	x	x	
beryllium	x			
cadmium	x	x	x	
chromium			x	
mercury	x	x	x	
lead	x		x	
thallium	x			
tellurium	x			
tin	x			
silver	x			
II halogen organic compounds				
II-1 alifatic compounds				
aldrin	x	x		
chlorohydrate	x	x		
chlorade	x	x		
2-chloroethanol	x	x		
chloropropene	x	x		
dibromide ethane (1,2)	x	x		
dichloroethane	x	x	x	
dichloroethene	x	x		
dichloromethane	x	x		
dichloropropane (1,2)	x	x		
1,3-dichloro -2-propanol	x	x		
dichloropropene	x	x		
dieldrin	x	x		
endosulphan		x		
endrin	x	x		
heptachloride	x	x		
heptachloroepoxide	x	x		
hexachlorobutadiene	x	x		
hexachlorocyclohexane	x	x		
hexachloroethane	x	x		
methylbromide			x	

monochloroacetic acid	x	x		
tetrachloroethane	x	x		
tetrachloroethene	x	x		
tetrachloromethane	x	x		
trichloroethane	x	x		
trichloroethene	x	x		
trichloromethane	x	x		
1,1,2-trichlorotrifluorethane	x	x		
vinyl chloride	x	x	x	
II-2 chloroethers				
bis(2-chloride isopropyl) ether	x	x		
epichlorohydrine	x	x	x	
II-3 monocyclic aromatic compounds				
dichlorobenzene	x	x		
dichlorotoluene	x	x		
DDT	x	x		
hexachlorobenzene	x	x		
monochlorobenzene	x	x		
monochlorotoluene	x	x		
tetrachlorobenzene	x	x		
trichlorobenzene	x	x		
II-4 bi- and tri-cyclic compounds				
monochloro ..	x	x		
polychlorobifenyl	x	x		
polychloroterfenyl	x	x		
II-5 chloride phenols				
2-amino-4-chlorophenol	x	x		
monochlorophenol	x	x		
4-chloro-3-methylphenol	x	x		
2,4-D (including salts and esters)		x		
2.4-dichlorophenol	x	x		
dichloroprop		x		
mecoprop		x		
MCPA		x		
2,4,5-T (including salts and esters)	x	x		
pentachlorophenol		x		
trichlorophenol	x	x		
II-6 nitro-aromatic compounds				

4-chloro-2-nirto-aniline chloro-dinitrobenzene 1-chloronitrobenzene chloronitrotoluene dichloronitrobenzene trifluarine	x x x x 	x x x x x x		
II-7 aromatic chloroamine and triazine chloroaniline chlorotoluidine dichloroaniline dichlorobenzidine monolinuron linuron propanil simazin 2,4,6-trichloro-1,3,5-triazine	 x x x x x x	 x x x x x x x x x		
II-8 chlorodioxin and -dibenzofuranen polychlorodibenzodioxine polychlorodibenzofuranes	 x x	 x x	 x x	
III organic phosphor compounds				
IV organic tin compounds dibutyltinchloride dibutyltinoxide dibutyltinsalts (others) tetrabutyltin tributyltinoxide triphenyltinacetate triphenyltinchloride triphenyltinhydroxide	 x x x x x 	 x x x x x x x x		
V persistent mineral oil and persistent hydrocarbons from petroleum *V-1 mono- and bicyclic aromates* benzene biphenyl ethylbenzene isopropylbenzene toluene	x x x x x x	 x x x x x	 x 	

xylene	x	x		
V-2 polycyclic aromates	x	x	x	
VI other organic compounds				
VII-cyanides cyanide	 x			
VIII asbestos crocidolyt crysotyl amosyt			 x x x	

D: Samenvatting (Summary in dutch)

De eerste stappen om de milieubelasting te verminderen zijn jaren geleden al genomen (Club of Rome, 1972, World Commission on the Environment, 1987). Tegenwoordig heeft de industrie te maken met een veelheid aan milieu wetten en -reguleringen, en verschillende soorten eisen van klanten en leveranciers. Het blijkt echter dat bedrijven er moeite mee hebben economische en milieu-georiënteerde eisen te combineren. Moderne milieu-informatiesystemen houden hier geen rekening mee en maken geen gebruik van reeds gebruikte systemen. Hierdoor is het verzamelen van correcte en consistente milieugegevens moeilijk, zo niet onmogelijk. Om dit te verbeteren heeft dit onderzoek zich gericht op de milieu-informatie eisen van een bedrijf en het ontwerp van een milieu-informatiesysteem dat aan deze eisen voldoet.

Beschrijving van het onderzoek

Milieu-informatie van een bedrijf is met name interessant voor overheden, ketenpartijen, omwonenden en voor het bedrijf zelf. Het meest opvallende verschil in informatie die deze partijen vragen is gelegen in het aggregatie niveau van deze informatie. Overheden richten zich veelal op gedetailleerde gegevens met betrekking tot afval, emissies en hinder. Klanten en leveranciers zijn eerder geïnteresseerd in sterk geaggregeerde gegevens, zoals product labels en certificaten die betrekking hebben op grote groepen producten, op het totale bedrijf of zelfs de hele bedrijfsketen. Bestaande milieu systemen richten zich met name op dergelijke geaggregeerde gegeven (milieu management systemen, levenscyclus analyse tools, milieu jaarverslagen).

Het ontbreken van middelen ten behoeve van meer gedetailleerde gegevens is een belangrijke tekortkoming, zowel om aan de vraag van bijvoorbeeld overheden te kunnen voldoen als om geaggregeerde informatie te kunnen genereren. Deze tekortkoming is gebaseerd op:

- het ontbreken van integratie tussen milieu-informatiesystemen en milieu tools;
- het ontbreken van integratie tussen de benodigde milieu-informatiesystemen;
- het ontbreken van integratie tussen milieu-informatiesystemen en andere bedrijfsinformatiesystemen.

Gedetailleerde milieu-informatie, met name met betrekking tot afval en emissies, is gebaseerd op product- en procesgegevens. Gezien de wenselijkheid om economische en milieu doelen te combineren, is in dit onderzoek aansluiting gezocht en gevonden bij Enterprise Resource Planning (ERP) systemen, die ook gebaseerd zijn op product- en procesgegevens.

Modellering

Gebaseerd op bovengenoemde ideeën is een modelleringsmethode ontwikkeld: de 'multiple input, multiple output proces' (MIMOP) benadering. Deze benadering maakt gebruik van het principe van massabalansen voor productieprocessen. Deze processen kunnen zeer klein zijn, maar ook het totale bedrijfsproces omvatten. In deze methoden worden onderscheiden:

- ❑ het toeleveren van materialen, productiemiddelen en energie als input van het productieproces;
- ❑ een black-box waarin de transformatie plaatsvindt; en
- ❑ het product dat resulteert van de transformatie, meestal vergezeld van verschillende co- en bij producten, de gebruikte productiemiddelen en energie.

Een black-box benadering is een goed uitgangspunt voor het modelleren van milieu-effecten. Voor de MIMOP benadering is bovendien gebruik gemaakt van mechanismen voor aggregatie en decompositie van processen, componenten en materialen, en van aggregatie over een bepaalde tijdspanne. Hierdoor worden de belangrijkste nadelen van een op het oog gedetailleerde methode weggenomen, terwijl het mogelijk is in te spelen op de (veranderende) vraag van klanten, leveranciers en wetgeving. Het belangrijkste voordeel van de methode is dat het bedrijven in staat stelt milieu-informatie op relatief eenvoudige wijze op te slaan en te raadplegen door gebruik te maken van reeds gebruikte bedrijfsinformatiesystemen, waaronder voor logistiek, financiën en kwaliteit.

Informatiesysteem

De integratie tussen milieu- en ERP informatiesystemen vindt plaats op een aantal niveaus. Het belangrijkste niveau is het registratieniveau, waar product- en procesgegevens eenmalig kunnen worden opgeslagen (milieu registratie systeem).

Vanuit het registratie systeem kunnen milieugegevens worden gebruikt, ten behoeve van specifieke milieu-informatie en voor andere functionele gebieden, zoals economische of kwaliteitsinformatie (milieu informatiesysteem).

De milieu-tools tenslotte, maken gebruik van bovengenoemde systemen. Hierbij gaat het om bestaande functionaliteit toegepast op nieuwe data, en om nieuwe functionaliteit (op conventionele en nieuwe data). Er zijn milieu tools bedoeld voor een individueel bedrijf, maar ook ten behoeve van een bedrijfs- of product keten.

Milieu registratiesysteem (ERS) Evaluatie van bestaande ERP systemen voor gebruik ten behoeve van milieu-informatiesystemen heeft tot de conclusie geleid dat de structuur van conventionele MRP systemen voor discrete productie niet geschikt zijn. Pakketten die specifiek zijn ontwikkeld voor meer proces-georiënteerde productie en gebruik maken van divergente productstructuren en recepturen zijn echter veel beter toepasbaar.
In de praktijk blijkt dat veel processen niet 100% discreet of procesmatig zijn; vanuit milieu-oogpunt zijn er weinig processen die slechts een enkel eindproduct opleveren, zonder enige vorm van afval of emissie. Het lijkt daarom een natuurlijke gang van zaken dat bedrijfsinformatiesystemen zich meer gaan richten op het ondersteunen van beide productiewijzen. Dit sluit bovendien aan bij het feit dat veel bedrijfsprocessen van nature zowel discrete als procesgeoriënteerde eigenschappen hebben.
Binnen het milieu registratiesysteem wordt het principe van materiaalbalansen gebruikt. Een materiaalbalans kan worden beschouwd als een bepaalde view op een reeds bestaand data model, waarbij het niet nodig hoeft te zijn dat dit data model wordt uitgebreid met nieuwe entiteittypen. Behalve volledige materiaalbalansen worden ook partiële balansen toegepast; hiervoor wordt slechts gebruik gemaakt van een (kleine) deelverzameling van materialen. In beide gevallen is het zo dat de materialen waar de balans over wordt opgesteld, geregistreerd moeten zijn in de samenstelling van producten. Tot op zekere hoogte kan dit worden afgehandeld in de stuklijst, voor een meer gedetailleerde informatie is aanvullende registratie nodig.
Het milieu-referentie data model dat gebaseerd is op bovenbeschreven benadering vormt de basis voor adequate milieu-informatie voor verschillende toepassingen. Het effect van een specifiek proces (en zijn alternatieven) kan bijvoorbeeld worden gebruikt in een levenscyclus analyse. Bovendien kunnen de uitbreidingen die zijn ontwikkeld voor het milieu registratiesysteem worden gezien als een interface tussen reeds geïmplementeerde ERP systemen en milieu-informatiesystemen.

Milieu-informatiesystemen Het milieuregistratiesysteem wordt gebruikt als basis voor een integraal milieu-informatiesysteem. Dit milieu-informatiesysteem bestaat uit een aantal (wederzijds afhankelijke) elementen: (1) juridisch, (2) productie, (3) economisch, (4) inkoop, en (5) kwaliteit en veiligheid.

Het *juridische* aspectsysteem is niet sterk gekoppeld met de overige componenten. Het geeft met name aan welke onderwerpen van belang zijn in de registratie.
In het *productie* deelsysteem geeft aan wat onderwerp van onderzoek is: processen, producten en productiemiddelen. Op procesniveau kan worden gekeken naar een enkele processtap, of naar een groep van processen tot aan het niveau van het totale bedrijfsproces. Op productniveau wordt onderscheid gemaakt naar een specifiek eind-product en een klant-order. Afhankelijk van de wijze van registreren, kunnen de gegevens toestandsafhankelijk en -onafhankelijk zijn, en betrekking hebben op een bepaalde periode.
De combinatie met het *economisch* aspect systeem heeft voornamelijk betrekking op milieukosten. Het berekenen van milieukosten is niet significant anders dan het berekenen van andere soorten kosten. Het is echter erg lastig om objectief te bepalen welke kosten als milieukosten kunnen worden beschouwd en hoe deze moeten worden toegewezen aan een bepaalde productgroep.
Geautomatiseerde informatiesystemen voor *inkoop* komen met name voor op operationeel niveau in het orderproces. Milieugerichte inkoop heeft echter meer betrekking op initiële inkoop: het selecteren van producten en leveranciers. Dit wordt nog nauwelijks door ERP systemen ondersteund.
Het *kwaliteit-* en *veiligheid* aspectsysteem, tenslotte, is nauw gerelateerd aan het milieu-aspectsysteem. De informatie is gebaseerd op dezelfde gegevens, hoewel de besturing van het primaire proces verschilt. Dit maakt verdere integratie mogelijk, waarbij dan sprake is van een gecombineerd of integraal zorg systeem. Een aanvullend voorbeeld is de toepassing van MSDS sheets; hierbij kan weer gebruik worden gemaakt van dezelfde database.

Milieu tools Het voorgaande heeft betrekking op lokale informatiesystemen. Milieu tools kunnen echter ook betrekking hebben op de bedrijfsketen. Dit onderwerp komt in de volgende paragraaf aan de orde.
Het belangrijkste lokale milieu tool is het milieu management systeem. Drie onderwerpen in een milieu management zijn van belang om te worden ondersteund door een informatie systeem. Ten eerste kan de *audit cyclus* worden ondersteund door work-flow management systemen. Ten behoeve

van *registratie en monitoring* van milieu effecten kan het milieu registratiesysteem worden gebruikt. Tenslotte wordt de rol van *milieuverslagen* besproken. Hoewel milieu(jaar)verslagen nu ook worden gemaakt, zijn niet altijd adequate en consistente gegevens beschikbaar. Een ERP systeem, uitgebreid met een milieu registratie en informatiesysteem, kan wel dergelijke data opleveren.

Milieu-informatie in ketens

De stimulans voor milieugerichte keteninformatie is vergelijkbaar met die voor een lokale milieu-informatie: de klantvraag, een groen image, wettelijke eisen en levensvatbaarheid van de keten en zijn ketenpartijen.

Vanuit milieu oogpunt is een enkel bedrijf als onderzoeksobject vrij beperkt. Echter wanneer de harde bedrijfsgrenzen ter discussie worden gesteld is het moeilijk vast te stellen hoe er wel moet worden afgebakend. Een welgedefinieerd begin en eind van een keten is vaak niet aan te geven. Om een keten toch te kunnen beschrijven, wordt gebruik gemaakt van zogenaamde informatie ontkoppelpunten. Door gebruik te maken van dergelijke ontkoppelpunten ontstaat een 'ontkoppeld netwerk'. Hierbinnen kan weer gebruik worden gemaakt van lokaal aanwezige milieu-informatiesystemen en -tools.

Om ketens te kunnen modelleren wordt gebruik gemaakt van interfaces tussen bedrijven in de keten, die betrekking hebben op product specificaties en product informatie. Een toepassing hiervan is productaansprakelijkheid, als middel om aan te geven dat een product voldoet aan een bepaalde klant-eis. Hiervoor kunnen twee toepassingen worden genoemd: tracking en tracing. Andere milieu tools die de bedrijfsgrens overstijgen zijn product certificering en retour logistiek.

Wel beschouwd zijn de genoemde keten toepassingen niet erg milieu-specifiek, maar worden bijvoorbeeld ook voor kwaliteitsdoeleinden gebruikt. In alle gevallen geldt echter, dat op lokaal niveau gegevens beschikbaar moeten zijn. Voor milieu toepassingen kunnen daarvoor het milieu registratie en -informatie systeem worden gebuikt.

Uit het onderzoek is gebleken dat het gebruik van reeds geïmplementeerde bedrijfsinformatie systemen bijdragen aan het verbeteren van de kwaliteit van milieu-informatie. Integratie met deze systemen leidt tot meer consistente milieu-informatie, voor een individueel bedrijf en voor een bedrijfsketen.