THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Information Quality in Industrial Environmental Management

Defining and Managing Quality of Environmental Information

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Abstract

This thesis aims to describe how quality of environmental information can be defined and managed to support industrial environmental management. Environmental information is used in industries to monitor and control the environmental aspects of products and processes. The usefulness of the results as a basis for environmental management decisions is dependent on the quality of the information.

The research has been financed by the Swedish national competence center CPM (Center for Environmental Assessment of Product and Material Systems) and has been performed in project collaboration with companies from different industrial sectors. The focus of this research has been to increase the understanding of (1) what information quality means and how to define explicit quality requirements and (2) how information can be managed to fulfil defined quality requirements, and how information review can be used to maintain requirements and to monitor performance.

A definition of environmental information quality in terms of quality dimensions is presented, based on quality requirements in the ISO 14000 series of standards and a user-based empirical definition of information quality. The research also shows that expressing information quality requirements as information needs in terms of a well-defined data documentation format is a feasible and concrete way to explicitly define requirements and to support environmental information quality management.

Different strategies have been used in this research to manage quality of information to fulfil defined quality requirements. They have been aimed at establishing and maintaining information management processes, and have concerned structured documentation of data from different sources, managing quality during generation of data within production sites, and review of data to maintain quality requirements. Education and training have also been central in the effort to support the research and to increase competence and understanding among practitioners. This work has contributed to increased quality of environmental information with regard to different quality dimensions in the different projects that have been performed.

General principles of total quality management (TQM) have been applied in this research. A procedure for implementing environmental information quality management based on TQM principles is presented, which incorporates experiences from the research that has been performed. This indicates that TQM can be used to effectively manage quality of environmental information.

Keywords: industrial environmental management, information quality, environmental information systems, information quality definition, information quality requirements, information quality management, information review, total quality management

Papers included in the thesis

I. Pålsson A-C., Carlson R. 1998. Maintaining Data Quality within Industrial Environmental Information Systems. *Proceedings of the 12th International Symposium 'Computer Science for Environmental Protection', Bremen 1998*. Band 1/Volume 1 p. 252-265.

II. Carlson R, Pålsson A-C. 2001. Industrial environmental information management for technical systems. *Journal of Cleaner Production*. 9 pp. 429-435.

III. Carlson R., Erixon M., Forsberg P., Pålsson A-C. 2001. System for Integrated Business Environmental Information Management. *Advances in Environmental Research.* 5/4 pp. 369-375.

IV. Pålsson A-C., Svending O., Möller Å., Nilsson C., Olsson L., Loviken G., Enqvist A., Karlsson G., Nilseng A. 2002. An industry common methodology for environmental data management. *Proceedings of SPCI 2002, 7th International Conference on New Available Technologies, June 4-6, 2002, Stockholm*.

V. Pålsson A-C. 2006. Dimensions of information quality for industrial environmental management. *Submitted to Journal of Cleaner Production.*

VI. Pålsson A-C. 2006. Defining and managing the quality of environmental information using total quality management. *Submitted to Journal of Cleaner Production.*

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1 Introduction

Different methods and tools are used for industrial environmental management, i.e. the management of industrial processes with regard to environment issues towards the goal of sustainable development. The methods and tools is used assess the environmental consequences of industrial activities. Common for all tools and methods is that they utilize data and information for the assessment and that the quality of the information that is used and managed will consequently influence the usefulness of the results. If the information is not of sufficient and known quality, it is difficult to use the results as a basis for different environmental management decisions.

This thesis is intended to increase the understanding of the meaning of environmental data and information quality and describe how quality can be achieved and maintained. This chapter introduces the context and application of this research, as well as how the research will support the application.

1.1 Sustainable development

The context for this research is sustainable development, as defined by the Brundtland commission in the United Nations: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (UN 1987). The report from the commission called for strategies to strengthen efforts to promote sustainable and environmentally sound development.

Sustainable development demands ways of living, working and being that enable all people of the world to lead healthy, fulfilling, and economically secure lives without destroying the environment and without endangering the future welfare of people and the planet. Several United Nations texts, for example the 2005 World Summit Outcome Document, refer to the “three components of sustainable development - economic development, social development, and environmental protection - as interdependent and mutually reinforcing pillars".

The focus of the research in this context is the environmental protection side of sustainable development, but taking into account economic constraints and conditions.

1.2 Industrial environmental management

The application of this research is industrial environmental management, i.e. management of technical processes leading towards sustainable development with regard to environmental protection. This involves both voluntary efforts by industries in terms of environmental management as well as efforts with industrial management and fulfilment of legislative or regulatory measures that are aimed towards the common responsibility of sustainable development.

A number of different systems, methods and tools are applied by industries to manage the environmental aspects of processes and products. Several ISO standards and guidelines have been developed to aid and harmonize the work. Examples are:

- *Environmental management systems (EMS)* which is a management approach to identify, monitor and control the environmental aspects of an organisation, described in ISO 14001, ISO 14004 and the EU regulation EMAS (Eco-Management and Audit Scheme).

- *Environmental labels and declarations* which are used to describe the environmental impact of products, either through specified and set limits such as environmental labels (referred to as type I environmental labels), through self-declared environmental claims (referred to as type II environmental declarations) or through third party certified life cycle based environmental product declarations (referred to as type III environmental declarations). These are described in the ISO 14020 series of standards.
- *Environmental performance evaluation* which is used to assess the environmental performance of an organisation or activity, described in ISO 14031
- *Life cycle assessment (LCA)* which is used to assess the environmental impact of a product or service throughout its life cycle, from the extraction of raw material, through refining, production, use and end-of-life treatment, described in the ISO 14040 series of standards
- *Emission trading* which is used to monitor and manage emissions of greenhouse gases, described in e.g. ISO 14064 and the EU regulation ETS (Emission Trading Scheme).
- *Design for Environment (DfE)* which is used to consider environmental aspects in product and process design, described in e.g. ISO/TR 14062
- *Environmental and sustainability reporting* which are used to communicate the environmental or sustainability performance of the organisation, described in e.g. ISO 14001, ISO 14063, and in the GRI guidelines for sustainability reporting.

1.3 Information for industrial environmental management

Industrial environmental management relies on information, irrespective of which tool or method is applied. To steer towards sustainable development, information about the current status is used by a decision maker or controller who has control of the system. In Figure 1 this is illustrated as a general control system (Carlson&Pålsson 2000). A decision for controlling the system can be taken based on the current status with regard to performance, the perception of sustainable development and management goals. The controllers can be found in different levels of the organisation, e.g. the top manager, a product or process developer, or a product or production manager.

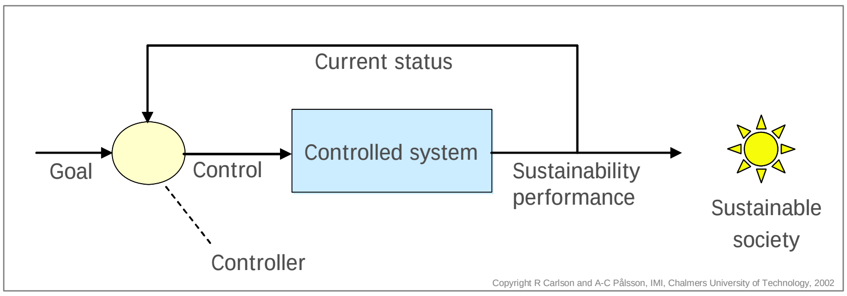

Figure 1. General control system for environmental management (Carlson&Pålsson 2000)

The data and information needed to assess the current status describe inputs and outputs of *technical systems* in terms of physical flows, such as use of raw materials and energy, emissions to air, water and soil, and generation of waste and residues.

Also, some type of description of how the physical flows affect or impact the *environmental system*, and how the impact on the nature system is valued and prioritised by the *social system* is needed. Thus, environmental management and assessment is an interdisciplinary field and implies using and assessing information acquired by different disciplines. For example, engineers acquire and model information about the inputs and outputs from the technical system, biologists acquire and model information about the environmental consequences of the inputs and outputs, and social scientists acquire and model information about the valuation and prioritisation, i.e. the social attitudes about the technical system's effects and impacts on the nature systems. In Figure 2 a high-level information model is shown describing the different types of information that is used and the relationships between the information (Carlson et al 1995).

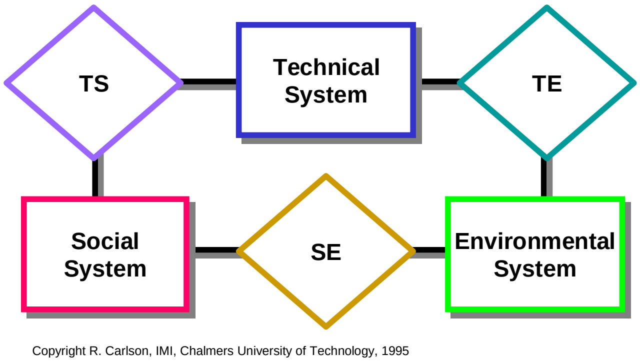

Figure 2. Information model describing the different types of environmental information (Carlson et al 1995)

Industrial environmental information management is supported by information systems. They are the means for providing decision makers at different levels with the information they need to do their jobs. Often the information systems used in environmental management are very simple, such as MS Word documents and MS Excel sheets or stand-alone software that is used for specific environmental assessment tasks (e.g. LCA, DfE) etc.

1.3.1 Data, information and metadata

The term *data* generally refers to "raw facts" whereas *information* is defined as "meaningful facts" or "data put in a context". Information is a coherent set of statements that forms a message. Information becomes knowledge when it is correctly interpreted and connected with prior knowledge (Eppler 2003, English 1999). It should be recognised that one person's information may be another's data depending on whether the recipient understands the data or their context. Data may become information when they are brought together with other facts in a way that makes sense, i.e. information is generated by compiling different pieces of data together into a context. Since information is generated from data, the quality of the generation of data and the quality of the generation of information is dependent on each other and should be managed in a coordinated and consistent way**.**

It should be noted, however, that in the environmental management literature the terms data and information are often used without clear distinction, and facts that are referred to as "data" should be interpreted as "information" according to the definition above. For example, data used in LCA are often referred to as LCI- or LCA-data. In practice, however, LCI-data are a compilation of several pieces of data, to describe the inputs and outputs of a defined model of a technical system, and does not make sense without a description of the model and the assumptions made. Thus, LCA data are not only raw facts but meaningful facts. In this thesis the general practice of how the terms are used in environmental management is followed.

The term *metadata* is generally defined as “data about data”, and is used to describe the context of the data. The term metadata is used for information systems, databases and data formats in two levels (Tozer 1999):

- Metadata about the file format (denotative); i.e. a description of the structure and the content of the format in terms of e.g. the specified content for specific data fields in the format.
- Metadata about the data themselves, represented in a file format (annotative); i.e. a description of the actual data contained in the format, e.g. in terms of the context and origin of the data.

Thus, data stored and communicated together with metadata are aimed to convey information to the users.

1.4 Environmental information quality

The focus of this research is on the quality of environmental information used in industrial environmental management. The quality of the results from different environmental assessments depends on the quality of the data and information used as input for the assessments as well as on how the information is processed and delivered to the intended users. The saying “garbage in, garbage out” is valid also for environmental management. The controller in the control system in Figure 2 will be in a better position to make a good decision about how to control the system if the information he or she receives is of known quality, i.e. that the information is accessible, that it accurately describes what it claims to describe, that it is understandable to the controller, and that it is relevant for the control situation.

Information quality is a multifaceted concept. Many different issues influence the actual quality and our perception of the quality of the information that is presented to us. There is a wide range of quality issues to consider for information and information systems, and they are all more or less interrelated. This concerns both the information content and how the information is captured, stored and delivered to the information users. For example, we must concern ourselves with quality of the:

- information content, i.e. what the information shall contain and describe
- processes involved in information management and administration and maintenance of the information system, i.e. collection, compilation, analyses, synthesis, review, presentation, delivery and utilization of information.
- development and application of the information structure in which the information is captured, stored and communicated
- development and maintenance of the technical implementation of the information system, in which information is inserted, stored, processed, and presented (database, user interfaces, software, etc)

Some central problems for environmental information quality are discussed in the following paragraphs.

There is often a lack of a common and shared view of what environmental information quality means among the providers and users of information. The providers and the users of the information can have different intuitive and implicit perceptions of what they consider as information quality, which they apply when generating and interpreting information. This can create communication problems. Information quality requirements and needs of the users are often not explicit or well known, i.e. the actual requirements of intended information users are often not well understood and specified.

Environmental information is not central business information within most organisations. The relationship between business development and environmental information is generally not well understood and established. This often hampers availability and accessibility of the information that is needed. There is often a lack of established routines for environmental information management, leading to the fact that information is collected and processed differently by different personnel and consequently the quality of information often is person-dependent. The information may not be sufficient to assess, for example, relevance and accuracy for the specific application for which it is to be used, or for follow-up of the performance. The information that is needed is generated in different functions within the organization for different purposes, documented in different internal reports, formats and information systems, but it is often not available in a form directly suitable for environmental assessments, and access to needed information may be obstructed by organisational barriers. There may also be a lack of knowledge and awareness of existing information quality problems and how to collect and process data that is needed, e.g. due to inexperience with the environmental assessment tool.

Environmental assessments require information from external sources, generated outside of the organisation, and for which the quality is difficult to both assess and control. For example, industrial organisations rely on information from suppliers, authorities, media, Non-Governmental Organisations (NGOs), universities, etc. The resources for environmental assessments are generally limited, with limited time for acquiring adequate and relevant information. The functions responsible for developing information to support environmental management often do not have the authority to set and enforce requirements on the quality of information delivered by external sources or by other business processes.

There is often a lack of coordination of management of environmental information used for different assessments performed within organisations. Different assessments can be made independently of each other by different personnel in different departments. For example, environmental reports are often developed independently of consideration of how the information that is acquired can also be used for other types of assessments such as life cycle assessments. This means that the information may not be available or may be incomplete for other environmental management purposes.

The fact that information used in environmental management is interdisciplinary, generated by different disciplines for different purposes, implies that the information can be difficult to interpret and understand. When performing environmental assessment, the person performing the assessment needs to interpret and use complex information with which they may not be familiar and which is not within their area of expertise. The information may also not be available in a form that is adapted for environmental assessments of industrial processes. This especially concerns information used to perform environmental impact assessments.

Environmental information is difficult to validate, due to the fact that there is no feedback from the environment to indicate errors in the information that is used to control environmental performance. The consequences may not be immediately discovered. The information that is used for assessing environmental impact could be generated without any connection with the real physical world that it is intended to describe, and can thus in fact not describe any real system.

A consequence from these problems is that available resources for environmental management are often not used efficiently and that poor quality of the information that is used as basis can hamper the ability for environmental control. This can result in a lack of credibility and faith in the results that are produced in environmental management efforts.

2 Related work

In this chapter an overview of the literature on information quality is presented, focusing on how this issue is addressed in both environmental management and for business information systems and databases.

2.1 General overview of the literature

In general, the approaches to information quality in environmental management are application specific, i.e. focussed on a specific tool or method. The attention is focussed on how to make use of and assess available information, and there is generally little or no attention paid to how to actively manage the quality of the information during acquisition. A main quality issue that is addressed is how to assess and communicate uncertainty, but often the meaning of the uncertainty is not well defined and is therefore difficult to interpret. Quality management principles and general information quality research are generally not utilized or acknowledged.

Approaches to information quality management for information systems and databases make use of and adapt general principles, methods and tools that are used for quality management of products. They describe how to manage quality during different stages of information management, both with regard to information system development and to information production and use. The starting point for these approaches is often information system development and maintenance. These approaches are intended to be applicable to any type of business information, but they lack descriptions of how they can be applied to a specific domain and the specific types of problems that occur when applied to specific types of information.

2.2 Information quality in environmental management

Interest in information quality differs between different methods and tools for environmental management. In general it seems that there is little discussion of information quality issues for environmental assessment tools and methods where the data used as a basis for the assessment are acquired internally through means over which the organization has control, and where the result is primarily used internally within the organization, for example information used in environmental management systems. The author’s general impression of the literature is that it seems presupposed that organizations have control over their internal data, and therefore specific data quality initiatives are not needed.

There seems to be more focus on information quality issues for methods and tools that are more externally directed, for example life cycle assessment (LCA) and environmental and sustainability reporting. LCA requires information from external sources outside of the organization, where the quality of the information cannot be overseen in the same way as internal information. For environmental and sustainability reporting information quality is also an issue, due to the fact that the reports will be scrutinized by different stakeholders. Errors found in these reports may jeopardize the credibility of the entire environmental management effort within the organization. There are also some standards available for managing the quality of measurements of emissions that is reported to authorities.

Much of the research in information quality for environmental management is directed towards how to assess, estimate and communicate accuracy and uncertainty. In general the approach is to make use of available information, without setting additional requirements on how the information is acquired. Instead the approaches try to “improve” the information after acquisition.

The approaches for estimating uncertainty of numerical data are generally based on qualitative indicators. An example is the pedigree matrix that was first developed by Funtowicz & Ravetz (1990) for environmental models, and has since then been adapted and applied for different applications, such as LCA (Weidema&Wesnaes 1996), and emission monitoring (van Sluijs&Risbey 2001). The idea in pedigree matrices is to estimate the uncertainty of data through a score based on a qualitative assessment of the data for a number of quality indicators. The quality indicators and the scores used for the assessment are intuitively and subjectively defined. Although such approaches may seem attractive and promising due to the fact that they are intended to provide a quantitative measure of complex information, the resulting uncertainty measures are difficult to understand and use in practice. There is no evidence or verification in the literature that the uncertainty measure resulting from applying a pedigree matrix represents any real uncertainty, as the concept of uncertainty is generally understood, i.e. in the sense of variability or the range within which the “true” value of the data is estimated to fall.

Data quality issues for LCA predominantly concern appropriateness or relevance of the data in relation to the goal and scope. Relevance is expressed in terms of different indicators; geographical and time-related coverage, precision, completeness, representativeness, consistency, and reproducibility (ISO 14044:2006). Much of the research regarding data quality within LCA has, however, been focused on reliability in terms of uncertainty (Björklund 2002). The concepts of precision and uncertainty are, however, not very well defined within LCA. Several approaches exist for quantitative estimation of the uncertainty of data and results. In these approaches attempts are generally made to incorporate also other quality dimensions into an uncertainty measure which is used as input in different stochastic modelling techniques (see, for example, Huijbregts et al (2001) and Kennedy et al (1996)). Most of these approaches use some type of pedigree matrix to estimate uncertainty in terms of standard deviations for data for individual input and output flows of a process, generally based on Weidema&Waesnes (1996). These approaches do not, however, discuss how to acquire “real” uncertainty information when the data are originally acquired.

With regard to sustainability reporting, a well known approach is the global reporting initiative (GRI). The GRI guidelines are developed through stakeholder consultations and describe reporting principles that should be applied in sustainability reporting. The most recent version released in October 2006 includes six principles for information quality that should be considered when developing reports (GRI 2006). The guidelines do not, however, provide guidance on how to manage data and information to ensure the quality of the information that is reported. Some guidance on how to assure the sustainability reports that are developed according to the GRI guidelines are also available (AA1000S 2002), but the guidance is general.

With regard to information disseminated by authorities, the US Environmental Protection Agency (EPA) has developed information quality guidelines which include specific requirements on information (US EPA 2002). The guidelines were developed as a response to the Data Quality Act for federal agencies, which is an attempt by the US Congress to ensure that federal agencies use and disseminate accurate information. The act requires each agency to publish agency specific guidelines for data quality management. A number of guidance documents have been developed (US EPA 2006).

Principles, methods or tools that are applied to manage product quality are generally not discussed or utilised in the approaches for managing the quality of environmental information. There is an American national standard for a quality system to support environmental data and technology programs (ANSI/ASQ E4 2002). There are also some approaches for environmental management that make use of insights from this domain, for example Product-Oriented Environmental Management (de Bakker 2002), application of Quality Function Deployment to incorporate environmental issues in product design (Masui 2003) or process mapping to improve information flow for environmental management (Pojasek 2004)

2.2.1 Environmental information quality management in the ISO 14000 series of standards

An analysis was performed of the documents in the ISO 14000-series with regard to how quality management of environmental data and information is addressed in these standards (Pålsson&Flemström 2004). The ISO 14000 series is the basis for environmental management within many organisations. All systems, methods and tools described by this series of standards require quantitative and/or qualitative data and information, where the quality of the data and information that is used and communicated will affect the credibility and the usefulness of results. Thus, the requirements and recommendations on how to manage data and information in these standards will have a large influence on the results of applying them and consequently on overall environmental management.

The aim of this analysis was to identify existing guidance and support for quality requirements and quality management of data and information in the documents, and to identify need for further support and guidance. Both finalised standards and working documents were included. The documents were reviewed and interpreted in terms of requirements, recommendations, and guidance on:

- Data and information quality definitions and requirements, i.e. quality aspects of the information that is used or reported in the system or tool
- Management of data and information to fulfil the stated data quality requirements, i.e. processes and procedures to define, collect, prepare and communicate data
- Documentation, i.e. requirements on documentation of procedures and results
- Evaluation, assessment, review, verification or validation of data and information, i.e. processes and procedures to ensure that data and information quality requirements are fulfilled

The analysis showed that the documents within the ISO 14000-series contain a variety of different definitions and aspects of data and information quality, but they do not provide sufficient guidance on how to manage data and information quality. Almost all documents include data and information quality requirements that should be considered or addressed when applying the system or tool, as well as requirements on different evaluations and assessments to be performed on the data. There is, however, little or no guidance or support on how to practically perform data collection and data management to ensure that data quality requirements are fulfilled.

This lack of support may lead to the result that quality requirements on data and information for the different systems and tools are interpreted in different ways by different users, leading to difficulties in comparing results. Quality management routines need to be developed independently by the users, and evaluation, assessment, review, verification or validation of data and information is difficult and costly. This also makes it difficult for organizations when planning, implementing and maintaining their environmental information management systems to support the different tools within the ISO 14000-series with data and information of appropriate quality.

2.3 Information quality for business information systems and databases

Most organisations use different information systems to support business processes. In parallel with the development of environmental management, different methods and tools have been developed since the 1990s for quality management of business information, information systems and databases. Most of these approaches are based on the same principles, methods and tools that are used for managing product quality. There is a large body of literature for managing product quality based on total quality management (TQM) (see, for example, ISO 9001:2000, Crosby (1979), Juran (2001), Deming (1986)). This knowledge and experience has in these approaches been applied to and adapted for data and information. The central elements in all approaches are also central elements for quality management of products, and they include:

- *Customer focus:* understand and define customer information needs and expectations. Information is seen as information products and the users are information customers
- *Well defined responsibility:* define and appoint responsibility for information quality management
- *Manage and improve production process:* define and manage information as a product from a well-defined production process, including both information system development and information generation and use

The most well-known and widely-used approaches to applying quality principles to information quality management are the ones developed within the Total Data Quality Management program at MIT (Massachusetts Institute of Technology in Boston) and by two practitioners, Larry English and Thomas Redman. Within the Total Data Quality Management programme a number of different methods and tools for information quality management have been developed. For example, general principles for managing information as a product (Wang et al 1998), the TDQM (Total Data Quality Management) methodology, which describes how to define, measure, analyse and improve information products (Wang 1998), and the AIQM methodology for information quality assessments and benchmarks (Lee et al 2002). The programme has also since 1996 organised and hosted annual international conferences on information quality (ICIQ 2006). English describes Total Quality data Management TQdM, which consist of five processes of measuring and improving information quality, and an umbrella process for bringing about cultural and environmental changes to sustain information quality improvement as a management tool and a habit (English 1999). Redman describes how to introduce and implement a data quality program, including descriptions of how different general methods and tools for TQM can be applied in the work (Redman 1996). These initiatives also discusses the impacts of poor information quality on business performance, see for example Redman (1998), Strong et al. (1997).

A number of different definitions and descriptions of what data and information quality means in terms of quality dimensions have also been developed (see, for example, Wang&Strong (1996), English (1999), Redman (1996), Price&Shanks (2004), Eppler (2003), Wand&Wang (1996).

These different approaches for information quality management are often described from the perspective of information system professionals, and are developed to be applicable to any type of business information. They do, however, lack guidance on how to apply the methods to a specific domain, for example how to handle the specific types of problems that occur when applied to specific types of information. None of these approaches have been applied in the approaches for managing environmental information quality.

3 Aim of research

The general purpose of this research is to show how information quality can be described, achieved and maintained to support industrial environmental management.

The aim of this research is to:

- Increase the understanding of what environmental information quality means and how it can be defined
- Describe how information quality can be managed, sustained and improved to facilitate industrial environmental management
- Introduce and show how established principles, methods and tools that are used for managing product quality can be applied and adapted for the management of environmental information quality, i.e. build on existing knowledge and experiences from total quality management research and development

The results are intended to aid information management and information system development for industrial environmental management. The target group is organisations that wish to improve their overall environmental management by improving the knowledge and the information used in environmental assessments.

Much of the research that has been performed has been focused on life cycle assessment and product-related environmental information, but with a clear ambition that it should be applicable also to information management for other environmental management missions. Also, the research has primarily been directed towards how to manage information that is used as input for different environmental management methods and tools.

Outside the scope of this research is how information is used for decision making. However, the work is intended to provide decision makers with information in line with their requirements and thus requirements of the decision makers are considered. Also, information structuring and general information system development are outside of the scope of this work. Research in this area has been performed by a colleague (Carlson 2006). The research in this thesis can, however, provide input to information structuring in terms of requirements etc., and it also provides support for assessing and using information structures.

4 Research design

The thesis is based on ten years of applied research within different projects in industrial and academic international environments. The author's main contributions and tasks in the projects have been to develop and implement information management processes in operational industrial situations, develop and perform information review, hold and participate in discussions about information quality and its meaning, as well as develop and deliver education and supervision in work with information management. The author's role in these different projects has either been project participant, project assistant or project manager.

Detailed literature reviews have also been performed regarding how information quality is handled, both in literature describing environmental management systems and tools, and in literature describing general information management with special focus on business information systems and databases. The major part of the research was performed before the detailed literature reviews. However, the reviews have confirmed that the approaches, methods and tools that have been developed and tested in the research are in line with the general developments described in the literature. The review also provided important elements to be considered and included in the synthesis of the research.

In this applied research, different methodologies to address identified environmental information quality problems have been developed and tested in case studies, in which industrial and academic practitioners have applied the methods and tools in their work. These case studies have been of different characters; some have been more exploratory where preliminary testing has been performed, and some have been aimed at full implementation into an operational solution. General quality management principles have been considered throughout the work.

The major part of this research was performed during the years 1996-2002. Since then, detailed literature reviews have been performed and the results have been analysed and synthesised. The results have also been applied in different projects within the research group Industrial Environmental Informatics, such as the OMNIITOX project aimed at developing information for toxicology impact assessment and the IMPRESS project aimed at implementing integrated environmental information systems. In these projects, the author has primarily been involved as a supervisor and a sounding board.

This research has been financed and performed within the Center for Environmental Assessment of Product and Material Systems (CPM) at Chalmers University of Technology. CPM is a Swedish national competence center, equally financed by VINNOVA[1], Chalmers University of Technology and Swedish industry[2]. The research within the center is performed in close collaboration between academy and industry.

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[1] VINNOVA: Swedish Governmental Agency for Innovation Systems

[2] Since the start of CPM in 1996 the following companies have participated: ABB, Akzo Nobel, Avesta Sheffield, Bombardier, Duni, Electrolux, Ericsson, IKEA, ITT Flygt, M-real (MoDo), Norsk Hydro, Perstorp, SAAB Automobiles, SCA, Stora Enso, SwedPower (Vattenfall), Telia Sonera (Telia), Tetra Pak, AB Volvo, Volvo Cars

5 Research work and results

5.1 Overview of work

This chapter describes the applied research work that has been performed in terms of content, results and experiences. Three major areas of research and development have been performed.

- *Define needs and requirements for environmental information quality*
  The focus of the research in this area has been to increase understanding of what data and information quality means and how to define quality requirements. This includes work with:
  - defining and applying the CPM data quality requirements, where information quality requirements were defined in cooperation and expressed in an information structure
  - developing and using dimensions of data quality to communicate and broaden the understanding of the concept of information quality
  - specifying environmental information as an information product
- *Manage information to fulfil defined quality needs and requirements for environmental information quality*
  The focus of the research in this area has been on how to generate and document information to fulfil defined quality requirements and how to review information to maintain requirements and to monitor performance. This includes work with developing and implementing:
  - methodology for data documentation to fulfil quality requirements
  - methodology for generation of data in line with quality requirements
  - methodology for information review to maintain quality requirements
- *Educate and train involved personnel to support the work with information quality management*
  The focus of the work in this area has been developing and providing support for practical work with environmental information quality management. This has supported the research in defining and managing quality of environmental information. This includes work with supervising practitioners, developing and giving courses, and developing manuals and other material to facilitate and support work with information quality management.

Each research and development area is described through the background and motivation for the work and a description of the content of the work and the methodology that has been developed and applied, as well as through the results. Also, experiences and analysis of the work are described.

The research has been performed in three main projects financed by CPM (Center for Environmental Assessment of Product and Material Systems):

- The establishment and maintenance of the CPM LCA database SPINE@CPM
- The CPM/SSVL project - Methodology for the forest industry's environmental data management (partly financed by the Swedish Forest Industries Water and Air Pollution Research Foundation (SSVL))
- The databases in networking project, in which the analysis and synthesis of this research have been performed.

All three projects have included elements from the three research areas.

5.2 Defining quality of environmental information

Papers that present this research:

- Pålsson A-C., Carlson R. 1998. Maintaining Data Quality within Industrial Environmental Information Systems. *Proceedings from the 12th International Symposium 'Computer Science for Environmental Protection' Bremen 1998;* Band 1/Volume 1 pp. 252-265
- Pålsson A-C. 2006. Dimensions of environmental information quality. *Submitted to Journal of Cleaner Production.*

5.2.1 Introduction

This chapter describes the work with defining quality of environmental information, and involves both how concrete and specific information quality requirements were developed, as well as the development of a broader understanding of the concept of information quality for industrial environmental management.

5.2.2 Information quality agreement expressed in terms of a data documentation format

An important requirement in the establishment of the CPM LCA database was that the database should be quality assured. However, at the time there was no definition of what quality meant and how this should be achieved. Therefore, a fundamental subproject in the project establishing the database dealt with defining quality requirements to be applied for the data to be published through the database. The requirements were defined in through a cooperative effort between academy and industry, where representatives for the different stakeholders in CPM participated; Chalmers, ABB, Akzo Nobel Surface Chemistry, Perstorp, SCA, Stora (now Stora Enso), Vattenfall and AB Volvo.

The work resulted in an information quality agreement published in 1997; the CPM data quality requirements, generally referred to as data documentation requirements or criteria. The requirements are expressed in terms of the SPINE and the ISO/TS 14048 data documentation formats (Arvidsson et al 1997, Arvidsson et al 1999, Flemström&Pålsson 2003a).

The basis, content and scope of this information quality agreement are described in the following subsections. The content of the requirements are also further described in section 5.3.2.

5.2.2.1 The CPM data quality requirements - Definition of data quality requirements developed within CPM

In developing the quality agreement, requirements expressed in the draft ISO 14041 standard and the ISO 9001 standard were considered and used as a foundation. The ISO 14041 standard provided the general quality requirements that should be considered in LCA, and helped assure that important issues pertaining to LCA methodology were not neglected. Data quality is in ISO 14041 generally defined as “characteristics of data that bears on their ability to satisfy stated requirements”. This standard further states that quality requirements should be specified with regard to a number of different aspects when performing LCA. The quality aspects to be considered in LCA studies concern technology, geographical and time-related coverage, representativeness, precision, etc. The ISO 9001 standard provided the general quality requirements and principles to consider when establishing quality management work.

Based on the requirements in ISO 14041 and the discussions within the project it was established and agreed that requirements for data quality differ depending on the specific users, target groups and purpose of the LCA study (Arvidsson et al 1997). In most LCAs, data describing many different types of technical systems are acquired and depending on the purpose of the study, different requirements are put on data quality and the type of data that can be used in the LCA. The requirements may concern both qualitative and quantitative aspects such as, for example, to what extent the data describe the technology under study, the precision of the data, etc. The quality of any specific LCI-data set is therefore dependent on the context in which it is used. This implies that any given data set may at the same time be considered to be of both high and low quality depending on the different perspective of the user.

This understanding and agreement led to the conclusion that the quality requirements can be expressed as information that is needed to allow the user to be able to independently assess the quality of the information and thus, transparency, reviewability and accessibility were considered as important quality aspects of the data. As quality was considered to be associated with the relevance of the data in a particular application, the quality of any given LCI-dataset when using it in a specific application may only be determined through a thorough knowledge of the system and of the data. It is up to the specific user to decide whether the data fulfil his or her quality expectations and requirements. Therefore, the data need to be documented in order allow for users to form an opinion of the relevance and other qualities of data. By transparently documenting the origin of data and making the documentation easily available, users can make their own assessment of whether the data are relevant or not. The documentation can be used to ensure that the data can be interpreted and used correctly.

5.2.2.2 Expressing information quality requirements in terms of data documentation formats

The requirements on needed information were explicitly defined in terms of the SPINE data documentation format, which is a format developed to structure environmental information in terms of data and metadata (Carlson et al 1995). The quality requirements were specified as a list of items to document in the SPINE format, based on and structured according to quality requirements in ISO 14041. It was established that the SPINE structure offers the means to structure LCI data documentation in an efficient manner and it was also verified that the SPINE structure is harmonious with the suggested quality requirements for LCI data in ISO/DIS 14040 (draft international standard). SPINE and the CPM LCI data documentation requirements were later compared with the final standard ISO 14041:1998 (E). After the publication of the ISO/TS 14048 data documentation format (ISO/TS 14048:2002), the requirements were also expressed in terms of this format, as part of the effort to translate SPINE tools and material into ISO/TS 14048. In the translation the original definition and meaning of the CPM data documentation criteria were maintained.

During the work with defining quality requirements, it was found that expressing quality requirements in terms of a common and structured data documentation format is an efficient method for users to explicitly express their information needs. For example, the abstract concept of “technology coverage” in the ISO 14041 was translated into a detailed documentation requirement that technology should be described in terms of scope and content. This made the work with information quality concrete. By using a common format, communication and interpretation is also facilitated, since the format provides a common language and specification for how to document and interpret the data, and data may easily be communicated between two parties sharing this common language. All relevant information to enable an assessment of the data is communicated together with the data.

5.2.2.2.1 Requirements on the data documentation format

Expressing quality requirements in terms of a data documentation format puts requirements on the data format. It should be well structured and yet flexible, be based on the user needs and requirements, and it should facilitate and support the tasks for which the information is collected, used and communicated. This must be considered when selecting a data documentation format. Otherwise there is a risk that restrictions and limitations in the format force users to define and specify quality requirements that are not relevant or sufficient for their needs or that the format does not support the tasks and consequently information suppliers and users will have difficulties in using it.

For example, the CPM quality requirements should be used to document data for any type of technical system that is studied in LCA, such as individual processes, plants, cradle to gate production systems for specific materials etc. The documentation criteria should also be used to document models of technical systems with an inner structure, i.e. models of technical systems that are composed of models of technical subsystems. Then the documentation of the aggregate model consists of the documentation of the technical subsystems and the documentation of the modelling of the aggregate model. Thus the format needs to be flexible enough to be able to handle these different types of information.

Both the SPINE and the ISO/TS 14048 formats fulfil these requirements. There are other formats available, of which the EcoSpold format is on of the most well-known. This format is used in the Swiss national LCA database ecoinvent and it is also used as exchange format in several commercial LCA software packages (Hedeman&König 2003). However, this format does not fulfil these requirements. The EcoSpold format is not well specified in terms of scope and content, it is difficult to interpret and use, and it does not allow documentation of aggregate models (Pålsson 2006a).

5.2.3 Dimensions of environmental data quality

Because the CPM quality requirements were expressed as documentation requirements, information quality was in a way considered as synonymous with documentation quality. The possibility to assess the different aspects of quality can in itself be considered as a measure of the quality of the data, i.e. the quality of the documentation of the data is in itself a quality aspect. This fact was not in line with the some prevailing perceptions of quality, e.g. that data quality is only associated with intrinsic properties of the information and is synonymous with precision and acceptable levels of uncertainty. Therefore, some explanation was needed as to why and how documentation of data is associated with information quality. There was a need for a better understanding of what environmental information quality means.

5.2.3.1 Intuitive understanding of data quality and data quality dimensions

To better understand and communicate the meaning of the CPM quality requirements, a definition of environmental data quality was developed in terms of different dimensions of quality. This definition broadened the concept of data quality beyond accuracy and uncertainty. There are a number of different quality aspects to consider, of which uncertainty is one. The only feasible way to be able to review and assess both qualitative and quantitative quality aspects of the data is through transparent documentation, and this requires that the documentation contains the specific information that the users need to assess the specific quality aspects they care about.

The different aspects that should be considered in data quality assessment can be categorised into the concepts *reliability*, *accessibility* and *relevance*. These concepts were introduced by Bengt Steen at Chalmers University of Technology in the discussions during the development of the CPM quality requirements (Steen 1996). To lend meaning to these concepts, they were disaggregated into concrete dimensions to be considered individually.

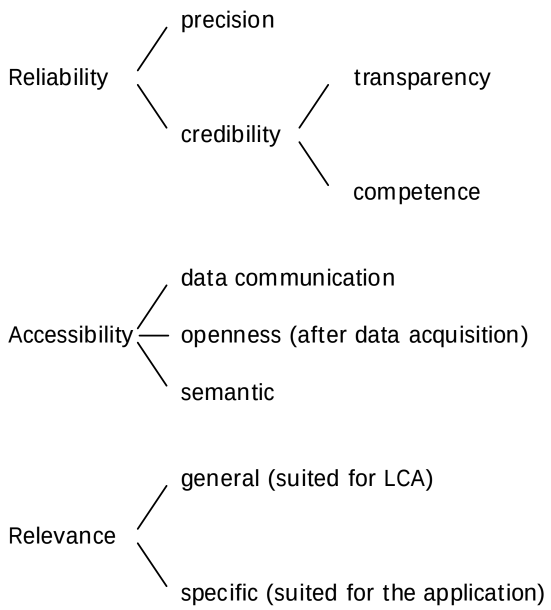

Figure 3. Dimensions of data quality developed in the work with the CPM LCA database, from Pålsson (1999a)

Reliability of data is an important quality aspect. The reliability depends on the *precision* of data and the *credibility* of the origin of the data. The *precision* of data concerns the uncertainty of data. The *credibility* of the origin of the data determines how credible the data may be considered. Credibility may be achieved through *transparency* and *competence.* A data set may be considered more credible if the data are transparently described and can be reviewed. Also, credibility may only be reached if the data have been acquired by someone with competence regarding the technology and the system that is described by the data.

Accessibility of data is often not considered as a quality aspect, but if the data are not accessible for the data users, the data reviewers etc., no other quality aspects can be considered. The accessibility of data concerns *data communication*, *openness* after data acquisition and *semantics*. *Data communication* is an important aspect of accessibility. In order for data to be useful, they need to be efficiently communicated between the data suppliers and the data users through different means such as mail, questionnaires, specific formats etc. Data communication may, however, only be performed depending on the *openness* after data acquisition. If aspects regarding openness, e.g. secrecy, are not solved or handled adequately, the accessibility of data will be obstructed. The *semantic* aspect of data concerns that the data should be understood by the intended users.

Relevance is also an important quality aspect. If the data are not relevant for the context in which they will be used they are not useful. For any specific data set there are two aspects of relevance: the *general* (suited for LCA) and the *specific* (suited for a specific application). The general issue, i.e. that the data are suited for LCA, regards the question of whether the data really describe a model of a technical system relevant for LCA. The specific issue, i.e. that the data are suited for the specific application, regards whether or not the data are relevant or valid for the application in which they are used.

5.2.3.1.1 The CPM quality requirements in terms of the quality dimensions

In relation to the CPM quality requirements, the dimensions have been used to provide an understanding of how and why documentation of data should provide sufficient information for any user to assess the different quality aspects. For example, with regard to reliability aspects, the precision should be explained and justified though a description of how the numerical data have been acquired and processed, the credibility should be explained by a specification and description of the person who has compiled and documented the data (competence), as well as how the compilation has been made (transparency). With regard to accessibility, the data should be communicated using a format that both the information provider and user are familiar with, and be understandable to the intended users. Also, any secrecy issues regarding the data should be known and specified, e.g. if confidential information is included. The relevance for LCA and the application can be assessed by the user through the general documentation of the data that allows different quality aspects to be assessed.

5.2.3.2 Deepening the understanding of information quality and information quality dimensions

The intuitively defined quality dimensions have been used in different projects, and in these projects the value of disaggregating the concept of quality has been evident. However, due to the fact that the dimensions were developed based on an intuitive understanding of quality, it has sometimes been difficult to justify its origin, relevance and rigor. Therefore a new set of dimensions has been developed and is presented in (Pålsson 2006b). These dimensions have a more solid foundation in both requirements specified for environmental information as well as in the information quality literature for business information systems and databases. The aim is to both capture the actual requirements and recommendations according to different environmental management methods and tools and put them into a general and coherent definition by making use of insights from general information quality literature.

Information quality can be defined using different approaches ((Marchand 1990), adapted from (Garvin 1984)):

- *User-based:* quality lies "in the eye of the beholder". The information sources that best satisfy the user's preferences are the ones they regard as having the highest information quality.
- *Production-based:* identify quality as "conforming to requirements", where the requirements can be of different types e.g. requirements set for the production.
- *Product-based:* quality is associated with the characteristics of the information products and can be measurable and quantifiable.
- *Value-based:* considers tradeoffs between competing criteria, where only one of which is information quality.
- *Transcendent:* assumes that information quality is absolute and universally recognizable. Information quality is synonymous with excellence.

These different approaches could lead to different definitions of quality that may be conflicting, which results in communication problems. Each approach however provides different perspectives on quality and this should be recognised since it provides an understanding of the viewpoints of different users, and it can be used to develop a common understanding of quality aspects and quality requirements. Different aspects of quality are more or less important depending on the perspective.

With regard to the different perspectives, the CPM quality requirements are user-based. Most other definitions and specifications of environmental information are product-based, specifying quality characteristics for information that is used and reported for a specific method or tool for environmental management. The quality characteristics are generally defined by the experts developing the methods and tools.

In the development of the new proposed set, these different perspectives are considered. The developed set is based on the quality aspects described by the ISO 14000 series of standards and the Wang&Strong (1996) user-based empirical definition of information quality. In the development of the set of dimensions of environmental information quality, the quality aspects found in the ISO 14000 series of standards have been interpreted, compiled and grouped based on the Wang&Strong definition. The resulting set is shown in Figure 4. A description of the categorisation and a definition of the dimensions are provided in (Pålsson 2006b).

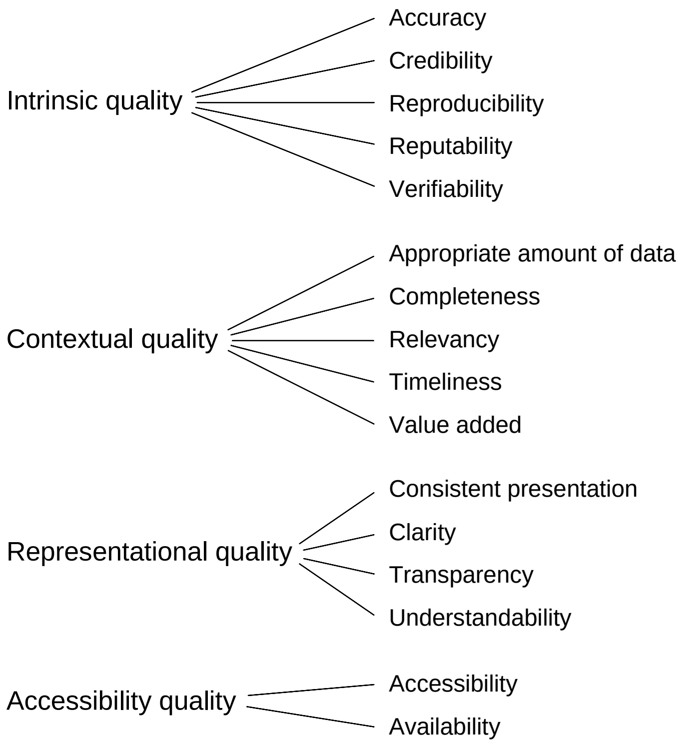

Figure 4. Dimensions of environmental information quality based on requirements in the ISO 14000 series of standards and the Wang&Strong (1996) user-based definition of quality

The ISO 14000 series of standards was selected as basis because they provide quality requirements for different environmental management methods and tools applied within industry, and the documents are developed in international consensus. The Wang & Strong definition of information quality was selected as foundation due to the fact that it is an empirical approach aimed to capture the voice of the customer, and it has reached acceptance and has been adopted in several approaches for information quality management. The Wang&Strong definition also includes a categorisation of information quality, found within the general information quality management literature. Other general definitions of dimensions in information quality literature for business information systems and databases are based on an intuitive understanding of quality and generally contain some overly technical dimensions, primarily aimed for information system development.

5.2.4 Environmental information as an information product

A viewpoint used in the literature describing quality management of business information systems and databases is that information should be seen as information products, rather than as by-products from different business processes, and that the strategic importance of information to support the business should be recognised (English 1999, Redman 1996, Wang et al 1998).

This viewpoint is also useful for understanding the role of documentation requirements, data documentation formats and information quality dimensions. The CPM data quality requirements expressed in a data documentation format provide a product specification for an information product, in terms of content and structure, i.e. the quality requirements specify the required content and the format specifies the structure of the product. The quality dimensions can be used to understand and define specific quality characteristics for this product.

The viewpoint of seeing environmental data or LCA data as an information product has been used in the establishment of an LCA data store and for establishing LCA data trade structures (Carlson et al 2000). In the establishment of the LCA data store, a classification of information product quality was developed based on the quality of the documentation. The classification involved three levels of documentation quality:

- Sufficient (i.e. sufficient information to use the data should be available),
- Acceptable (i.e. the information may be sufficient, but will most likely require further investigation to be able to use it), and
- Unsatisfying (i.e. the information is not sufficient and will require further investigation to be able to use it).

This classification has been applied to each dataset in the data store SPINE@CPM, i.e. the data store for the CPM LCA database, as a basis for pricing the data.

Defining and seeing environmental information as an information product also facilitates the understanding of why and how the principles, methods and tools of total quality management can be used and adapted to manage the quality of environmental information, and also facilitates practical work with information quality management

5.2.5 Experiences and analysis of results

A shared understanding of what quality means and well-defined quality requirements that are accepted by both providers and users of the information are an important basis for systematic management of the quality of the information in all stages of information generation, communication and use.

The CPM quality requirements have been used as a basis for different efforts in environmental information management by establishing a common platform from which to work. Since the publication of the criteria in 1997, they have been applied for all data published through the SPINE@CPM database (566 LCI datasets in August 2006). The data published in the database have been acquired and documented by industrial practitioners within CPM or by academic practitioners, e.g. M.Sc and Ph.D. students. The requirements have also been used to support practical work with environmental information management for different applications within companies and other organizations, where they have been reaffirmed and have been found to be valid. For example, they have been used in the forming of LCA data networks such as the national network Sirii (Erlandson&Carlsson 2002), in company internal databases for different environmental management purposes, and for documentation and review in the Swedish system for certified environmental product declarations (EPD) (Eriksson et al 1999, MSR 1999). In this work, they have contributed to improved quality of environmental data in terms of transparency and reviewability

The intuitively defined quality dimensions have been used in several contexts to discuss the concept of environmental data quality, and they have been useful for raising awareness for a broader understanding of what data quality means. They have been found to be generally applicable for describing quality of different types of environmental information and have been used as a basis for quality definitions and discussions in several projects within Industrial Environmental Informatics. For example, the OMNIITOX project aimed at developing an information system for toxicology data (Carlson et al 2003), the RAVEL project aimed at developing a tool for Design for Environment (Dewulf et al (ed) 2001), and the IMPRESS project aimed at implementing and integrating different methods and tools for environmental management (Carlson et al 2006). Other available definitions of environmental information quality are usually defined for a specific tool or method and are not generally applicable.

The work with the quality requirements and dimensions has led to a raised awareness of what environmental information quality means within the participating companies and this awareness has influenced and aided work with environmental information. The fact that the quality requirements were specified as concrete documentation requirements and that the dimensions were intuitively simple to understand facilitated adoption and use in internal discussions and work with environmental information quality.

The new set of quality dimensions is intended to provide a coherent definition of information quality for industrial environmental management. The difference from the intuitively defined dimensions is that the new dimensions are based on actual requirements specified in ISO 14000 series of standards, and on a general empirical definition of those quality characteristics that are most important for users. Thus, the aim with the new dimensions is to ensure that important issues according to these standards as well as issues that are important in general for information users are included. They have, however, not yet been tested and should be confirmed and validated in further studies.

5.3 Managing quality of environmental information

5.3.1 Introduction

While establishing the CPM LCA database it soon became evident that available data did not fulfil the quality requirements that were set for the data to be published through the database, simply because the required information was not captured when the data were acquired. Within the different data acquisition subprojects within the CPM database project, it became clear that data are not originally acquired in accordance with requirements (Carlson&Pålsson 1998). It was difficult for those responsible for delivering data to the database to supplement the information in line with the requirements and find information describing the conditions under which the original data had been acquired because the knowledge was no longer available. Early in the CPM database project the author made a study of the transparency of commonly used data while documenting data describing different means of transportation. An attempt was made to trace all sources of data to original measurements, but this failed due to the fact that information about assumptions, modelling choices and calculations that were made when compiling the data were not documented, and the persons responsible for the data could not describe how this had been done.

Based on this work, an early insight was therefore that the knowledge should be documented simultaneously with the acquisition, by the person acquiring the information, and that the quality if the information should be managed during the acquisition and processing of data.

Three parallel strategies have been used for managing the quality of the information, aimed at establishing and maintaining processes to ensure that the information quality requirements are fulfilled:

- Employ a methodology for environmental data documentation; manage and document available information from different sources
- Employ a methodology for generation of data and information within production sites; manage and document data when it is originally acquired and compiled at production sites
- Employ a methodology for information review; monitor performance and maintain quality requirements

5.3.2 Methodology for environmental data documentation

Data documentation is an integral part of environmental information quality management to ensure that relevant information is captured and communicated together with the data, in line with quality requirements. In this respect, much effort have been made to describe how to work practically with documentation using data quality requirements and data documentation formats, and how documentation can be integrated and implemented in the practical work with data acquisition and management.

As mentioned in the previous chapter, the CPM quality requirements were specified as a list of items to document in the SPINE format, based on and structured according to quality requirements in ISO 14041 (Arvidsson et al 1997, Arvidsson et al 1999). They were not, however, described in a way that facilitated practical work with documentation when data were acquired. Pedagogic descriptions and procedures for documentation were needed to make the requirements manageable.

A methodology for data documentation was therefore developed to aid the practical work with documentation in order to fulfil the CPM data quality requirements. The aim of the methodology was to ensure that data were correctly documented according to the requirements using the agreed-upon data documentation format, before it was submitted for publication in the CPM LCA database. The methodology is based on practical experiences from documenting data according to the requirements, and discussions with industrial and academic practitioners about the practice regarding data management for LCA, as well as supervision of the practitioners' work with data documentation at their work-place. The methodology describes both *what* to document based on the requirements, and *how* to do it, and was published in manuals to support documentation work (Pålsson 1997, Pålsson 1999a, Flemström&Pålsson 2003b).

At the time there was also no explicit definition of LCA data, which made discussions and work difficult. Different types of data were all referred to as LCA data; both data used for compiling LCA data as well as the resulting data used in LCAs. A practical definition was therefore developed to clarify the concept, and a description was developed of how and why different types of information should be documented based on the CPM quality requirements. The descriptions of documentation were based on the SPINE structure, but introduced some further concepts to facilitate understanding (e.g. choices in modelling, recommendations and administrative information), and were expressed in the language and terminology used by the users. The definition and description was generalised and applied to information associated with other environmental management tools and methods in order to show how the same quality requirements and documentation could also be used for other tools and methods and that information for different purposes could be coordinated.

The following subsections present the definition of environmental data as a model of a technical system, the description of documentation of models of technical systems as well as how to work practically with data documentation to integrate documentation with everyday work processes.

5.3.2.1 Definition of environmental data

5.3.2.1.1 <u>First definition: Life cycle inventory data – a model of a technical system</u>

The first definition of environmental data was developed to clarify the concept of life cycle inventory (LCI) data:
LCI data are data describing environmentally relevant inputs and outputs of a defined model of a technical system (see Figure 5). The inputs and outputs consist of energy and matter that is used in the technical system to fulfil a well-defined function of the system, expressed by a functional unit. For example, the technical system can be a production site that produces polyethylene. The function of the system can then be defined as "production of polyethylene", and the functional unit as, for example, 1 kg polyethylene. Examples of relevant inputs and outputs are natural resources, raw materials, energyware, ancillary material, products, by-products, emissions to air, water and soil, residues, etc. The models have a well defined scope, in terms of the activities that are performed to transform the inputs into the outputs, and boundaries

towards surrounding systems. The scope of the technical systems that are studied in LCA range from process steps or production lines within a site, entire plants, transports and transportation routes, and complex composite systems such as production systems for specific products from cradle to gate.

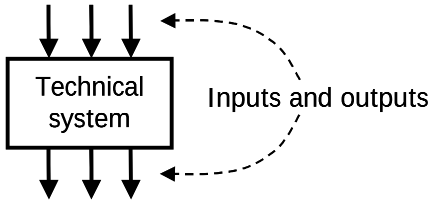

Figure 5. A model of a technical system

A model of a technical system can have an inner structure, i.e. be composed of models of technical systems, for example as a combination of unit processes (see Figure 6). There are in general two types of models with an inner structure: *flow models* and *average models* (Carlson & Pålsson 2001). For example, when performing a LCA study, a flow model of the studied product system is accomplished by linking models of smaller technical systems together in a flow chart. The models are linked to each other by their inputs and outputs. Other types of flow models may also be constructed and used in environmental management. For example, a model of a production line within a site may be composed of models of the included process steps. In addition to flow chart models, the models with an inner structure may consist of a number of similar models of technical systems when forming an average, for example an industrial average for a specific product, based on information about the different production sites included in the average.

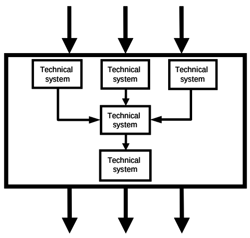

Figure 6. A model of a technical system, composed of models of technical systems

5.3.2.1.2 Generalisation of definition: Models of technical systems for different applications in industrial environmental management

The definition of environmental data was generalised to apply also to data used in other environmental management methods and tools:
Models of technical systems are used within a number of different applications in industrial environmental management. The models that need to be handled within an organisation can in general be divided into two different types:

- activity- and process-related models which describe environmental impacts of an activity or a process.
- product-related models which describe environmental impacts of the production of a selected product or product group.

Depending on the application in which it is used, the model has different content and system boundaries. An understanding of the similarities between the models used in different applications can facilitate coordination of information management. The following provide a brief description of applications within which models are used, and how these models are generally defined.

Activity- and process-related models:

- *Environmental management system:* To measure environmental impact of the activity and set environmental goals, models describing, for example, organisational units (departments) or production steps are used. The models are generally designed during the environmental investigation, where the activity's input and output flows are surveyed, and are subsequently used to follow up the defined goals. In these models the parameters that have been identified as environmental aspects for the activity are included.
- *Environmental reporting:* In environmental reporting, models describing the entire activity are used and communicated. These models include the parameters that are relevant for the activity and that are required by customers and other stakeholders.
- *Environmental reporting to authorities:* In environmental reporting to authorities, models describing the plant according to the control programme are used. These models generally only include the part of the plant and the parameters that are specified in the control programme.
- *Process optimisation:* In process optimisation, models of individual process steps or production lines are used to optimise and steer processes, e.g. with respect to a specific parameter.

Product-related models:

- *Life cycle assessment (LCA):* In life cycle assessment a model is created which describes the environmental impact of a product or a service during its entire life cycle, from extraction of natural resources, through all processing stages, use and final waste management. The model is created by building a composite system as a flow chart, in which the included components describe the processes and transports that are included in the production and handling of the studied product or service.
- *Eco-labelling:* Models used in different types of eco-labelling are specified by the body responsible for the eco-label. In a certified environmental product declaration (EPD) according to the Swedish system, for example, the model describes a life cycle assessment of the product, conducted according to the requirements and product specific requirements that apply for EPD.
- *Product development:* In product development, models of production systems are used to describe expected changes in environmental impact due to changes in e.g. composition of the product etc.

5.3.2.2 Description of documentation of models of technical systems

A description was developed of how to practically interpret and use the CPM quality requirements. In short, documentation of models of technical systems according to the CPM quality requirements may be considered to consist of six separate, but closely integrated sections (see Figure 7) (Pålsson 1997, Pålsson 1999a). The type of information within each section regards different choices made during modelling and data acquisition. To fulfil the requirements, all sections should be documented. The model is described in qualitative terms regarding how the model was the designed, together with the quantitative data for inflows and outflows and information regarding how the numerical data was obtained. Also, more general aspects are described, for example how the model should be used and how the information may be distributed.

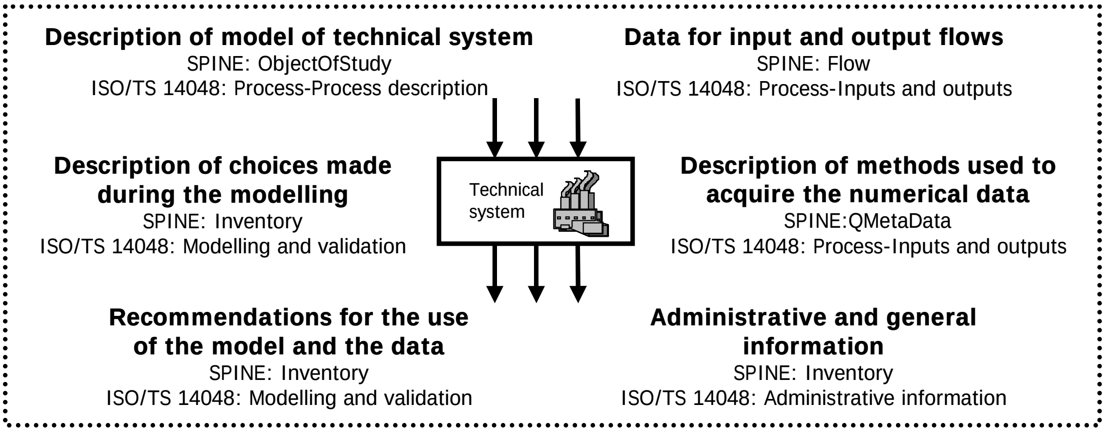

Figure 7. Documentation of models of technical system according to the CPM quality requirements, expressed in terms of the ISO/TS 14048 and the SPINE data documentation formats

For each section, detailed information items (data fields) are specified in terms of the SPINE and the ISO/TS 14048 data documentation formats. The different types of information are:

1. *Description of the model of the technical system*, where the content of the system is described, with regards to, for example, the included processes etc.
2. *Description of choices made during the modelling* and the objective for the choices, e.g. the purpose, the choice of functional unit and system boundaries etc.
3. *Data for input and output flows* to the system, i.e. quantitative data on flows together with information on the origin and destination of the flows in terms of environmental media and type of flow.
4. *Description of methods used to acquire the numerical data*, i.e. a transparent description of the assumptions and sources used for the data.
5. *Description of recommendations for the use of the model and the data*, e.g. areas of application and a general description of the quality of the sources that have been used.
6. *Administrative and general information* regarding, for example, how data may be distributed and who is responsible for acquiring and documenting the data.

5.3.2.3 Working practically with documentation to fulfil quality requirements - integration with everyday work processes

To facilitate the work with structured documentation according to the CPM quality requirements, there was a need to support integration of documentation with everyday work processes. The work with documentation was seen as additional work that required extra resources, instead of something that was intended to facilitate the environmental management work and in the long term decrease required resources for information management. Therefore, methodology and guidance was developed regarding how and why documentation should be developed.

Structured documentation of models of technical systems that are used for environmental management provides efficiency in data and information management. The documentation facilitates sharing and interpretation of the information allowing the information to be easily reused in new applications. Information to assess different quality aspects is easily available. The work with documentation also provides a structured work procedure that ensures that all information is documented in the same way and that information is not lost. Additionally, the documentation also provides consistent and transparent reporting that is readily reviewed and easy to verify. Flexibility in generation of reports is supported. Reports can be easily generated independent of application and can be adapted to different target groups.

Much of the information used in environmental assessments, and especially LCA, is acquired from different data sources, for example internal information systems, written reports, etc. When using such information, much time is often spent on interpreting and analysing the material, and adapting it to suit the application for which it will be used. Often the information is not sufficiently documented in the original source or the documentation is difficult to interpret. The person using the material may supplement the information in the original source, based on previous knowledge of the business and the technical system or other sources. Thus, when using the information additional knowledge is gained, which will be lost if it is not explicitly described and documented. However, the person performing the interpretation and adaptation may not be consciously aware of the fact that additional knowledge is gained. Therefore, general and specific guidance on how to handle data from different data sources was described to support the practical work (Pålsson 1999a).

To facilitate the work with documentation, a description showing how to integrate practical work with data documentation when performing an LCA was also developed. During an LCA project, there is a lot to gain by working consistently with documentation of the data and the study from the beginning of the project. This description illustrates how consistent work with documentation efficiently supports the inventory and the interpretation in LCA. It consists of a procedure in four steps (see Figure 8). In each step, the result is documented according to the CPM data documentation criteria, using the ISO/TS 14048 or SPINE data documentation format (Pålsson&Carlson 2000).

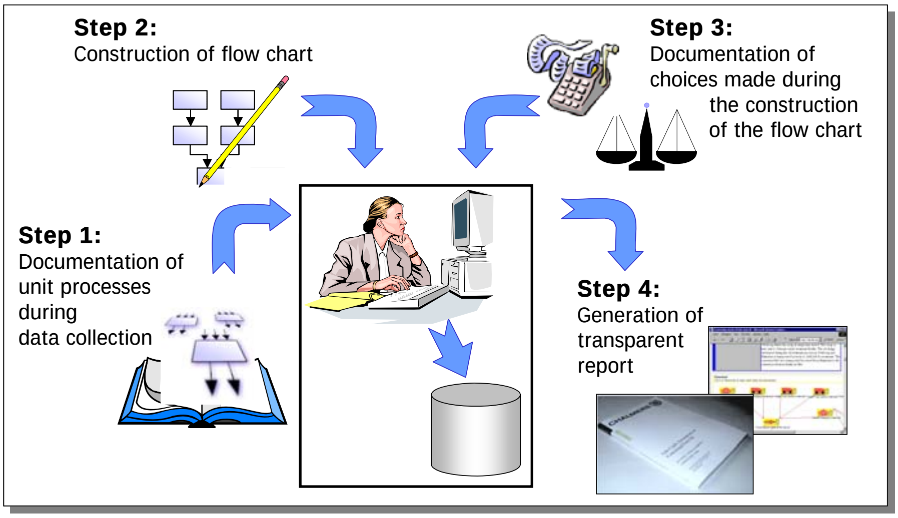

Figure 8. Working with documentation during an LCA project , based on Pålsson&Carlson (2000)

5.3.2.3.1 Concept of Sufficient documentation

The concept of “sufficient” documentation was developed both to support work with the CPM data documentation criteria and with how to choose a suitable level of ambition for the documentation. Documentation of data requires resources and some guidance was needed for how to efficiently use available resources.

Data sufficiently documented according to the CPM documentation criteria should ideally not need further research for the data user to be able to interpret and correctly use the data. In practice the general ambition for documentation may vary depending on the intended use of the data and the contextual environment in which the data will be communicated. The concept of sufficient documentation is thus very much dependant on the application and the receiver of the information. Thus, when working with documentation one should set the level of ambition based on what is known of the application and the receiver. Some trade-off may be needed between available resources for documentation and the value of the information for current and future needs.

When determining level of ambition one should carefully consider by whom the data may be used and all possible applications for the data. Data that are only to be communicated within a specific context, e.g. internally within an organisation, may require a less detailed description than would be required if the same data will be communicated externally, e.g. between a customer and supplier. Within an organisation users might be assumed to share a common terminology and much information is implicit and more or less general knowledge within the company regarding technology, processes, etc., or the knowledge is documented elsewhere in the organisation. Consequently, such details do not require an explanation within the organisation. However, when the data are transferred to a different contextual environment the terminology and implicit knowledge needs to be explained in order for the receiver of the information to be able to correctly interpret and use the information. The receiver of the information can not be expected to hold the knowledge that is internal within the company.

Also, documentation of the data constitutes an investment, and depending on how valuable the data is considered to be, the ambition for the documentation will vary. For example, if it is known that a data set will only be used in a specific application and not communicated, a less detailed description may be sufficient. However, if the data will be reused in many applications and by several users (e.g. be included in a company internal database) a more detailed description is necessary to avoid further costs for data. It should be considered that investments made in environmental management may be lost if the information that is generated and used is not documented to allow for follow up and review.

Some practical advice for a general level of ambition is to consider if information that seems obvious today regarding, for example, interpretation of material, modelling, etc, will be equally obvious in a year from now when the information is needed again. For example, the fact that information was missing in the original sources is important information in itself and should be documented. Also, the complete documentation should be coherent and consistent in different part.

It may be difficult to know at the time of data documentation how the data will be communicated and for what the data will be used, other than the immediate intended application for which it was acquired. This can make it difficult to determine a relevant and sufficient level of detail for the documentation. The person responsible for the documentation should, however, aim to capture all relevant information available at the time of the documentation, and thus provide a good basis for prospective data users.

5.3.2.4 Experiences and analysis of results

The methodology for data documentation was developed to facilitate the practical work with the CPM quality requirements, and has been used both within the work with LCA database at CPM and by industrial practitioners when developing databases and information systems for different environmental management applications (see also section 5.2.5). It has supported implementation of information processes and has improved the management of environmental information. This has, for example, been evident in the data that have been submitted by industrial practitioners to be published in the CPM LCA database. The quality of the documentation of data was substantially increased after the methodology was disseminated through manuals, supervision and courses and was applied by the practitioners submitting data to the database. In addition to LCA, the methodology has been applied for other environmental management purposes, e.g. environmental management systems, environmental product declarations, emission trading and risk assessment (see e.g. Carlson et al (2004), Eriksson et al (1999), Flemström&Tivander (2006), Flemström et al (2006).

The methodology for data documentation is based on and described in terms of the CPM quality requirements. The general methodology can, however, also be applied using internal quality requirements in terms of documentation. But there have been some difficulties in communicating the fact that companies can specify and set their own internal quality requirements based on their specific needs and apply the methodology based on those, and then work with continuous improvement of the work. The CPM requirements have been considered to be strict and difficult to fulfil for the data acquired for internal purposes, due to limited available resources for the work.

A general issue when applying the methodology has been how to secure any additional resources (i.e. work time) that may be needed to adequately document information, even though the value and the purpose of the documentation may have been clear. Industrial practitioners have had difficulties communicating the need and the value to the management controlling the resources needed for the work.

The general methodology for data documentation can also be applied to data for environmental impact assessment, i.e. assessment of the environmental consequences of technical processes. The general incentives for how and why environmental data should be documented and the idea of developing user support and ways to integrate in everyday work processes have, for example, been used in the OMNIITOX project, where an information system for toxicology data was developed (Tivander et al 2004).

5.3.3 Methodology for generation of data and information within production sites

Papers that presents this research:

- Carlson R., Pålsson A-C. 2001. Industrial environmental information management for technical systems. *Journal of Cleaner Production*. 9 pp. 429-435.
- Carlson R., Erixon M., Forsberg P., Pålsson A-C. 2001. System for Integrated Business Environmental Information Management. *Advances in Environmental Research*, 5/4 pp. 369-375.
- Pålsson A-C., Svending O., Möller Å., Nilsson C., Olsson L., Loviken G., Enqvist A. Karlsson G., Nilseng A. 2002. An industry common methodology for environmental data management. *Proceedings of SPCI 2002, 7th International Conference on New Available Technologies, June 4-6, 2002, Stockholm*

5.3.3.1 Introduction

Environmental data describing models of technical systems originate from real technical processes. To ensure the long term supply of data, different ways by which data can be acquired and documented according to quality requirements already at production plants have been explored. The general purpose has been to identify and design environmental information management processes, to incorporate documentation and to fulfil quality requirements. The work has also included finding ways to coordinate and integrate information management for different environmental management applications.

In this section three main developments are described. Feasibility studies were made in **Emission possible,** which was a subproject in the CPM LCA database project. The insights from this subproject and other general developments in the database project led to the development of a general model, **PHASETS,** that describes the tasks and communication surfaces involved when acquiring data on a technical system. This model was tested and implemented in a project within the Swedish pulp and paper industry through the **CPM/SSVL project.**

5.3.3.2 Feasibility study – Emission possible

While establishing the CPM LCA database different studies determined that data in general were not readily available within the plants in a form which is appropriate for LCI, and that the reasons for this may be lack of consistent, efficient, effective and feasible tools and methodology. First attempts to acquire data at production plants were made within the CPM database projects in a subproject named "Emission possible". In this project the possibility of integrating LCI data acquisition with environmental management systems was explored. The work was performed by case studies at production plants within three companies with different production technology: Vattenfall, Ericsson and Stora. In the case studies, the CPM quality requirements and the documentation methodology were applied for the information that was acquired. The results were positive in terms of feasibility, environmental control and data quality (Carlson&Pålsson 1999).

However, the case studies clearly indicated the need for methodology regarding acquisition of data. The data documentation methodology that was applied only describes how to handle and document the results from data acquisition, but it did not describe how to practically acquire the data to be documented. The industrial practitioners who performed the case studies had some difficulties with acquiring data, due to the fact that they lacked a structured working procedure to support the work. Also, the case studies were performed by practitioners who did not work at the production plant, and they were not familiar with the process and internal information systems and reports. This in combination with a lack of a methodology made it difficult for them to involve personnel at the production plant in the work, and communicate the purpose and the results from the work.

5.3.3.3 General model for acquisition, processing, reporting and interpretation of data and information: PHASETS

The PHASETS model (PHASEs in the design of a model of a Technical System) was developed to facilitate information management and increase the understanding of how information is generated. The model was developed independent of a specific industry sector, based on experiences from the development and maintenance of the CPM LCA database and related work.

PHASETS structures environmental data handling for different purposes and has been especially designed to be the basis of an efficient and quality-managed environmental information system (Carlson&Pålsson 2001). The structure provides a conceptual model for sharing understanding of information management. It can be used to design processes and routines for acquisition and reporting of environmental information and data, to coordinate environmental data handling for different applications, to assess and control costs for environmental data acquisition and to develop and manage secure handling of environmental information. Also, the structure provides a definition of data transparency.

The PHASETS model was generalised to describe the generation of any system model used for environmental assessments, into the model PHASES (PHASEs in the design of a System) with its applications PHASETS (Technical System), PHASENS (Nature System) and PHASESS (Social System) (Carlson&Pålsson 2000).

5.3.3.3.1 <u>Description</u>

PHASETS consists of six phases, where each phase describes defined work tasks in acquisition, compilation and reporting of environmental data for a technical system; from specification of parameter and measurement system, compilation of measurement values, compilation of a model of a technical system to final reporting. (see Figure 9).

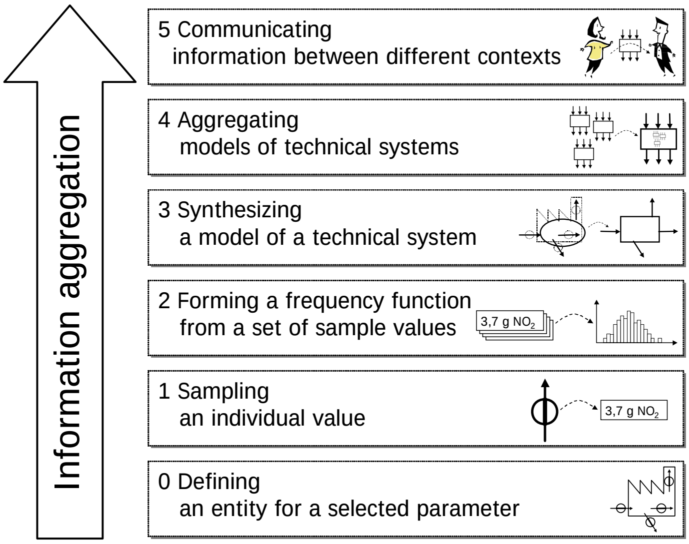

Figure 9. The PHASETS model, from Carlson&Pålsson (2000)

Within each phase in PHASETS, information from earlier phases is compiled, i.e. data and information is reported upwards in the structure, to the preparation of a final report. PHASETS phases are (see Figure 9):

0. *Defining an entity for a selected parameter* - *Specification of parameter and measurement system*
   The choice of entity to measure and the setting up of the measurement system defines the simplest concept; that is, the meaning of a measured value. In practice this involves specifying the parameter that is measured and the measurement system in terms of, for example, measurement method, equipment, frequency, location, maintenance, etc. This supplies the fundamental interpretation of the measured parameter.
1. *Sampling an individual value* - *Acquisition of measurement value*
   Sampling results in a value for the simplest concept, that is, a measured value, i.e. individual measured values are registered for the measured parameter.
2. *Forming a frequency function from a set of sample values* - *Compilation of acquired measurement values*
   The frequency function aggregates sets of measured values into statistically expressed concepts, i.e. the acquired measured values are compiled into different types of mean values for a specified interval, for example.
3. *Synthesising a model of a technical system* - *Compilation of a simple model*
   The systems synthesis further aggregates the frequency functions from phase 2 into structured models of technical systems. A "simple" model of a technical system is designed and compiled, using the information for individual parameters that were acquired in the previous phases and by specifying system content and system boundaries.
4. *Aggregating models of technical systems* - *Compilation of a composite model*
   The models of technical systems synthesised in phase 3 may be aggregated into complex composite models describing, for example, averages or cradle to gate systems;
5. *Communicating information between different contexts* - *Reporting of information and data*
   Between any two phases 0–4 the resulting data and information are communicated from the generator to the consecutive phase, i.e. reporting of

information and data between the different phases of PHASETS and externally.

Information may also be reported downwards in the structure for specification of questions and requirements on the information that is acquired and compiled, and for feedback of the information management work, for example identified errors or improvement potentials.

5.3.3.3.2 *Using the PHASETS model for information quality management*

The PHASETS structure can be used for understanding, assessing and designing processes for environmental information management. Roles and responsibilities for quality management can be distributed through the entire chain of environmental data handling. The quality of the result from each phase depends on how well the tasks within the phase have been performed, how well tasks in the previous phases have been performed and, how well the reporting between the phases works. Each phase and the reporting between the phases are thus equally important for the quality of the final result. Thus, when using PHASETS for quality management, the quality within each phase may be handled separately, independent of previous and subsequent phases, and the quality of the transfer of information and data between phases may be handled separately as well.

5.3.3.3.3 *Using PHASETS as basis for an integrated environmental information management system*

The PHASETS model can be used as the basis for developing an integrated environmental management system. General principles and a general system architecture for such a system were developed and presented in the paper "System for Integrated Business Environmental Information Management" (Carlson et al 2001a). In this system, the documentation of results from the different phases in PHASETS is supported by user interfaces adapted to the specific work task, where the different phases share a common information platform. This architecture has been used as basis in development of a prototype for an integrated information system named VIEWS (visualisation of Integrated Environmental Work Space), that demonstrates how information for LCA, DfE, EMS, chemical risk management, and emission trading can be shared (Erixon et al 2006).

5.3.3.4 Application, adaptation and tests of the general model within production sites: The CPM/SSVL project - Methodology for the forest industry's environmental data management

The main project where information quality management within production sites has been explored, tested and implemented is the "CPM/SSVL project – Methodology for the forest industry´s environmental data management". In this project, the PHASETS model was tested and implemented to support data and information management within production sites in line with the CPM quality requirements.

The project aimed to:

- *Allow for the compilation of a common database for the forest industry*
  The data for the database are acquired at participating plants with a common and comparable way of working.
- *Quality assure environmental data management*
  Documented routines for processing, compiling and reporting of environmental data are incorporated into management systems (ISO 9001, ISO 14001 etc.) and are adapted to the unique prerequisites at each plant.

- *Simplify and co-ordinate compilation of environmental data for different purposes*
  Structured environmental data management provides simpler handling, where data for life cycle assessment, environmental labelling and environmental reporting can be co-ordinated, for example.
- *Facilitate communication of environmental information to customers and other stakeholders*
  Environmental data for different stakeholders are easily available and well-founded.
- *Set an industry standard for handling of environmental data*
  A common methodology supplies a common language and way of working within the forest industry.

The project was initiated and funded by the forest industry, through the Swedish Forest Industries Water and Air Pollution Research Foundation (SSVL) and was performed as a project collaboration between the major Swedish-related pulp and paper companies and CPM during the years 2000-2001. The author managed the project, and the following companies participated in the project: AssiDomän, Duni, Holmen, Kappa, Korsnäs, M-real, SCA, Stora Enso, Södra and Rottneros.

The work was performed using case studies within six production sites at different companies. In parallel with the case studies, material to support implementation was developed (Pålsson et al 2005a, Pålsson et al 2005b, Pålsson 2005). Also, the importance and value of the methodology was disseminated within the industry at a seminar and at an international conference (Pålsson et al 2002).

During this project the representatives from the different participating companies saw the methodology as a practical tool to solve some of their problems with environmental information management, and that there were several advantages with having an industry-common methodology. For example, the methodology can provide efficient, assured and accessible environmental information and data for process as well as product that can be critically reviewed to meet demands from the market. The internal compilation and reporting for the system (product, process, administration) can be simplified. Unambiguous and easily accessible information is produced for customers/users and authorities (national and EU) for both current and future needs. This can give an advantage to other industries as well.

5.3.3.4.1 Description of the methodology

The forest industry's methodology for environmental data handling consists of:

- A structured work procedure when introducing the methodology
- A common view of documentation

The structured work procedure is based on the PHASETS model. The common view of documentation is based in the CPM quality requirements expressed in the SPINE and the ISO/TS 14048 data documentation formats (please refer to section 5.2.2 and section 5.3.2).

Structured work procedure when introducing the methodology
The implementation of the forestry industry's methodology for environmental data handling at production plants was divided into four stages (Figure 10). In each stage, specific tasks and information in acquisition, processing, compilation and reporting of

environmental data for the plant is handled. The work procedure is described in detail in the manual that was developed to support the practical work (Pålsson et al 2005b).

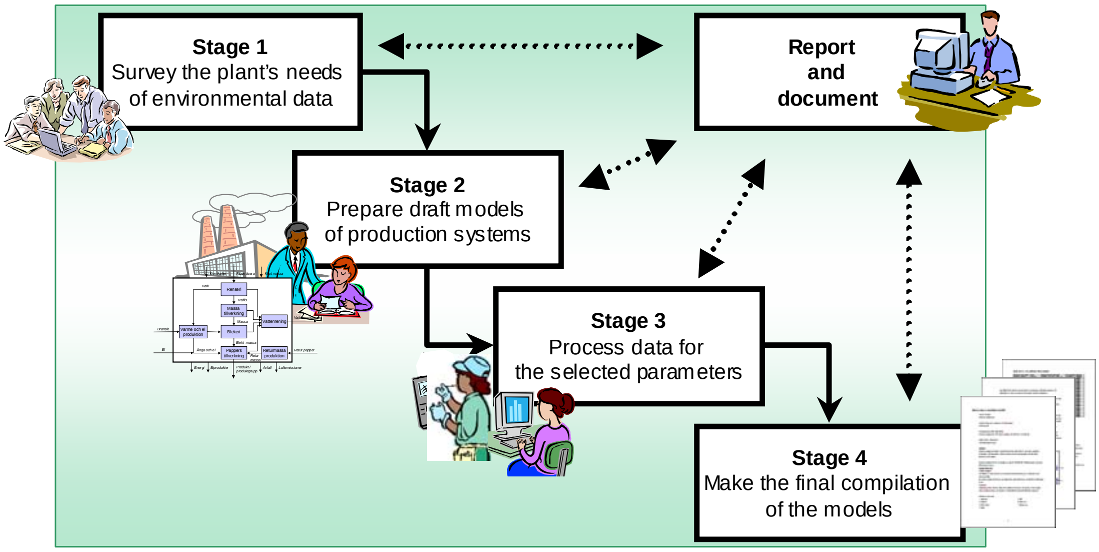

Figure 10. Work procedure for implementing the methodology (Pålsson et al 2005b)

The foundation for this work procedure is the PHASETS structure. For implementation, the different phases of PHASETS have been grouped into four stages (Figure 11). In the implementation, the work begins at the top phase (phase 5) and then proceeds further down in the structure. At each stage, requirements are specified on the work that needs to be performed in the subsequent stages. This facilitates the effort and makes it efficient.

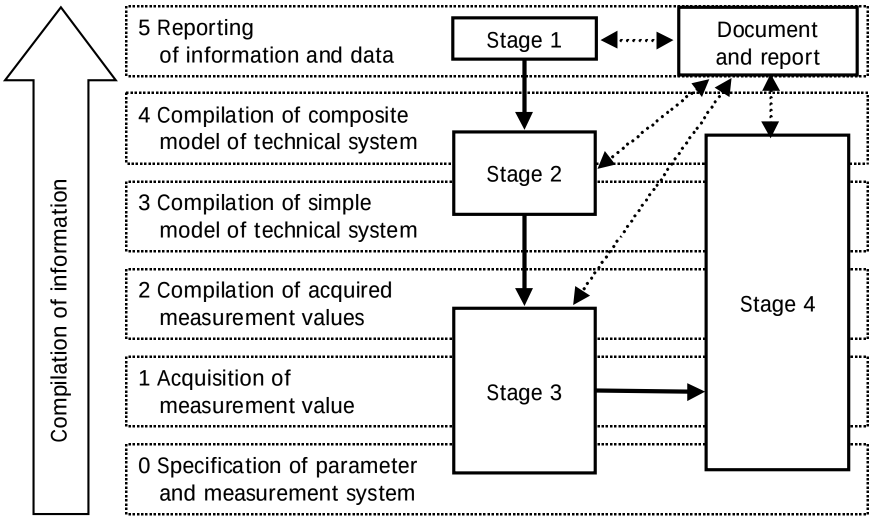

Figure 11. The work procedure for implementation of the methodology, and which phases of the PHASETS structure that are handled in each stage of the implementation (Pålsson et al 2005a).

In **stage 1** the plant's needs for environmental data is surveyed. The survey involves identifying the stakeholders that request environmental data and their specific requirements on the data. The survey provides the basis for determining which models need to be handled, and for how to prioritise and control the further work. This stage corresponds to phase 5 in the PHASETS structure (Figure 11).

In **stage 2** the first draft models of production systems describing the production of the products or product groups that were selected are prepared based on the survey of environmental data needs from the previous stage. The production systems may be prepared as simple or composite systems. In this stage the parameters that shall be reported for the systems are also selected. This stage corresponds to phase 3 and phase 4 in the PHASETS structure (Figure 11).

In **stage 3** data are processed for the parameters that were selected for the draft models. Allocation issues for the draft models are also investigated. This stage corresponds to phase 0 to phase 2 in the PHASETS structure (Figure 11).

In **stage 4** the final compilation of the models is made, based on the information that has been acquired and prepared in the previous stages of implementation. This stage corresponds to phase 0 to phase 4 in the PHASETS structure (Figure 10).

In each stage, the routines that are identified and designed for the work, and the results that are achieved are **documented and reported**. Routines concern work tasks, methods used, communication paths etc.

The documentation guarantees reviewability and verifiability of the information, both of which will contribute to credibility. It provides control of the information which will contribute to better confidence in the information. Also, the information can be reused in different applications, which will reduce costs. Reporting and documentation corresponds to phase 5 in the PHASETS structure (Figure 11). The models that are prepared and compiled were documented in the SPINE format or the ISO/TS 14048 format according to the CPM data documentation requirements.

Integrating the methodology in management systems

One of the main issues in the methodology is to ensure continuity, and that the data management processes is integrated with the everyday activities at the plant to ensure continuous and consistent data management, both within individual plants and at different business levels. To ensure that the routines are maintained, a prerequisite in the methodology is that it should be easy to integrate into any existing management system. The methodology should structure and co-ordinate existing data handling at the plants, and make the information easily accessible for new applications.

When introducing the methodology one should therefore start from what is already being done, investigate what already works and what may be improved, and design routines for tasks which are missing or do not work sufficiently. Established management systems, such as ISO 14001, EMAS and ISO 9001, should be utilised. Also, in order for the methodology to be integrated, any new routines that are needed to work according to the methodology should be incorporated in the management systems. New or altered routines should only be designed when necessary for the information to be handled and used more efficiently and effectively.

The type of information that is already handled within plants probably varies in the different stages of implementation of the methodology. For example, well-established routines may be available for acquisition and processing of data for different parameters, which is handled in stage 3 of the implementation. Established routines for the preparation of models of technical systems (performed in stage 2) may, however, be missing, and then new operative routines may need to be introduced.

Coordination and integration of information management:
Different models may be required for different applications, due to the fact that it is generally difficult to design models that may fulfil all of the different stakeholders' information needs. For example, the model that is used in communication with customers may not be useable in communication with authorities, since these stakeholders have different requirements on the information. However, by identifying common elements between the different compilations of environmental data that need to be handled at the plant, the work can be made more efficient. For example, product and process related models could be coordinated by building the production system as a composite model. By defining the included process components generally, these may be used to construct different types of composite models that describe the activities at the plant in different manners. When doing so, however, the process components and the results of the different composite models should be validated to ensure that the results reflect the real process as accurately as possible.

During the design of models, requirements on quality and level of detail in the model are balanced against costs and area of application. The model should not be more detailed than can be justified economically with respect to defined needs. It is generally practical to work with the models step-by-step by making a first draft, testing whether it works, and refining and adjusting when needed.

In the ideal case, the acquisition and processing of data for individual parameters are common for all different types of models that need to be handled, and the information that is prepared can easily be used to make different types of compilations for the activities at the plant. In reality, though, the processing of data is often particular to a specific application, which is not necessarily generally useable for all different types of models. This specifically concerns the compilation of acquired measurement values into different types of mean values. This needs to be considered and analysed in order to coordinate the handling as far as possible.

Choosing scope when introducing and using the methodology
The scope when introducing and using the methodology is selected based on the plant's own needs and requirements. For example, one may choose to use the methodology to structure all aspects of environmental data handling at the plant, or to use it to specifically structure product-related environmental data, or to only use it to acquire the basis for the compilation of an industry common database. The level of detail in the models that are defined may vary from a very detailed composite model to a simple model ('black box').

During the implementation, an overview and review of the plant's handling of environmental information may be performed. The implementation may also be used as a test of routines for environmental data handling within environmental management and quality systems. This may, for example, be used to identify possibilities for improvements in the environmental data handling and the quality of environmental information and data.

The full potential concerning coordination, efficiency and quality is achieved when the methodology is used to structure all aspects of environmental data handling at the plant. The methodology may then function as integrated support for the plant's environmental work.

5.3.3.4.2 Results and experiences from practical work with applying the methodology within production plants

In the CPM/SSVL project the methodology was developed, adapted, tested and evaluated through practical work within pilot studies at six production plants in the pulp and paper industry. During this work, the basic theoretical structures (i.e. PHASETS and SPINE) have been adapted to practical tools for environmental management. The work within production plants was divided into two phases. During the first phase (year 2000), the methodology was developed and adapted to the industry by pilot studies at Kappa Kraftliner Piteå, SCA Ortviken och Stora Enso Skoghalls Bruk. During the second phase, the methodology and the material was evaluated by testing it at three other plants: Korsnäs, Duni Kisa samt M-real Husum. During this year the work at the plants that participated during the first year continued by updating the models that were developed and by making the final implementation of the methodology. In all three plants this also involved transferring responsibility for the work to a new person.

Overview of results

The practical work at the production plants demonstrated the potential of the methodology for structuring the plants´ environmental data handling. In short, the major difference compared to the earlier working method is that the work resulted in better data documentation. The work at all participating plants resulted in data documented according to the CPM quality requirements, and such complete documentation was not available for data that were acquired before. This concerns both documentation of the production system and the methods used for handling and compiling data. As a result, better control and oversight of the environmental data handling process has been achieved. In some cases, questions that could not be answered before can now be answered. For example, an integrated pulp and paper plant (that produces both pulp and paper) can deliver environmental data for only the pulp production, and differences in environmental performance for different products can be distinguished. This information was not available earlier.

Another valuable result of this work is that it provided a thorough *overview of how information about all relevant flows is managed*, raw material flows as well as emissions to air and water and waste. By applying the methodology and procedures, complete documentation is available describing where and how the values of these flows should be collected. This substantially facilitates updates and comparisons since the collection method is described, and it can also be used for identifying potentials for improvement in, for example, routines for the work, precision of results, etc. For some flows, e.g. the use of raw materials, the collection and processing of data was generally not well specified at the participating plants.

During the work at the plants, *different levels of detail and scope* have been chosen. There have been different purposes for the models, and the models that have been designed have been differently detailed, from very detailed models with many included processes to a “black box”. During the work the models have also been redesigned and further developed to better suit the needs. This demonstrates the flexibility that is built into the methodology, and the degrees of freedom for how production systems can be modelled. Each plant can choose a suitable and feasible level of ambition based on their needs, how the specific plant is designed and for what the resulting information will be used.

The work has also shown that the methodology can be *integrated into and support management systems,* such as environmental and quality management systems. Information in existing systems was utilised and only routines and instructions which were missing or needed to be improved were supplemented or changed.

Based on these results, the methodology has been shown to be useful for supporting environmental management within production plants and companies. It can both be used as a tool in practical work and as an integrated part in the environmental management system. The production plant can choose the way in which they want to use it based on their specific needs and requirements.

Scope of the use of the methodology
During this effort, the application for the methodology was enlarged from only a product perspective to include all environmental data management within plants. In the pilot studies during the first stage of the project the methodology was tested and used to acquire product-related data. Such data can among other things be used as a basis for the development of an industry-common database. This is important because the initial assignment from SSVL was to create the foundation for an industry-common database for the industry's products. However, this project demonstrated the usefulness and the strength in the methodology, and the possibility of coordinating all different types of environmental data that need to be handled within a plant, i.e. both product and process-related data. The pilot studies during the second phase therefore aimed to coordinate the internal handling of environmental data, to be used as a basis for different reports, where data for an industry common database are only the subject of one of these reports.

Results from each stage in the procedure:
Some specific experiences and results from each stage in the procedure may be described as follows:

- Stage 1

This step was not specifically performed during the first phase of the project (more than implicitly). During the work it was, however, realized that a survey of stakeholders and their information needs is necessary in order to utilize the resources efficiently in the implementation. This is an extremely important first step. Here the level of detail and scope for the work is defined.

- Stage 2

In the modelling of production systems at the plants, different approaches have been chosen, from detailed composite systems to a "black box". The models that were developed could be further developed, e.g. by introducing new parameters, changing level of detail (fewer or more sub-processes), etc

An important lesson from this work is the importance of starting simple. One should start from the needs that were identified in the survey (stage 1) and not design more complicated models than are needed to fulfil the requirements. They can always be enhanced. It is easy to model more subprocesses than necessary in the beginning, when ambition and enthusiasm is high. In both Skoghalls Bruk and Kraftliner the models were redesigned during the project. For example, the model at Skoghall was reduced from a detailed composite system with 20 subprocesses into a model with 8 subprocesses. This is characteristic of the procedure: the models are developed in line with experiences and needs.

Based on the experiences from the modelling effort, it is also recommended to start from where existing measurement systems are placed. Thus, one should make a first draft of the model definition(s) (stage 2), then continue to stage 3 and investigate how data are acquired and processed for the included parameters. It could be necessary to change the model (system boundaries, etc) depending on where the measurement system is located. In this way, some allocation problems can be avoided. The work can also discover needs for new measurement systems and measurement points, to better control the activity based on the information needs that are identified.

- Stage 3

A thorough investigation has been performed at the participating plants of how processing of data is performed for the relevant parameters, in terms of measurement systems, acquisition of data and compilation of the acquired data. In this stage, much of the routines and documentation were already available at the participating plants. They all had an environmental management system according to ISO 14001, and in most of the plants the processing of data for emissions to air and water was regulated according to a control programme. Data for consumption of raw materials and production of by-products were, however, compiled in different ways.

During the project the need for new measurement points has been identified, to achieve better control of environmental performance. For example, it was identified that some internal flows between sub-processes were not measured and had to be estimated or modelled in other ways.

The participants reported that an especially valuable result from this stage was that they had a reason for investigating how data are processed and that they achieved a collected overview of how to collect data for “all” environmentally relevant flows.

- Documentation and reporting

Part of the documentation that was needed for the work was already available in different internal information systems. The models that were defined in the project, however, were new and required documentation. The documentation was made in the SPINE format, using the CPM quality requirements. The documentation was either performed using the freeware tool SPINE@CPM Data Tool or MS Word documentation templates.

A lesson from the work with documentation is that one should carefully consider what reports are already available and which reports need to be created. It is costly to introduce and maintain new reporting routines. There may already be existing information and reports that contain the information that is needed.

Organisation and responsibilities for the practical work at the different plants
The personnel that were responsible for the practical work with the methodology within the plants have varied:

- Internal personnel:
    - At Kraftliner and Kisa the responsible person worked as environmental coordinator within the plant
    - At Korsnäs an internal working group was formed, but with one main responsible person
- External personnel:
    - At Skoghalls Bruk, Ortviken, and Husum the responsible person(s) who performed the implementation work did not work within the plant. For Skoghalls Bruk and Husum, the responsible person(s) worked at a central environmental department within Stora Enso and M-real respectively. For Ortviken, the responsible person worked at another SCA production plant.

Depending on who was responsible, different experiences have been made. Internal personnel have a great advantage in the work by being well acquainted with the plant and the existing routines. They did, however, have difficulties in setting aside enough time. The work functioned best at the plant where a working group was formed, since the responsibility could be distributed among different functions and different areas of responsibility could be assigned between the participants. External personnel had some difficulties with getting enough time with the involved personnel at the plant and acquiring the information that was needed. Also, the competence and knowledge of the content of methodology was not naturally disseminated within the plant.

Based on these experiences, it is recommended that one form an internal working group for the implementation work.

Education and training
During the project the need for courses focused on the methodology was identified. The participants took a ”SPINE course” at CPM. This course was intended to provide an introduction to and support for working with data management and data documentation in a structured and common way, using the SPINE format. The course was, however, not especially designed for the methodology that was developed.

Resources for the work
It takes time to start working with and implementing the methodology, but in all participating plants the time invested was considered well spent, since the work resulted in better data and routines. The time needed varies depending on:

- Scope, i.e. the extent of environmental data management to be included and level of detail of models that are designed
- How the work with environmental data is organised, i.e. if much is already available or if it is a new way of thinking for the management
- How familiar the person responsible for the implementation is with both the methodology and the plant.

5.3.3.5 Experiences and analysis of results

5.3.3.5.1 PHASETS

The value of the PHASETS model when applied to environmental information management has been demonstrated through the CPM/SSVL project described in this thesis. It has also been used as basis for the EU project CASCADE to develop a procedural guideline for collection, treatment and quality documentation of LCA data (Weidema et al 2003).

The particular benefit of PHASETS when applied to information quality management is an increased understanding of how environmental information is managed, by making the different central tasks and processes explicit. This understanding can be used for benchmarking existing processes and when designing and introducing new processes for environmental information management. It can also be used to assess the transparency and quality of information from external sources.

5.3.3.5.2 The CPM/SSVL project - Methodology for the forest industry's environmental data management

The methodology developed for the forest industry has shown potential for industrial environmental data management with increased quality in terms of documentation, relevance and routines, with the same or even decreased costs. The methodology provides a stable and common basis for credibility and openness in communication with different stakeholders. In the project, however, no quantitative indicators to measure costs in relation to benefits were used, and there are therefore no quantitative results describing how large the return of the investment may be. The methodology adapts well to what is already done within plants and is valuable for internal work within companies. The methodology is a prerequisite for making industry compilations and to hold discussions about comparability. It does, however, not deliver comparable results between two different plants, without an agreement of what comparability means. The methodology in itself provides great freedom to design and set boundaries for systems, choice of methods to acquire data, etc

In this project, the initiative for the introduction and implementation of the methodology came from the "bottom-up", i.e. from the practitioners working with environmental data. They did, however, experience a lack of commitment and interest from the management. This made it difficult to disseminate and distribute responsibilities to involved personnel and also hampered the further dissemination of the methodology within the companies and within the industry. Efforts were made within the project to communicate the potential with the methodology to management levels, but it was found difficult to describe the benefits and the value in a way that the management could accept. Concrete examples showing how the use of the methodology lead to benefits for the individual production sites were lacking.

In all participating plants the methodology was used to benchmark existing processes and also to introduce new processes for acquiring and compiling environmental data, based on PHASETS model. This provided a better understanding of the information management within the plants. Immediate improvements were found in the pilot studies (e.g. better control of flows, possibility to answer questions that could not be answered before), and potentials for further improvement were found. It was, however, difficult to relate benefits in improvement to the costs for implementation. The work did not include measurable indicators or other ways to measure ”success”, that could quantify the improvements in some way. Although the participants knew that the quality of the resulting data was improved, in the sense of being better documented and well founded, it was difficult to demonstrate the implications and value of this. This created difficulties in analysing the improvements as well as making further improvements.

In this project, the potential for coordinating and integrating environmental information management for different purposes was clear, in terms of more efficient information management and better control. This was also an important motivation for the implementation, in order for it to be feasible and justifiable in terms of work investments. It may be difficult to justify investments if information for only one environmental method or tool is improved.

After finalisation of the project, the results have been used in further internal work within some of the participating companies, e.g. a M.Sc. thesis project was performed at SCA Edet (Nilsson 2002). Also, the results were used as the basis for PCEM (Policy controlled environmental management work) which aimed to make the environmental policy operative for everyday environmental management work, with special focus on information management. By integrating the formulation of the environmental policy with the formulation of goals and objectives for the environmental management work, and linking it with information quality management, the top management can distinctly take responsibility for and achieve control of the environmental performance of the company. The methodology supports work with environmental management systems such as ISO 14001 and EMAS and was developed in co-operation between Chalmers University of Technology and six Swedish industrial companies. (Carlson et al 2004).

Additionally, the project resulted in a licentiate thesis by one of the project participants, in which he presented a thorough stakeholder analysis for Stora Enso (stage 1 in the methodology) as well as suggested allocation procedures to be applied within pulp and paper plants (Svending 2001, Svending 2003)

A project with similar aims as the CPM/SSVL project has been performed within the Swedish Steel industry (Axelsson et al 2002). The project was inspired by the methods and tool for data documentation and management developed within CPM, especially the PHASETS model. The focus of this project was to investigate common information needs within the industry and try to define common processes and relevant parameters. Such attempts were made also within the pulp and paper industry during the CPM/SSVL project, but it was found that it was difficult to reach consensus due to e.g. different technical conditions within pulp and paper plants. Also, the steel industry project aimed to identify requirements for developing an environmental information system for the industry (Axelsson et al 2004). In the CPM/SSVL project, the need for an information system to support the work was identified, but this was not further explored.

5.3.4 Methodology for information review

Paper that presents this research:

- Pålsson A-C., Carlson R. 1998. Maintaining Data Quality within Industrial Environmental Information Systems. *Proceedings from the 12th International Symposium 'Computer Science for Environmental Protection' Bremen 1998*; Band 1/Volume 1 pp. 252-265.

5.3.4.1 Introduction

While establishing the CPM LCA database, SPINE@CPM, one requirement was that the data published through the database should be quality reviewed. At the time there were, however, no available methods or tools to support this review. A methodology for information review was therefore developed and implemented (Pålsson 1999b, Pålsson&Carlson 1998). Review of environmental information is performed to ensure that quality agreements or other data quality requirements have been fulfilled. The purpose of the review is to monitor performance and maintain the defined quality by continuously reinforcing conformance with the data quality agreement or requirements and detecting any deviations. Review may also be performed as an educational activity, to provide feedback to the supplier of information on their work.

This content and scope of this methodology is described in the following subsections.

5.3.4.2 Establishing and maintaining review

Different quality aspects of data may be reviewed and, consequently, different types of review may be performed on any specific dataset. When a review function is established it is important to clearly specify the purpose and scope of review, and the review procedure including which quality aspects are covered, at which stage the review is performed, etc.

5.3.4.2.1 <u>Roles, responsibilities and competence</u>

Review requires well-defined roles and well-defined responsibilities and authority in relation to those who acquire data both to and from the information system. Figure 12 shows a schematic picture of the general organization and roles for an environmental information system.

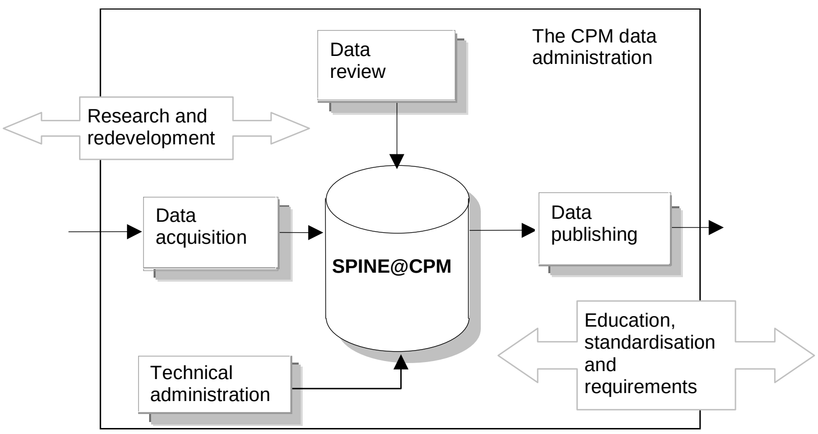

Figure 12. General organisational functions for an environmental information system, from Carlson&Pålsson (1998)

Depending on the scope for the review, different competencies may be required of the reviewer. Thus, different quality aspects may be reviewed by different persons for a specific data set. The reviewers need to be well familiar with the quality requirements and which specific aspect to review as well as who the users of the system are.

5.3.4.2.2 Stage in data acquisition when review can be performed

One must consider at which stage of the data acquisition and documentation processes the review is to be performed, i.e. if the data should be continuously reviewed when they are acquired and documented or of the data should be reviewed when they are finalised.

Continuous review during acquisition and documentation implies that the reviewer is involved as a reference during the work with documentation. This enables detection of errors and deviations from the quality requirements at an early stage. The person responsible for the data may thus get continuous feedback on the work and can instantly make corrections. This type of review may be efficient when the data suppliers are not well familiar with the agreed data quality requirements. However, this type of review may be very resource demanding. The reviewer may also get too involved with the practical work with data.

Review of the finalised dataset implies that the reviewer receives the finished result after documentation. This type of review is generally less resource demanding than the first type. However, it requires that the data suppliers are well familiar with the agreed data quality requirements. Otherwise, depending on the quality of the initial work, the review procedure may be quite extensive both for the reviewer and the data supplier and resemble the first type of review.

5.3.4.2.3 Quality aspects for review based on CPM quality requirements

Well defined quality requirements that are known by all functions involved are a prerequisite for efficient review of data. Below is a description of data review based on the CPM data quality requirements.

The CPM quality requirements specify that quality of data is considered to be closely related to the quality of documentation of the data. Thus, review of data according to the CPM data documentation criteria involves review of documentation and quality aspects of the documentation. According to the CPM quality requirements, the documentation of data should allow for an independent assessment of the quality and the relevance of the data for a given application. The purpose of the review is to assess whether the documentation is sufficient and to identify logical errors and inconsistencies in the documentation as well as decline in documentation quality.

With regard to this, different aspects can be reviewed based on the quality dimensions reliability, accessibility and relevance. Review of *reliability* concerns completeness, coherency and consistency of the information, i.e. that the information is sufficient to be able to use the model. Also, agreement of the documentation with the original source can be reviewed. Review of *accessibility* considers whether the information is understandable, the clarity of the language and terminology used, and whether the documentation format is used correctly. Review of *relevance* determines whether the information is relevant for the use of the model. The review of these different aspects is discussed below.

Review of reliability
The review functions as a link between the data suppliers and the data users. The review should therefore check that the information is sufficiently complete, coherent and consistent to enable any user to assess different qualities of the data. The reviewer therefore must be well familiar with the requirements and the context of the data users. The data reviewer should determine if relevant information which may be vital to the data users is missing in the documentation, or if there are inconsistencies. This saves time both for the data supplier and the data users. Generally the data supplier may more easily supplement missing information at an early stage when the data are still familiar and the data user does not need to spend time acquiring the information.

Often the person(s) responsible for the documentation of the data set has compiled, revised, interpreted and analysed the information from the original source of data. This involves a risk of misinterpretation or distortion. To be able to review the agreement of the information with the original source, i.e. that the material has been correctly complied, revised, interpreted and analysed, the reviewer needs to be as familiar with the information in the original source as the data supplier. Consequently, this type of review should ideally be done by the person(s) responsible for the original source. Otherwise this type of review is a very resource demanding task, since it would imply a review of both the original source and the work with reformatting and interpretation.

The quality of the original source could also be reviewed. This type of review is facilitated if the reviewer holds expert knowledge or has previous experience of the technical system that is described by the data. Irregularities and obviously unreasonable assumptions or data in the dataset may then be more easily detected. The accuracy or “correctness” of the data set may also be reviewed by other methods, such as comparisons with data describing similar technical systems, mathematical models, etc.

Review of the agreement between the documentation and the original source or of the quality of the original source is not included in the review for SPINE@CPM. The data suppliers are assumed to have taken actions to ensure the agreement of the submitted information with the original source before the data are submitted.

Review of accessibility
In order for the information to be used correctly by the users, it is important that it is understandable. The SPINE@CPM database is published via the Internet and thus has a very broad audience. The background and the knowledge of the receivers of the information may not be specified, other than that the receivers may be expected to hold general technical knowledge. This is considered in the review.

The reviewer should ensure that the language and terminology is adapted to the known data users, based on how the data are published and communicated, and that technical jargon is avoided The language and terminology used in the documentation should be adapted so that it can be interpreted by the known receivers of the information. This may include translations of technical terms and terminology.

An important task for the reviewer is to ensure that the data documentation format is used correctly. In order for information documented in a specified documentation format to be easily interpreted and communicated, the requirements of the format must be followed. The ease of interpretation and the ability to efficiently search for information is obstructed if the format is not used as specified.

Review of relevance
In order for the information to be easily interpretable, only information that is relevant for the use of the model and the data should be included. The reviewer should ensure both that the relevant information is available and that irrelevant information is avoided.

5.3.4.2.4 <u>General procedure for data review</u>

The general procedure for review at SPINE@CPM is outlined in Figure 13.

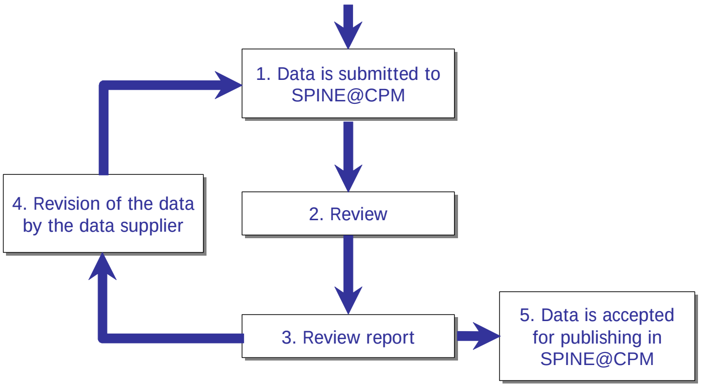

Figure 13. Data review at SPINE@CPM

The procedure consists of 5 steps:
1. Data are submitted to the SPINE@CPM data administration.
Data are documented according to the CPM data documentation criteria by personnel at the CPM member companies and submitted to the SPINE@CPM data administration.

2. Review.
Review of data is made in accordance with the CPM data documentation requirements with regard to the aspects described above. During the review the data are also classified, depending on how well the CPM data documentation requirements are fulfilled.
Note: The data are also reviewed by the data users. Reports from data users on inconsistencies or errors in data published at SPINE@CPM are forwarded to the data supplier for action. The data are then resubmitted to SPINE@CPM for review and then published.

3. Review report.
The result of the review of data is documented in a review report. The review report contains a general assessment of the documentation and specific comments on the documentation. It may also contain suggestions for supplemental information and corrections. The suggestions for supplementary information and revision may be *required* (i.e. data may not be accepted to SPINE@CPM without further revision by the data supplier) or *recommended* (i.e. the data can be accepted to SPINE@CPM but the data supplier is recommended to make further revision before the data are

published). The report should also be specific about the prioritisations of the suggestions, i.e. which parts that are most important to correct. The data are then either accepted for publishing or returned to the data supplier for revision.

4. Further revision of data by the data supplier.
If the data are not accepted after the review, i.e. if supplemental information and corrections are required, the review report and the data are sent to the data supplier for further revision.
Steps 2-4 are repeated until data are accepted for publishing.

The person responsible for review does not alter or supplement documentation of submitted data. Such work is done by the person responsible for the documentation.

5. Data are accepted and published at SPINE@CPM.
When the data does not require any further revision, data are accepted and published at SPINE@CPM.

5.3.4.3 Experiences and analysis of results

The review methodology was developed and established during 1997 and has since been used at SPINE@CPM for review of all datasets published through the database (as of August 2006 the database contains 566 datasets). The data for SPINE@CPM are acquired by both industrial and academic practitioners, and the review has contributed to the fact that the quality of documentation of data that are published have been held at a stable level. In addition to providing continuous monitoring and maintenance of the quality of the database, the review process has also provided feedback to the different industrial and academic practitioners that have submitted data to the database, thereby increasing their competence in both documentation and review of data. The fact that there were specified and agreed quality requirements for the database made it possible to clearly specify and manage the review. A review function is especially important for information systems with many different users from different contexts.

This methodology has also been used within internal company databases as well as serving as a basis for establishing the review requirements for the Swedish system of third party certified environmental product declarations (Eriksson et al 1999, MSR 1999).

The methodology can be compared to the peer-review procedure used for scientific publication. A similar procedure is also being developed and introduced for the German LCA database ProBas (Ciroth et al 2005). The organisation of this database is similar to SPINE@CPM, but there are no agreed and specified documentation or other quality requirements, and thus aspects to be reviewed are more difficult to specify and maintain. Also the Swiss national database ecoinvent includes a review function with regard to different aspects (Frischknecht R et al 2004).

5.4 Education and information to support quality management of environmental information

Information and education are needed to support understanding and practical work with information quality. Research has shown that different roles in information management and different modes of knowledge have a great impact on data quality (Lee&Strong 2003). Also, different types of skills are important for data quality work (Chung et al 2002).

Education and training has been an important element throughout this work. In the development of methodology, much effort has been made to simultaneously develop pedagogical material and to explain how to work. The author has supervised a large number of practitioners, both at the university and in industry, and has developed and delivered courses teaching students how to work with data and information to achieve and maintain quality of the information. The author has also developed a number of manuals describing how to practically work with documentation and information management.

The early educational efforts were performed by visiting industrial practitioners at their work places and supervising their work with documentation to fulfil the quality requirements that were specified. This led to the development of courses in data documentation and information management. The first course was given to industrial research institutes in 1999, and was designed as a three-day course, with theoretical and practical parts. It was later given to industrial and academic practitioners on four occasions during the years 2000-2001. After 2001 only short courses have been given, due to the fact that the interest in the full courses decreased. This is probably partly due to the fact that the practitioners who had taken the course disseminated the knowledge through internal education sessions at their workplace.

Much effort has been spent on describing how information quality management and especially structured data documentation can support and facilitate environmental management work, and why resources should be set aside for this purpose.

5.4.1 Experiences and analysis of results

The efforts in education and training have increased the competence of a large number of industrial and academic practitioners with regard to environmental information quality management. The practitioners have utilised their competence in the internal work of building company databases and in their everyday work with environmental information.

These efforts have supported research focused on defining and managing quality. In addition to disseminating and increasing competence among practitioners, this education and training has provided important feedback and input promoting further development of support for the practitioners and alignment and integration with their everyday work.

6 Procedure for implementing and maintaining total quality environmental information management

Papers that presents this research:

- Pålsson A-C. 2006. Dimensions of information quality for industrial environmental management. *Submitted to Journal of Cleaner Production*
- Pålsson A-C. 2006. Defining and managing the quality of environmental information using total quality management. *Submitted to Journal of Cleaner Production*

6.1 Introduction

The applied research described in the previous chapter has supplied elements and experiences for how quality management of environmental information can be performed in practice. The experiences from this work has been used in the development of a general procedure for how to define and manage quality of environmental information to support industrial environmental management

The procedure is named Total Quality Environmental Information Management (TQEIM) and is presented in further detail in Pålsson (2006c). It is based on the fundamental principles of total quality management (TQM) and on a synthesis of experiences from applied research within different projects. It incorporates insights from information quality management for both environmental management and business information systems and databases. The aim is to structure the research that has been performed and to provide guidance for implementing and maintaining quality management of environmental information within an organisation, as well as support further research in the area. The procedure is intended to be applicable to any type of quantitative environmental information that needs to be managed within an organisation. Examples include information for life cycle assessment (LCA), Design for Environment (DfE), environmental management systems (EMS), emission trading, etc.

The procedure is based on two fundamental assumptions:

- Environmental information can be seen as information products and the users of information as information customers
- Established principles for total quality management (TQM) can be applied and adapted to manage the quality of environmental information products

These assumptions are in line with the general developments in information quality management for business information systems and databases. This research has shown that principles, methods and tools developed and applied to quality management of physical products can be used to effectively manage information quality. They can also be applied and adapted to support environmental information quality management.

TQM provides a systematic approach for quality management, and establishes a clear connection between quality requirements and management. By using well-known and established principles of TQM for managing environmental information, implementation can be facilitated, especially in organizations that have quality management systems. It is both easier to communicate and introduce, since much is already available within the organisation in terms of thinking and terminology.

The common elements of the different descriptions of total quality management can be condensed into six fundamental principles; *customer focus*, *process orientation*, *basing decisions on facts*, *continuous improvement*, *management commitment*, and *involvement of people* (based on Bergman&Klevsjö (2001)). *Customer focus* implies working actively and systematically to try to fulfil the needs and expectations of the customers, both internal and external. *Process orientation* implies that the work should be performed in well defined value-creating processes. *Basing decisions on fact* implies that facts should be well founded and that the performance with regard to quality should be measured and monitored. *Continuous improvement* implies working systematically to improve the quality of processes and products. A fundamental rule is that "there is always a way to achieve higher quality at a lower cost. *Involvement of people* implies facilitating for employee participation in the work with quality management and continuous improvement. *Management commitment* implies that work with quality issues must be based on the commitment and active support from the management. These general principles have been incorporated and translated into the different parts of the procedure.

6.2 Description of the procedure

This section describes and explains the procedure for implementing and maintaining quality management of environmental information based on TQM principles, named Total Quality Environmental Information Management (TQEIM). The procedure is aimed to increase quality and controllability of environmental information and support long-term continuous provision of information to support environmental management.

The procedure consists of three fundamental parts:

- Define needs and requirements for environmental information quality. This involves:
  - Understand and identify the needs of information customers
  - Specify and define information products and information quality requirements based on the needs
- Manage information to fulfil defined needs and requirements for environmental information quality. This involves:
  - Assess the current situation with regard to information products and quality requirements
  - Develop strategies for the information quality management work, to ensure that information products are produced in line with quality requirements.
  - Establish, maintain and continuously improve information processes, e.g. change existing processes or introduce new processes based on the strategies that were developed.
  - Establish and maintain measuring and monitoring of the work, e.g. through information review.
- Educate and train involved personnel to support the work with defining and managing environmental information quality, to increase knowledge and understanding and to ensure that the personnel have relevant competence for their job.

The work with the three fundamental parts should be supported by management. Roles and responsibilities in the work should be well defined and known by all involved, and therefore the implementation must involve clear assignment of responsibilities for the different activities in information quality management. Routines should be implemented in existing management systems, such as quality and environmental management systems, to ensure maintenance and that the work will be part of the everyday work within the organisation.

Documentation of information is an integral part in information quality management efforts, to ensure that the relevant information to fulfil the needs and requirements of the information customers is captured. This must be considered all through the procedure.

Integration and coordination of information management for different environmental management purposes, e.g. EMS, LCA, DfE, etc., should also be considered. Coordination can simplify the handling of information, reduce costs for information and reduce or eliminate some information quality problems.

The concept of continuous improvement is a fundamental element in the procedure. The general idea is that it is possible to work with it at different level of scope, i.e. start where you are and with available resources and reach results from that point. Thus, work systematically with quality based on the procedure to improve from the starting point, with available support and resources. The procedure can be used to manage information quality for one environmental management method or tool, but is most effective when information management for different methods and tools are coordinated.

6.2.1 Define needs and requirements for environmental information quality

Before any environmental information quality management effort is started, one should first identify the needs of the users, i.e. the information customers. The information customers must be known and their needs and expectations should be understood and identified. This establishes the customer focus, from which to base further work with information quality management. The customers of environmental information products are both external and internal to the organization. External information customers include customers and suppliers, authorities, and trade associations. Internal information customers are intermediate and final customers within the information chain, e.g. production, product development, and management.

The information customers' needs and requirements should be expressed as information products, in terms of the type and content of the information that is needed, and as information quality requirements on the information product that can be managed throughout the information management chain. Examples of environmental information products are environmental reports, LCA studies for a specific question, environmental product declarations, etc.

The specification of information quality requirements is facilitated by a common understanding of what quality means that is shared and accepted by those involved with environmental information management. Most people have their intuitive perception of what is meant by quality, but this perception generally differs between individuals. The different viewpoints and dimensions of environmental information quality presented in section 5.2.3.2 (from Pålsson (2006b)) can be used as a basis for a establishing a shared understanding. When defining the quality requirements it is important to have a clear customer focus, and to carefully consider both current and future needs and consider the strategic objectives or goals that the information is intended to support. Where possible, quality requirements should be defined and agreed upon in cooperation between providers and of users the information to ensure that the quality requirements are feasible to fulfil and that the requirements are sufficient for users' needs.

Information quality requirements should be defined as requirements on documentation, to ensure that the relevant information to assess and use the information is captured together with the data. To support work with documentation, the documentation requirements should be specified in terms of a well-defined documentation format. The format provides both a well-defined specification of the information product and facilitates specification of the quality requirements of the information product. A documentation format that is shared by providers and users of data can both serve as a checklist when acquiring and documenting the data, as well as facilitate interpretation and use. An example of quality requirements expressed in data formats is presented in section 5.2.2, and a discussion of how environmental information can be understood as information products is presented in section 5.2.4.

Information quality requirements can be specified at different levels. The general level is as common requirements on documentation to allow for users to independently form an opinion of the relevance and appropriateness of the information for their purposes. The next level is as detailed requirements on the content of information in terms of indicators to be included, required precision of data, system boundaries, etc. This is needed when performing an LCA study or when developing an environmental report, for example. The specification can be done at different levels. For example, having specified which indicators should be included, quality requirements can be set for the information that is used as a basis for the indicator as well as the indicator result. In this way controllability is increased.

6.2.2 Manage information to fulfil defined needs and requirements for environmental information quality

The needs and requirements of environmental information, in terms of information products and information quality requirements, are used as basis for management of information to fulfil the requirements.

First, an assessment of the current situation with regard to information products and quality requirements is made, to develop an understanding of the current information management process. In the assessment existing processes for managing information are identified and assessed. This provides the basis for deciding whether the processes should be changed in some way or whether new processes need to be introduced in order to fulfil the requirements. Also, data and reporting formats that are used should be assessed with regard to their ability to convey relevant documentation according to requirements. Deficiencies should be identified and noted.

The assessment of current status is used as basis to develop strategies for implementation and maintenance of information quality management work to ensure that information products are produced in line with quality requirements. The strategies should involve a specification of how to establish, maintain and continuously improve information processes, how to measure and monitor performance as well as needs for education and training to support the work. In the development of strategies, available resources and level of maturity must be considered. Also, one should consider whether and how to coordinate and integrate environmental information management for different purposes. Different strategies are needed depending on the source of the data, i.e. whether they are acquired internally from production processes (primary data) or they are acquired externally from different sources such as literature (secondary data). Examples of strategies and methodology for these types of data are described in section 5.3.2 and 5.3.3.

To ensure that the needs and requirements for environmental information products are fulfilled, well defined environmental information management processes should be established, maintained and be continuously improved. Environmental information is generated in different information management processes. To be able to control and manage the quality of the information, it is important that these processes are well understood and defined. This enables work with improvement and facilitates integration and coordination of data collection for different purposes. Sources of quality problems can more easily be identified. The PHASETS model described in section 5.3.3.3 and the implementation procedure described in section 5.3.3.4 can be used as a foundation for understanding, identifying and describing existing processes, as well as a basis for changing and developing new processes. Documentation is a central task in information management processes, necessary to ensure that relevant information is captured. This should be kept in mind when developing the processes and should be incorporated in the practical work. Processes should be standardised and should minimise sources of errors.

Measuring and monitoring of the performance of environmental information quality management should be established, to ensure that quality requirements are maintained and to provide input to the process of continuous improvement. Information review can be used to establish checkpoints to monitor the performance and maintain requirements (see section 5.3.4). The quality review is performed to ensure that quality requirements are fulfilled.

6.2.3 Educate and train involved personnel to support work with environmental information quality management

Education and training is central to all parts of this work to disseminate knowledge and understanding of the different tasks involved in environmental information management and to increase competence. When introducing environmental information quality management it is important to express the work in the terminology used by the personnel involved and to explain both the purpose and the content of the work.

7 Conclusions

A well-defined definition of quality and well-specified quality requirements are a fundamental basis for systematic work with environmental information quality. Thus, when establishing and maintaining environmental information quality management an explicit definition of quality and well-defined requirements that can be accepted and used by all involved with information management should be agreed upon. A practical and feasible way to define environmental information quality requirements is to translate user needs and quality expectations into information needs, and express the information needs in terms of a well-defined data documentation format, i.e. as documentation requirements. The identification of user needs and quality expectations is facilitated by a shared and explicit understanding of what information quality means. Environmental information quality is a multidimensional concept that goes beyond accuracy and uncertainty. The dimensions of environmental information quality described in this thesis can be used to increase the understanding of what environmental information quality means.

The definition of quality and accepted quality requirements are used as basis for managing the quality of information through the different stages of information management, from original acquisition to use. Documentation is a central part in information management processes to ensure that relevant information is captured, to fulfil the requirements, and environmental information quality management needs to be integrated with everyday work-processes. The three strategies that have been used in managing quality of information, i.e. management of information from different data sources through data documentation, managing the quality of data during generation of data at production plants and review of data, have contributed to improving the quality of information to support environmental management within the participating industrial organisations. Documentation improves quality of information in terms of transparency, verifiability and accessibility. Management of the quality of data during production can improve the accuracy, relevance and availability of the information that is produced. Review can be used to monitor and maintain accepted quality requirements.

Environmental information quality management needs to be supported by education and training. This is a central element to ensure that the personnel involved are well familiar with both the quality definition and requirements as well as how to manage the quality through the different stages of environmental information management. Increased understanding and knowledge of what information quality means and how it can be managed can in itself lead to improvements in the quality of information. With this understanding, quality issues can be kept in mind when generating, assessing and communicating environmental information.

This work and associated developments are based on, and in line with, principles of total quality management. This shows that these principles can be used to effectively manage the quality of environmental information, and render environmental management work more effective. The TQEIM procedure described in this thesis can be used a basis for establishing and maintaining environmental information quality management in line with these principles.

8 Further research

This section outlines some suggestions for further research:

Evaluate quality requirements in relation to the decision
Quality requirements should be based on the needs of the users of the environmental information, i.e. ultimately the decision makers who use it as a basis for controlling the environmental performance of some activity. It is in theory possible to generate data and information that fulfils all quality dimensions. However, this is generally too costly, and a trade-off needs to be made. A better understanding is needed of how to make the trade-off between quality requirements with regard to the decision for which the information will be used, and with regard to the resources needed to produce the information. Also, the needs are often implicit or the users may have difficulty articulating their needs. Further studies should be made on how to define sufficient quality requirements in relation to the decision, in order for the information to support decisions.

Better understanding of information content to fulfil specific quality dimensions
There is a clear relationship between information quality dimensions and information content. There is, however, a need for a better understanding of how to design the information content to ensure that specific quality dimensions are fulfilled. For example, how can information effectively be prepared to ensure that the quality dimensions “understandability” and “clarity” is fulfilled? Cognitive science can provide basis for developing a better understanding on these issues.

Business case for managing environmental information quality
In the research that has been performed, it has been difficult to assess the benefits of implementing information quality management in relation to the costs for implementation and maintenance. This is partly due to the fact that no quantitative indicators or ways of assessing information quality costs and improvement have been used. To better understand the relation between value and cost, a business case for environmental information quality management should be developed.

Evaluate the procedure for total quality environmental information management
Parts of the procedure developed for implementing environmental information quality management based on principles of TQM have been tested in the research that have been performed, but the procedure has not been tested in full. To evaluate the procedure it should to be tested and confirmed in further studies, e.g. through case studies within industrial organisations.

Environmental information vs. business information
Environmental information is often generated from business information produced by different functions. This implies that it is generally not sufficient to implement information quality management only for functions responsible for generating environmental information, since it affects other business processes. Instead information quality management needs to be implemented for all information that is handled. Case studies should be performed to better understand the mechanisms, for example through a comparison of any differences between how quality of business information is handled and managed within a specific company, compared to how environmental information is managed within the same company.

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Ann-Christin Pålsson, October 2006

Paper I

Maintaining Data Quality within Industrial Environmental Information Systems

Ann-Christin Pålsson and Raul Carlson[1]

Abstrakt

Ein System ist entwickelt worden, das auf dem SPINE-Datenmodell basiert. Das System ist modularisiert, einschließlich der SPINE-Datenbanken, der besonders geentworfenen Daten, die Software anfassen, der dynamischen Web-Seiten für Datenbankpublikation und, die des wichtigsten Teils, eine Methodenlehre für die Datenbehandlung und –kontrolle.

Es wurde versucht, um eine allgemeine Annäherung zu erreichen, die jede quantitative korporative Umweltinformation anfassen kann. Das Ziel ist, mit dem ankommenden Standard innerhalb der ISO 14 000 Serie einzuwilligen. Dieses Papier schränkt korporative Umweltinformation ein auf Sein Informationen, die die Abhängigkeit zwischen den korporativen Aktivitäten und der natürlichen Umwelt System beschreibt.

Es gibt die grundlegende Undurchführbarkeit, die mit Einschätzung der Datenqualität der Umweltinformation betreffend ist beide Modelle der technischen Systeme und der numerischen Korrektheit der quantitativen Parameter dazugehörig ist. Diese Undurchführbarkeit wird in diesem Papier, sowie eine Annäherung behandelt, die auf methodologischen Vereinbarungen und Unterlagen basiert ist.

Um Befolgung der Datenqualitätsvereinbarung sicherzustellen, ist eine Kontrolle Funktion mit dem System umfaßt worden.

Damit das System zur Funktion als beabsichtigte, muß das System mit den vorhandenen Informationssystemen integriert werden und die organisatorischen Programme muß ausgedehnt werden, um Verantwortlichkeiten für das Umweltinformationsystem auch zu umfassen.

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Abstract

A system has been developed, which is based on the SPINE data model. The system is modularised, including SPINE databases, specially designed data handling software, dynamic web pages for database publication and, which is the most important part, a data handling and review methodology.
It was attempted to reach a general approach, which can handle any quantitative corporate environmental information. The aim is to comply with the upcoming standard within the ISO 14 000 series. This paper restricts corporate environmental information to being information that describes the interaction between the corporate activities and the natural environmental system.
There is fundamental unfeasibility associated with assessment of data quality of environmental information regarding both models of technical systems and numerical correctness of quantitative parameters. This unfeasibility is discussed in this paper, as well as an approach to a data quality agreement based on methodological agreements and documentation.
To ensure compliance with the data quality agreement, a review function has been included with the system.
In order for the system to function as intended it needs to be integrated with the existing information systems and the organisational routines needs to be extended to also include responsibilities for the environmental information system.

1. Introduction

This paper describes the Swedish national LCA-database system (SPINE@CPM) developed within CPM with special regards to data quality maintenance. The system is based on the SPINE data model and relational database structure (Carlson et al 1995), (Carlson et al 1998). The CPM group has attempted to reach a general approach, which can handle any quantitative corporate environmental information. The reason for this is of course the upcoming standard for LCA, which is part of the general standard for environmental management system (ISO 14 000 series).

The quality maintenance approach handles the issue of LCA data quality similarly to any environmental information system holding quantitative data on corporate activities, regardless of whether the data is to be used for LCA or any other decision support method. Regardless of proposals for management and indication of LCA data quality, e.g. (Weidema 1996), most quality aspects of LCA-data are general and need not be expressed in terms of LCA methodology. For data to be useful in LCA, however, there are some specific data quality aspects to consider e.g. choice of relevant flows (de Smet/Stalmans 1996), not covered within the scope of this paper.

Typical information handled within LCA is data sets on production units. Such data sets are combined into a flow model of a delimited technical system, to analyse and assess the environmental impact of a material, product or service throughout its life cycle. The assessment generally include raw material extraction, processing, transportation, manufacturing, distribution, use, reuse, maintenance, recycling and waste treatment (figure 1).

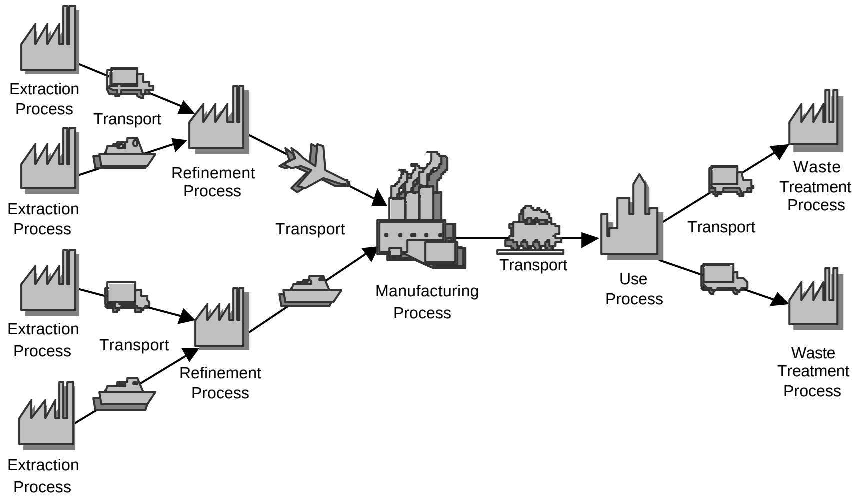

Figure 1

As outlined in figure 1, an LCA generally comprise information regarding different types of technology and different industrial sectors. Considering the possibility that data and information may be communicated between different actors in different sectors, the handling of the information at any site, within any organisation may be simplified if the data is interpreted general and equal, regardless of technology or industrial sector. This also implies that the same data quality routines can be applied regardless of technology or industrial sector.

2. Environmental information systems

Any corporate environmental information system is established in order to improve the possibilities to efficiently control the environmental impact from the corporate activities, with the means of environmental management systems. So is true also for the LCA database and environmental information system SPINE@CPM, which therefore is partly industrially financed.

Examples of areas to control in regards of environmental impact include operation and maintenance of machinery and production plants, product design and usage of products produced and different strategic actions towards markets within which the corporation partake (Netherwood 1996).

2.1 Environmental information on corporate activities

In this paper we restrict corporate environmental information to being information that describes the interaction between the corporate activities and the natural environmental system. It is considered that the activities physically are performed by technical systems and that the physical interaction between the natural environment and the activities is performed by physical flows to and from technical systems (figure 2). Most of the interactions are not direct, but causal via other activities and technical systems. The interactions are described as use of resources and energyware, and as emissions and waste generation associated with the activities of the technical systems.

A corporate activity may for example be the production of a telephone set. The technical system then is the production line within the plant, which enables and performs the production of the telephone sets. The interaction with the natural environmental system occurs both directly through emissions from the plant and causally via the suppliers of components and energyware and via the customers of the telephone sets and via the waste managers, for example.

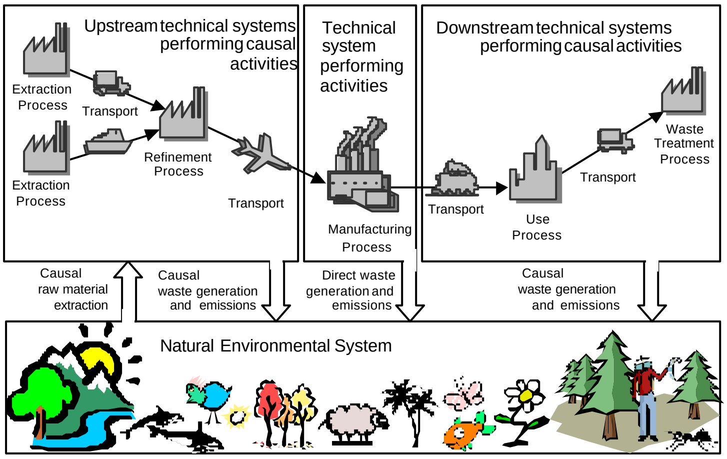

Figure 2

In order to interpret and environmentally assess the corporate activities, the corporate environmental information system also needs to include data on for example the natural environment (Saur 1997). Regardless of the actual importance of such information, it will not be discussed within the scope of this paper.

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2.2 Description of technical system

A description of a technical system or subsystem is a model of the system. We will therefore refer to descriptions of systems as models of systems. We will also mean that models of technical systems are manifested as descriptions of technical systems, in terms of natural language, sketches and languages specifically designed for descriptions of technical systems.

Within the Swedish competence centre CPM, a model of a technical system, from an LCA perspective, is defined as (Pålsson 1997):

- a model and a description of its included technical subsystems which defines the system's technical boundary
- a model of its inflows and outflows (matter and energyware), normalised to a system function
- a description of one or more system functions, i.e. a functional unit or functional flow such as products or services supplied by the system

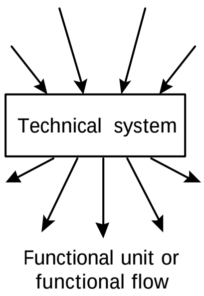

Figure 3

In the example of the production of a telephone set, the included technical subsystems are a description of all operational stages along the production line, including also allocated shares of common production facilities and other support functions. Inflows are described by, for example, data on use of components, energyware, ancillary materials and inflows to common facilities. Outflows are described by data on the production of telephone sets and, for example, data on waste generation and emission outlets from the production and from common facilities and functions. The system function of course is described as the production of telephone sets.

3. Levels of environmental control

Different types of decisions at different levels of environmental control are based on environmental information from within a plant and are combined with other types of information regarding the surrounding systems, both regarding the technical and the natural environmental systems. STORA, the Swedish based multinational forest, pulp and paper corporation suggests the following three levels of control (figure 4) (Bresky 1998).

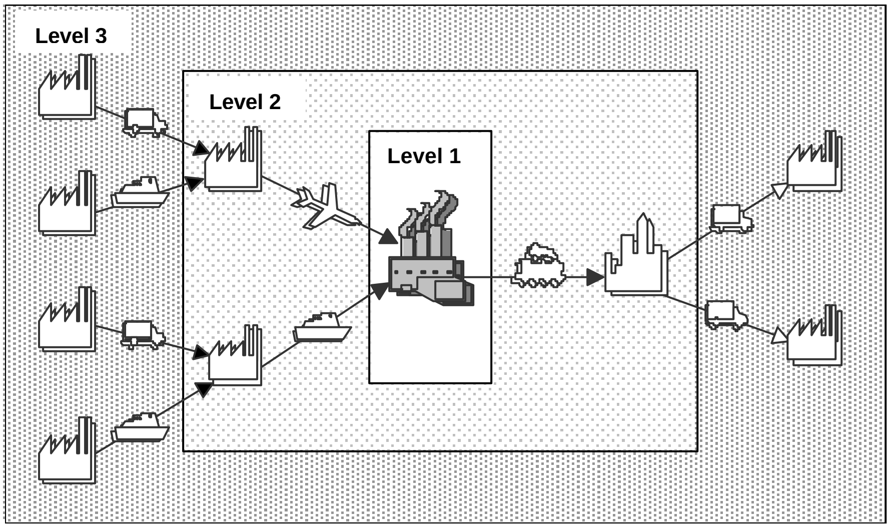

Figure 4

Level 1. *Local control between gates of production plant.* To control the environmental impact from the local technical system, analyses of air and water emissions are combined with information of the local environmental sensitivity.

Level 2. *Extended local control.* Extends the local technical system to also include environmental aspects of technical systems controlled by business partners. This type of local environmental control is generally integrated with the environmental management system. This management system often controls and manages the environmental aspects of the choice of suppliers, transports to and from the plant and waste management. This level of control is enabled by combining information of the plant's local environmental information with logistic information and with the local environmental information of the suppliers and waste managers.

Level 3. *Life cycle approach*. The responsibility and the domain of control of an environmental management system can be extended by the application of LCA methodology. Such an extension implies the inclusion of all relevant technical subsystem that can be accounted for in the manufacturing from raw material extraction to the final disposal of the product. This is done to avoid environmental sub-optimisation, such as e.g. the use of scarce resources or environmentally unfavourable waste management procedures for the final disposal of products.

Environmental information on the different technical systems and subsystems to combine for the different levels of control, needs to be acquired from different sources, for example from economical information systems within companies or general information from literature (Santos 1997).

A data acquirer meets difficulties, and needs to apply different methods when acquiring data on different parts of a product's life cycle. At level 1 it is generally possible to retrieve data from measurements, while, at levels 2 and 3, estimations and assumptions may have to be made, regarding local conditions of raw material extraction, suppliers, customers and waste managers, for example. This gives that the data on which decisions are to be based is of different quality, i.e. is of different reliability.

4. Difficulties with environmental information data quality

For each of the three different levels of control, the ability to identify environmental priorities accurately and efficiently, and the ability to navigate in the direction towards the most environmentally significant goals depends on the reliability of the environmental information. Also, the goals need to be identified and reached aptly, in order to avoid being faced with realised but unpredicted environmental damage or even catastrophes.

Therefore, an important issue for the environmental control function, at any level of control, is to efficiently acquire and maintain data quality, in means of its reliability. Reliability regards both the description of the technical system in subject, and numerical correctness of quantitative parameters of the system. Data quality maintenance is needed regardless of the type of data source, i.e. regardless of whether data is measured within a plant or whether it is modelled from different types of estimations and assumptions.

From the viewpoint of decision-making and control, the means for acquiring the data is irrelevant. The relevant issue rather is if the data, which is accessible to the decision-maker, sufficiently well corresponds with an ideally correct description of a technical system and an ideally correct numerical description of its quantitative parameters.

Regarding data quality maintenance, there is fundamental unfeasibility associated with assessment of quality of both models of technical systems and numerical correctness of quantitative parameters. The following sections will discuss aspects of this unfeasibility.

4.1 Unfeasibility of assessing correctness of models of technical systems

The description of any fairly complex real system is necessarily a gross simplification. During the modelling i.e. the simplification, some of the environmentally relevant properties regarding the system may not be included with the model. Excluded relevant properties may be in different states in the model and in the real technical system, causing the forecasting of the simplification to deviate from the actual outcome. The significance of the exclusions is difficult to appreciate in a decision-making process.

For more than fairly complex technical systems, such as product manufacturing, goods transportation or waste management, the difficulties with the modelling increase with also including difficulties with the system boundaries e.g. excluded or included subsystems or functionality may differ between the model and the real world representation.

Models of technical systems may be distinctly separated from any physical manifestation of the technical system they describe e.g. environmental reports may be stored in records at governmental authorities, or life cycle data, describing a production from cradle to gate, may be stored in a database containing general LCA data. Due to a decision-maker's ignorance regarding the technical systems and his lack of access to them for a correctness comparison, the reliability of the models may not be assessed. This has been studied in a project within CPM, where the feasibility to use environmental reports as a basis for reliable LCA-data were examined (Erixon/Ågren 1997).

4. 2 Unfeasibility of assessing numerical correctness of data

To truly assess numerical correctness, data need to be related to a correct reference such as a calibrated numerical reference model. Such a numerical reference model may be designed from mathematical process models or mass balance calculations.

The unfeasibility with the approach of a numerical reference model lies in the difficulty with mathematically modelling a real technical system, with respect to realities, such as leakage, mechanical deterioration, mismanagement and other unpredictable influences to the quantitative environmental parameters of the system.

It should be noted that this unfeasibility is also associated with the difficulty with finding a correct model of a technical system.

5 An approach to managing environmental information data quality - a data quality agreement

Due to the unfeasibility regarding assessment of correctness of both models of technical systems and of quantitative parameters of these technical systems, a different approach to data reliability is needed: both systems modelling and mathematical modelling strongly depends on subjective assumptions and choices of methods. This subjectivity suggests another approach for managing data reliability, instead based on organisational agreements and on structuring of routines.

5.1 The data quality agreement within SPINE@CPM

Within SPINE@CPM the agreement included a common view on how to interpret and handle environmental data, in terms of descriptions of technical systems (see figure 3). A set of documentation requirements, referred to as the *CPM data documentation criteria,* was commonly defined and agreed upon (Arvidsson 1997).

Basically, the agreement defines a description of a technical system to be considered reliable if it has been retrieved or attained using reliable methods. In other words, if the data is supplied with sufficient documentation describing these methods, the data user will be in a position to judge whether the methods used can be considered reliable or not, i.e. whether the data should be considered reliable or not.

There are several levels of methods to consider in regards of the design of a model of a technical system. A procedural approach for this design process has been developed at CPM. The model consists of six steps (Carlson/Pålsson 1998a):

0. Identification of conditions for acquisition of numerical entity
1. Acquisition of numerical entity
2. Statistical treatment of a set of numerical entities
3. Design of model of technical system
4. Aggregation of models of technical systems
5. Communication of environmental information on model of a technical system

The reliability of a method for acquiring numerical data depends on the methodological choices of each of the six steps: at step 0, the conditions for the acquisition, e.g. the state of a real technical system or modelling assumptions regarding this state; at step 1, the method for acquiring the numerical entity, e.g. the application of a measurement method or the modelling assumptions; at step 2, the statistical treatment of a set of numerical entities, e.g. the production of a frequency distribution or the identification of numerical boundaries of a subjective estimate and at step 3, the modelling resulting in the final design of a dataset describing a technical system, e.g. a detailed model based on causalities within a production system or a theoretical model of a technical system. Step 4 describes system analytical numerical treatment, such as LCA calculations or averaging. Step 5 describes data communication between different contextual environments, such as internal reporting and market communication.

Each step delivers a definite result, either simply numerical or as a complex description of a technical system. For each step the choice of method is arbitrary, within the range of available methods, while the resulting data is the result of the actual choice of method. The actual methodological choice needs to be sufficiently unambiguously documented and communicated to the following step, together with the resulting data.

It should be noted that the procedural description above is regardless of whether the methods are technical measurements or methods for estimations.

Note: Documentation of methods and other relevant information regarding data is in itself data, on a meta level, and are therefore generally referred to as metadata.

6. Means for fulfilling data quality agreement within SPINE@CPM

In order for the personnel at the CPM member companies to comply with the agreed data handling routines, they are first educated in the CPM data handling routines. Also they are supplied with a manual, specifically developed for the purpose and they are free to contact the CPM data administration at Chalmers University of Technology for questions.

Also continuos development of further methodological aids are being made within the CPM group. An example is the procedural approach for the design of a model of a technical system, described in section 5.1.

7. Maintaining data quality within SPINE@CPM

Since data reliability was considered dependant on documentation of choices and methods it was considered a risk that the system unnoticed could deviate from its original quality intentions. Therefore a review function, based on requirements on the documentation, was included with the system, with purpose to maintain the defined quality. The purpose of this function is to error-detect and to continuously reinforce conformance with the data quality agreement.

The review function is performed by a person well familiar with the requirements of the quality system. An important task for the review is to identify logical irregularities and decline in documentation quality.

It needs to be stressed that no “environmental knowledge” of the reviewer is required, e.g. such as knowledge of amounts of emissions from different technical systems or special knowledge in ecology. This is due to the difficulties discussed in sections 4.1 and 4.2.

The review follows the procedure described in figure 5.

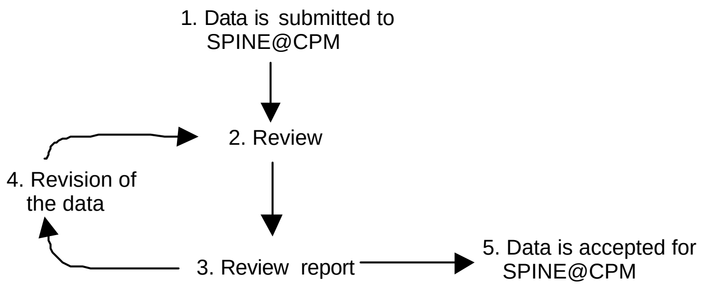

Figure 5

1. Personnel at the CPM member companies submit data to SPINE@CPM.
2. Review of the data is made in accordance with the CPM data documentation requirements, i.e. in regards of quality of the documentation of the model of the technical system and choice of methods.
3. A review report is written, which may contain notes and comments from the reviewer or requirements for supplemental information and corrections.
4. If the data is not accepted by the review, i.e. if supplemental information and corrections is required, the review report is sent back to the data supplier for further revision of the data. Steps 2-4 is repeated until the data is accepted by review.
5. If notes and comments of the reviewer require no additional revision, data is accepted for SPINE@CPM.

8. An environmental information system for data quality review

8.1 SPINE

The fundament of the SPINE@CPM information system is the SPINE data model and database structure. It is used to express the documentation criteria and the quality aspects of data (section 5), and it also defines the fundamental design of the software supporting this system.

SPINE was designed within a Nordic industrial project, holding a broad range of competence, including computing science, LCA and ecology. Participants came from about 15 large Nordic industry companies, Chalmers University and other competence groups. The result from the project was a technical report describing the model and which also includes a complete script for implementing the model into a relational database management system (Carlson et al 1995).

SPINE was designed as a relational database since it was planned to be the format for a national LCA database, but also because it was designed to bridge data-gaps between different types of LCA software and other software for environmental decision-support. It was intended that many different software should use the same database format for their data storage.

Today there are three fully developed and commercially available decision support software tools based on SPINE: EcoLab (Nordic Port), EPS Design System (Assess) and LCA iT (Chalmers industriteknik).

8.2 The technical functions of the SPINE@CPM information system

SPINE@CPM was developed within a project within the CPM group, in order to increase the accessibility of data on technical systems for LCA-research and industrial LCA-related applications. The aim of the project was to establish a national LCA database system. The project started in 1996 and it was finalised in the beginning of 1998 (Carlson/Pålsson 1998b). The system developed within the project is designed to support the data review function as described in section 7.

Figure 6 depicts the SPINE@CPM system technically: The database system is modularised, with the main module being the SPINE@CPM Data Tool, a software developed within the project. The data tool includes all functions of the system and all users within the system may use the same tool for their tasks. The tasks of the system are to

- enter data into the system
- quality review data
- move data sets between different SPINE-databases and different users.
- publish data at SPINE@CPM

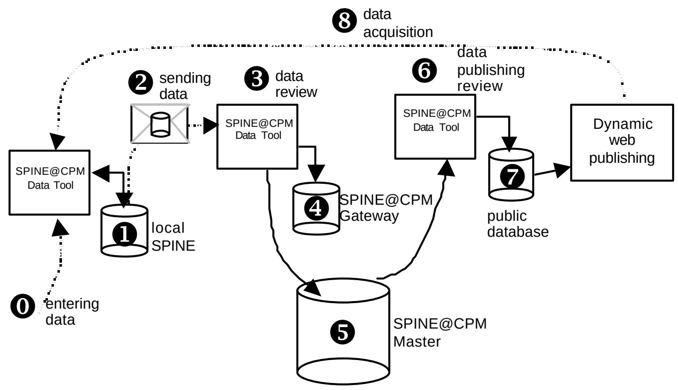

Figure 6

The data suppliers entering data (0), generally situated at the CPM companies, are equipped with a copy of the tool, together with a local database (1). The data review function (3) uses the tool for reviewing the documentation, and for moving accepted data sets between the received databases and the master database (5). Databases are transmitted from the data submitters via e-mail (2) to the review function at CPM. Review reports are also sent by e-mail, from the review function to the submitters (not shown in figure 6).

The system has one secure master database server (5), in which all quality-reviewed data are stored. The content of this database is never deleted, since the master database will also function as a reference, when comparing different copies of the same data set.

Data is published via Internet (7) using dynamically generated HTML-pages. These pages are generated from a local copy of the master database, both for security reasons and because it is not required to publish the entire content of the master database. Before any data is being moved from the master database to the public database the data is again being reviewed (6), in order to select which data to publish.

9. Conclusions and further development

In spite of the simplicity of the system, the difficulties with establishing it should not be underestimated. The difficulties with the harmonisation process far exceed the difficulties with both the reaching of the data quality agreements, and the development of the technical equipment. Examples of difficulties are secrecy, organisational motivation, rate of propagation of the understanding of the details of the agreement within the organisation and the establishment of the reviewer's role.

In order for the system to reach a sustainable establishment within a corporation it needs to be integrated with the existing information systems and organisational routines. In addition to this, the organisational routine needs to be extended to also include responsibilities for the overall maintenance of the environmental information system. For example, an organisational position needs to be formulated regarding secrecy, extension of an understanding of the details of the agreement into the organisation and the role of the review.

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Paper II

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Industrial environmental information management for technical systems

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Abstract

This paper describes a procedural approach for modelling a technical system for industrial environmental assessments. The approach is formulated as a procedural and conceptual model, denoted PHASETS (PHASEs in the design of a model of a Technical System). The objective of PHASETS is to serve both as a linguistic model for documents describing a technical system, as well as to serve as a guideline when accomplishing or assessing a model of a technical system. The PHASETS approach for information management and data quality control is independent of data format but relies on organisational commitment, for authorisation and for supplying the necessary competence needed to maintain the quality routines. Some applications for PHASETS are described.

Keywords: Integration; Communication; Information system; Environmental management system; Life cycle assessment

1. Introduction

Industrial sustainable development requires analyses and assessments of vast amounts of information about technical systems. An increased understanding of what sustainable development means has led to the formulation of new requirements and duties, which the industry needs to meet and fulfil. Today the information amounts handled within industrial environmental information systems are huge and difficult to overview. Harmonisation and standardisation efforts, regarding management [1,2], tools [3–5] and formats [6–10] are attempts to facilitate the handling and the interpretation of this information. However, to fully make use of harmonisation of industrial environmental management activities and information formats there is a need also to have a common understanding of how descriptions of industrial activities are created, what they mean, and how they should be communicated.

This paper describes PHASETS (PHASEs in the design of a model of a Technical System). PHASETS is a *procedural description* for how a model of a technical system is compiled. PHASETS is one specification of the general model PHASES (PHASEs in the design of a model of a System), which describes from a top-down or bottom-up perspective how information about a system model is acquired, communicated, aggregated, and reported [11]. In one end the definition of the measured entity, and in the other end the reporting-result. The description of PHASES, and implicitly PHASETS has a number of practical implications.

The procedural description is divided into six separate phases, distinguishing separable work tasks. This view of PHASETS can be used as a template for an *organisational schema* for environmental information management. PHASETS is also a *communication model*, which describes the paths traversed by information within the information system. The PHASETS procedural description includes all tasks performed when modelling a technical system from a general perspective, hereby supplying a *common conceptual frame* aiding the apprehension of an otherwise complex idea. A common conceptual frame is also a necessary foundation for a shared *reference model* for design of industrial environmental information systems and information management routines.

PHASETS is intended for different applications, such as:

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- Design of routines for generation of reliable and credible industrial environmental information and data;
- Design of routines for reliably communicating credible industrial environmental information and data;
- Estimation and control of costs for industrial environmental data acquisition;
- Development of a consistent security system for corporate environmental information management;
- Define and enable data transparency;
- Achieve data quality.

The use of PHASETS in these applications is further discussed in Section 4.

2. Environmental data on technical systems

Environmental management concerns management of the environmental performance of technical systems, and therefore needs information that describes the managed technical systems. For example, Environmental Management Systems (EMS) and the inventory part of Life Cycle Assessment (LCA) generate vast amounts of information describing environmental aspects of technical systems, for example, data on physical flows or environmental performance indicators (EPIs) [5].

Depending on the management's responsibility, the managed systems are different, and they are differently modelled and described. However, the managed systems have similar information needs, in that they require information about the environmental impact from industrial activities (Fig. 1):

(A) They consider the scope of the technical system, that is, the *technical system components and system boundaries*.
(B) They consider the flows of environmentally significant matter and energy into and out of the technical system, that is, the *in- and outflows*.

For the example of EMS and LCA the differences in the information required is that LCA considers also the function of the technical system. This is in Fig. 1 expressed by C, the *functional flow, or other functional unit*. The system boundaries and the system content for models applicable in EMS are generally different from

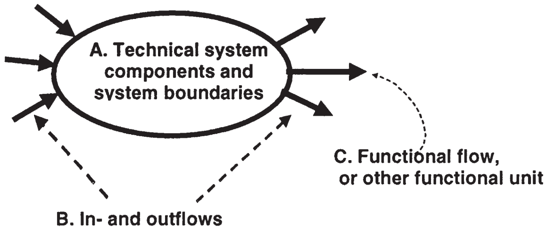

Fig. 1. A model of an environmentally managed technical system.

models applicable for LCI. When modelling a technical system applicable for EMS, the models are drawn to include the management's organisational units, while models useful for LCA are drawn to include technical subsystems that are associated with a specific function, such as the production of one or more products or services.

3. PHASETS — PHASEs in the design of a model of a Technical System

3.1. Overview

When designing a model of a technical system, modelling actions are taken, which may be more or less conscious or deliberate. Throughout the modelling different information about the observed system is used, such as results from measurements and estimates, descriptions of processes etc. The quality of the resulting model, and implicitly its usefulness for decision-makers depends on both the modelling actions taken and on the quality of the information used in the modelling. Thus, to assess the quality of such a model one should assess the quality of both the information used for the modelling, and the quality of the modelling actions. The PHASETS model structures both the generation of the information used in the modelling, as well as the modelling actions.

The PHASETS model describes the path that data management should follow while generating a model of a technical system, from defining measured entities, through the modelling, to the final communication of the result. The path is divided into six phases, each of which is self contained and distinctly separated from previous and subsequent phases. Within the phases, well-defined distinguishable tasks are performed, which requires a homogeneous input and which supplies a meaningful, homogeneous and interpretable output. Communication between each phase is stressed in the PHASETS model, and is defined and described generally, as one separate and generic phase.

Each phase may in itself include many tasks, complex or simple. To keep the model at a general level, it does not allow for further sectioning of the existing phases. The tasks within each phase may, however, be described in detail in specific implementations. It is also likely that in different information systems and organisational routines some of the phases are merged or grouped differently.

The structure, that is, the formatting of the actual information handled within and communicatded between the phases is not covered in this paper. It should, however, be recognised that in order to enable data quality management, one needs both a format for communication and storage of the information and a structured way to handle information. The PHASETS model provides a structured way to handle the information, an in any given application of PHASETS, a format has to be chosen or specifically developed.

3.2. The PHASETS model

PHASETS is described as a procedural and conceptual model based on communication and information aggregation. Data and information pass through phases, where sets of simple or basic concepts are communicated to formulate more aggregated and complex concepts within each phase.

Following the direction information takes for reporting, PHASETS may be described sequentially as (Fig. 2), from bottom-up:

0. Defining an entity for a selected parameter; The choice of entity to measure and the setting up of the measurement system defines the simplest concept; that is, the meaning of a measured value;
1. Sampling an individual value; The sampling results in a value for the simplest concept, that is, a measured value;
2. Forming a frequency function from a set of sample values; The frequency function aggregates sets of measured values into statistically expressed concepts;
3. Synthesising a model of a technical system; The systems synthesis further aggregates the frequency functions from phase 2 into structured models of technical systems;
4. Aggregating models of technical systems; The models of technical systems synthesised in phase 3 may be aggregated into complex concepts describing, for example, averages or cradle to gate systems;
5. Communicating information between different contexts; between any two phases 0–4 the resulting data and information, is communicated from the generator to the consecutive phase.

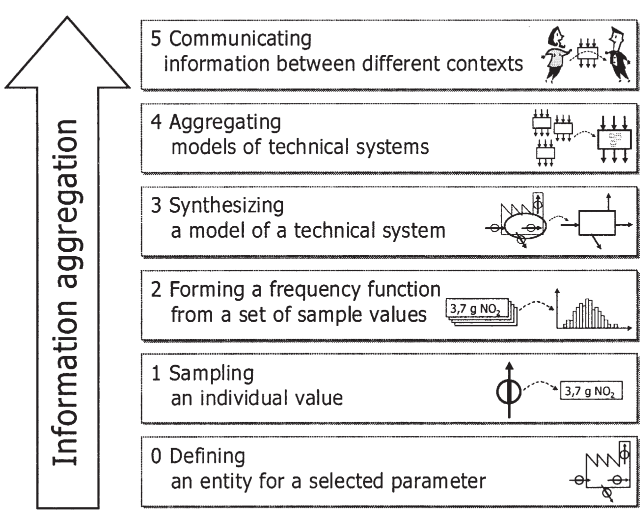

Fig. 2. The phases in the PHASETS model.

The six phases in the PHASETS model will be described in detail in the following sections. The model is approached top-down, the way it will be seen from, for example, a decision-maker.

3.2.1. Communicating information between different contexts, phase 5

This section refers to phase 5 in the PHASETS model, see Fig. 2.

Information is correctly communicated between different users within different contexts if the receiver understands the meaning of the information as it was intended by the sender [12].

Meaning is preserved during communication if the message contains enough information for the meaning to be reconstructed by the receiver. Considering that sender and receiver has different contexts the message must bridge the differences in terminology, language and implied meanings between the context of the sender and of the receiver. For example, literally equal terms may address entirely different concepts within the receiving contextual environment, implied meanings may not be identified, and not intended meanings might be imposed. The sender should be aware of this and design the message accordingly. This is general for communication between contexts, and is addressed in organisational communication theory [13] and cognitive theory [12]. It is also the key issue for standardisation work [14].

Practically, there are three ways of communicating meaning during contextual transfer of information:

1. *Documentation*. Supplying a rich and sufficient documentation using terms and language shared by the communicating parties. Such may be the result from standardisation, common education and commonly addressed dictionaries.
2. *Dialogue*. The information receiver may ask the information supplier for clarifications of meaning. To ensure correct use, the supplier may also review the receiver's handling of the information.
3. *Implicit*. When observing or participating in the actual data generation communication is implicit, that is, the receiver implicitly retrieves information as experience.

The current lack of documentation of environmental information indicates that present communication is made as dialogue or implicit. These forms generate no documentation that can be addressed or referred to after the communication is closed. This results in difficulties in terms of quality control, review, and assessment. As most informal communication dialogue and implicit communication are expensive since they require personal contact between sender and receiver, as well as reconstruction of facts each time they are needed.

Formal communication should primarily be based on documentation, which enables effective and independent information review and retrieval. This paper only addresses this type of communication, that is, it will from here on be assumed that communication between each phase in the PHASETS model is based on written documentation, for example, electronic or paper based.

3.2.2. Aggregating models of technical systems, phase 4

This section refers to phase 4 in the PHASETS model, see Fig. 2.

Models of technical systems (see Section 3.2.3) can for different purposes be aggregated into new models of technical systems, for example, when compiling the product system for a life cycle inventory (LCI) or when compiling different types of averages of technical systems. These compiled aggregates are new models of technical systems, with specific purpose, properties, functions and scopes. As examples, two important types of aggregates are discussed; flow charts and averages.

3.2.2.1. Flow chart modelling Flow chart modelling means aggregation of different system models into a flow chart (see Fig. 3). Examples are process flow charts for plant analyses and LCI product systems. Depending on the use of the model different modelling methodology and mathematics are applied [15].

3.2.2.2. Averaging Averaging means mathematical aggregation of similar models of technical systems into a new virtual model, representing an average system model. The modelling includes specification of the scope and requirements on the included system models and the mathematical summation of frequency functions of flows (see Fig. 4). Mathematical treatment for formation of averages requires each of the summed models to be equal with regard to a set of specified physical and mathematical aspects [16].

Examples of averages are:

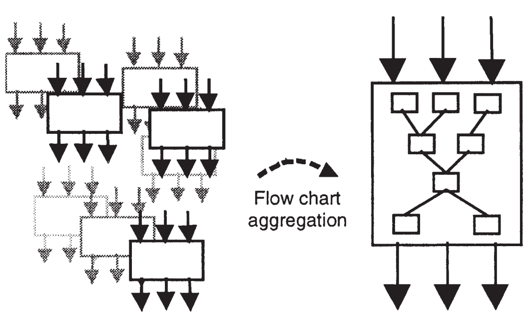

Fig. 3. Aggregation of technical system models by a flow chart modelling.

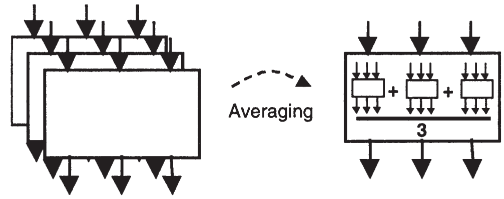

Fig. 4. Aggregation of technical system models forming an average technical system model.

- *Industrial averages — different technical systems.* Industrial averages are compiled by averaging different but physically similar models of technical systems into a new system model. Industrial averages may describe a specific sector, market or product.
- *Interval averages — the same technical system.* Interval averages are compiled from system models describing the same physical technical system during different intervals, for example, time intervals or product volume intervals. The resulting system model is a model of a technical system describing a specific time or product volume interval. An example of such an average is a corporate annual environmental report describing the environmental performance of a plant.

Interval averages differ from industrial averages in that they include averaging over the same physical technical system, while industrial averages are compiled from models of different physical technical systems.

3.2.3. Synthesising a model of a technical system, phase 3

This section refers to phase 3 in the PHASETS model, see Fig. 2.

A model of a technical system is originally defined from a synthesising procedure for example, by synthesising results from detailed analyses of a real technical system, or by synthesising estimates of parameters into a coherent model [17]. A technical system model is synthesised for a specific purpose from which it derives all properties [18].

A model of a technical system has well-defined properties, that is, a system model scope limited by boundaries, and an interface describing the interaction between the system and its environment, cf. Fig. 1. In practice, such systems are not independent of the observer, that is, the modeller, which means that a model of a technical system does not necessarily describe a physically existing and separable technical system [19].

When communicating information describing a synthesised technical system model special care should be taken to communicate information about the system boundaries and the system content and of any modelling made to for example, transform input data on flows supplied from phase 2 (see Section 3.2.4).

3.2.4. Forming a frequency function from a set of sample values, phase 2

This section refers to phase 2 in the PHASETS model, see Fig. 2.

As a basis for synthesising a model of a technical system, as described in Section 3.2.3, the modeller needs to have numerical data on relevant parameters, prepared in the form of statistically expressed numerical values. Results from measurements, for example, sets of sample values, are generally not useful in the form in which they are originally recorded. Instead they are aggregated into statistical parameters, which describes frequency functions. Such functions statistically describe trends and levels of the measured entities. To acquire these statistical parameters, statistical data analysis is applied to the sets of sample values.

The choice of statistical methods is not arbitrary but is inherent from the measurement system, which defines the meaning of the measured values (dealt with in phase 0, below) and the sampling process that generates the sample set (dealt with in phase 1, below) [20].

When communicating information that describes a frequency function, special care should be taken to clearly communicate the interval for which it is valid, as well as any relevant discrepancies during that interval.

3.2.5. Sampling an individual value, phase 1

This section refers to phase 1 in the PHASETS model, see Fig. 2.

The origin of data about a physical entity is an observation, for example, a sampling of an individual value from a measurement system. A measurement system is the systematic monitoring of one physical entity [18]. For example, it may monitor a total emission outlet by recording each individual sampling result.

Data may also be the result from for example, estimations based on experience, retrieval of data from literature or the execution of a mathematical model. Also these recordings are here referred to as sampling.

When communicating a sample value it should be supplied with documentation of whether the circumstances under which the sampling were made were in accordance with the specifications of the systematic of the measurement system or if any deviations from the specified sampling routines were made.

3.2.6. Defining an entity for a selected parameter, phase 0

This section refers to phase 0 in the PHASETS model, see Fig. 2.

This phase defines the origin of data on any measured entity in PHASETS. Unless an unambiguous definition of this entity is established there is little meaning of communicating information about it.

A measured entity originates from a measurement system, which is designed with regard to what aspect to control by the resulting information [18], for example, control of the production with regard to legal aspects or environmental market requirements.

The design of the measurement system should also consider whether the entity should be correlated with other measured entities. For example, if the amount of emissions should be correlated with the production rate, the measured entities and the measurement systems must be synchronised.

A measurement system may be simple, for example, a computer recording quantitative properties of occurrences of the entity being measured, or it may include several steps of sample analysis and data treatment before one sample value can be recorded. That value may in itself be described in terms of probability etc.

The meaning and the interpretation of a measured entity are equally important for estimates, data taken from literature, or results from mathematical models.

When documenting a measurement system, special care should be taken to ensure that known relevant aspects under which the measurement system is valid are clarified, for example, measurement ranges and uncertainty intervals, as well as correlation with other measurement systems and entities should be clearly described.

4. Applications

In this section some applications of the PHASETS model for industrial handling and communication of environmental information and data are described. The PHASETS model may be applied as a structuring aid for:

- *Design of routines for generation of reliable and credible industrial environmental information and data*: business requires effective environmental information management, that is, the environmental management needs a reliable decision base and the market requires credible environmental market statements. Business competition requires efficient management that is, the routines for the environmental information and data needs to be efficiently integrated with the established corporate routines. PHASETS is an organisational reference model when identifying the data management routines that need to be made reliable.
- *Designs of routines for reliably communicating credible industrial environmental information and data*: as environmental information and data are communicated from original source to final reporting, the data and information passes through many organisational units. The reliability of the data and information is affected by different expertise within the involved organisational units. In the communication, there is a risk that misunderstandings may introduce unpredictable and untraceable errors in the final results. Conse-

quently, there is a need for a reliable quality assurance of the environmental information management. The PHASETS model not only the activities involved in the handling of environmental information, but also the communication between the different activities. If PHASETS is used for the design of information management routines it will also facilitate identification of areas where communication errors may be introduced.

- *Estimation and control of costs for industrial environmental information and data acquisition*: today companies face a number of parallel environmental information acquisition duties, for example, authority or corporate environmental reporting and LCI data requests from customers. With an integrated strategy for these duties, costs may be shared with other duties and reduced by allocating costs to already implemented activities. By applying the PHASETS model, the different activities involved in the handling of environmental information can be clearly defined and distinguished, and a structured overview of the entire corporate environmental information system may be obtained. A result from this is that the costs for these activities may be estimated, budgeted and controlled.
- *Development of a consistent security system for corporate environmental information management*: environmental business requirements put demands on new potentially sensitive information to be acquired, compiled, stored and communicated within the organisation. This leads to emergence of a new corporate information system, which needs to be designed as thoroughly as for example, the economical information system, to meet security management standards. PHASETS structuring of internal and external environmental information management supplies support to such a thorough design process. All users, communication channels and access roles may be well identified, which allow for a well-structured secrecy control.
- *Define and enable data transparency*: credibility is based on openness, and to achieve openness concerning industrial environmental information, one must enable review of information and data. Review requires transparency. Transparent information can only be achieved with a structure supporting transparent information management. PHASETS is such a structure, which enables review at all levels of data and information handling and communication.
- *Achieve data quality*: considering quality as a measure of degree of fulfilment to a specification, an EMS designed on the basis of the PHASETS model will enable achievement of any data quality specification. The paths through which the data quality specifications are broken down and distributed to the responsible persons are given by PHASETS.

It should be recognised that phases 0–3 may be performed differently with higher usability in the consecutive phases by applying statistical experimental design methods [18].

5. Implementing PHASETS

PHASETS is first of all a conceptual model describing a procedural path. It requires interpretation for each specific application, but then serves as a common basis for understanding for the different actors. Users and roles, organisational units and communication channels, methods and equipment can be structured in an efficient and effective way in accordance with the phases of the model.

Practical work with implementing PHASETS in, for example, the Swedish forestry, pulp and paper industry shows that when implementing PHASETS the information requirements of the resulting reports should first be investigated and well defined. It is natural to then consequently continue down through the model, starting with defining the models to acquire information about. In phase 4 the required system model units are identified. In phase 3 these models are defined, including the system content, its boundaries and its environmentally relevant parameters. From phase 3 it is practical to continue directly to phase 0, to identify or implement measurement systems for relevant parameters, as well as to formulate sampling routines. Phases 0 and upward are then a practical execution of the PHASETS model, which follows the preparing steps (definitions of phases 5, 4, 3, 0) of the implementation. Each phase is connected using the rules of communication and preservation of meaning described in phase 5.

6. Conclusions

The PHASETS model aids in the identification of mutual models for environmental information managment for different applications, for example, EMS monitoring and LCI data acquisition. With PHASETS companies may considerably increase the capacity for their voluntary environmental control, at for example, site, corporate, or life cycle levels. The PHASETS model also enables quality control of environmental information management, and if fully implemented throughout a supply-chain, it enables comprehensive data transparency for entire LCI studies.

Due to choice of organisational structure the acquisition of data for use within the EMS is often separated from the generation of data for LCA purposes. This is true for companies not being streamlined for market orientation, that is, not being product flow oriented or for companies which have formulated environmental goals for their organisation but not for their products. Within such organisations LCI data is not generated within the EMS routines. LCI data acquisition and generation is instead run as separate projects on demand. Regardless of routines organisations may still apply the same general structure for information management for for example, EMS and LCI as formulated by PHASETS.

PHASETS reduces the complexity of information describing models of technical systems, by structuring the data handling, instead of removing information. By practically connecting final reports with measurement systems and intermediate data treatment, PHASETS serves as a model for ideal transparency of industrial environmental data and information.

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Paper III

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System for integrated business environmental information management

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Abstract

By making use of current business information technology, such as Internet-accessible tools, and industrial environmental management tools, standards, policies and legislation an information system for environmental information management has been designed. The system is named Integrated Business Environmental Information Management (IBEIM), and it includes operational, procedural and organisational support for a business' entire environmental information management. IBEIM consists of a system architecture and an information and data content. The system architecture is designed from three thoroughly developed information models, i.e. a reference model for information aggregation and communication, an information model for data structuring, and a modularization including module interface specifications. The content is stored in a common information platform, and includes, for example, a structured knowledge system. IBEIM efficiently supports and integrates environmental information management for Environmental Management Systems (EMS) tools, LCA and other environmental process modelling tools, and Design for Environment (DfE) tools. With this system, integration communication and reports are handled in a consistent and compatible way all through an organisation of any size. IBEIM is also designed for supply chain communication.

Keywords: Information system; Modularised system architecture; Industrial environmental management; PHASETS; SPINE; ISO 14048; STEP; Environmental database; Environmental supply-chain management; Environmental reporting; Information quality maintenance

1. Introduction and purpose of the IBEIM system

Since the 1960s, the industries have faced ever increasing environmental demands externally, from customers, authorities and NGOs, and, during recent decades, also from internal business control functions, i.e. environmental management systems. To meet these demands, the needs for environmental information management have grown simultaneously. Every new demand has been met by implementing a new information management activity, which has led to the current situation, where most industries have many parallel and unsynchronised information management activities. For instance, it is commonplace to have separate systems for governmental reporting, internal yearly re-

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porting, internal environmental management, life cycle assessment, etc. However, much of the information used in these separate systems is the same, and it is an economical sub-optimisation to independently acquire, document, analyse, store, communicate, and quality control the same information in all different systems.

The system for Integrated Business Environmental Information Management (IBEIM) is designed to encompass and integrate all environmental information management activities within business organisations, and in their external communication. The design is based on an overall view including all current needs and has an open design towards future demands, as long as these future demands are formulated in a way similar to current demands. This means that environmental management concerns industrial and other human activities and is expressed in terms of environmental indicators and physical flows that are assessed with for example impact and risk assessment methodologies.

IBEIM structures information acquisition and storage. It supplies a structured approach to information communication and aggregation, all the way from measured entity and up to highly aggregated reports. In addition, it supplies standard communication formats as well as translations between different formats. All these functions and structures are needed for a truly integrated information system.

IBEIM makes use of current business information technology, i.e. Internet technology and client server modularization.

Currently, the ideas of IBEIM are being applied in the development of different corporate environmental information systems within, e.g. the Swedish forestry, pulp and paper industry, the European RAVEL (Rail Vehicle eco-efficient design) project, and ABB. The Swedish forestry, pulp and paper industry is introducing the system as work routines that may allow for implementation into computer systems, the RAVEL project aims for a methodology and a computer system supporting the total supply-chain during train design projects.

2. Scope of system

The scope for IBEIM is the same as the scope for the industrial environmental responsibilities and activities described in the ISO 14000 standards. One boundary for the scope is drawn at defining environmentally relevant physical entities and indicators, as described in ISO 14031:1999. The reporting to an end-user of the system draws another boundary, for example, internally for aggregated environmental performance reports or statements for the director, or externally for simplified environmental product declarations, for example according to ISO 14020 series (1998) (ISO 14020:1998), presented to customers.

IBEIM is prepared for full supply-chain information management, meaning it is open for communication with each customer–supplier interface. Many different reports can be generated as information for customers, and the customer may be free to either import the report into their own IBEIM, or to acquire them as separate pieces of information. In addition, IBEIM generates supplier-questionnaires on demand and may even allow suppliers to enter information directly into the IBEIM information platform. In a fully integrated IBEIM, the customer and supplier may share access to parts of each other's systems (see also Fig. 2).

Any industry already has much of the information needed in IBEIM structured in other information management systems, such as economic, logistic, product data management, etc. systems. IBEIM does not require parallel storage and structuring of this information, but instead connects to and reformats the information in other systems, on demand.

IBEIM does not require additional tasks or activities, additional personnel or much additional education. Instead it simplifies and increases efficiency in already established routines and tasks.

3. Components of system

IBEIM is a structured information system, i.e. a system architecture with an information and data content.

The IBEIM architecture is built from three elements (see also Fig. 1):

- A basic information platform, the data structure, implemented as a relational database for storage, and a standardised format (STEP) for data communication within the system and between separated sub-systems (ISO/IEC 9075:1992; ANSI X3.135-1992; ISO 10303-11:1995, 10303-21:1995). Using STEP as the communication format will ensure external compatibility with other software and internal transparency between system modules.
- PHASETS (PHASEs in the design of a model of a Technical System), which is a reference model including six phases for communication and aggregation of industrial environmental data and information (Carlson and Pålsson, 2000). Each phase in the model describes functions and management tasks, without specifying how these tasks should be performed. The reference model serves as a template for the architecture of the IBEIM system, and as a task and a reporting sequence for the different types of information handled within the system.

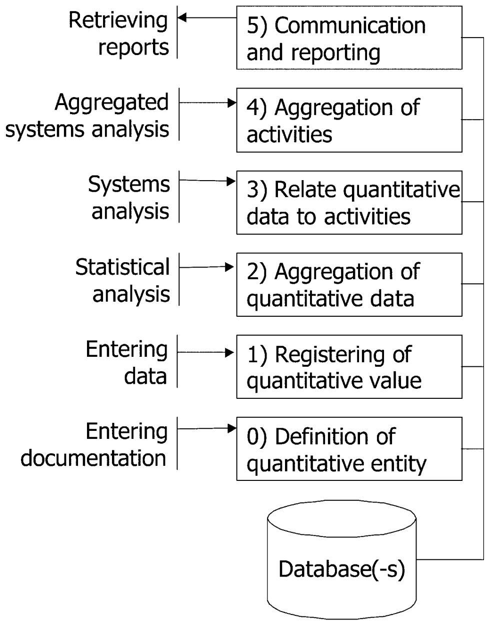

Fig. 1. Schematic illustration of the IBEIM system modularisation.

- A modularization based on the information platform, i.e. the data structure of the database, the distinguished phases of the reference model PHASETS, and on organisational tasks that the users perform, i.e. the organisational structure. The modularization is documented as an application programmers interface (API) specifying the interfaces and the communication and collaboration between software modules of the system. The formulation of an API makes it possible to add/change modules according to present needs in the form of for example plug-ins. The API documentation will be maintained in a public forum and will be publicly available for different software developers to apply and conform to. The current IBEIM systems being built do not make use of the IBEIM API.

The IBEIM information and data content:

- Descriptions of all activities related to each of the six phases in PHASETS, supporting communication and aggregation of industrial environmental information (Carlson and Pålsson, 2000). Except for the description and documentation of the main phase activity, each phase also involves related information, such as procedures for the control of documents, education, auditing, and following-up, etc. Roles, responsibility, and authorities can be defined, and be sufficiently described as well.
- A knowledge system, referencing external or internal information sources, such as environmental and quality standards [ISO 14000 family of standards, EMAS (The Council of European Communities, 1993) and ISO 9000 family, etc.], national and international environmental legislation and regulation, environmental customer demands to support the company purchase department, environmental benchmarking for the line of business, etc. The knowledge system is an integral part of IBEIM, in that its structure is described in the IBEIM database and data communication structures, and in that data in the database reference documents that can supply the user with definitions or general information through context sensitive pointers within the system.
- Environmental records and communication forms, such as policy and goal statements, results of environmental assessments (life cycle assessments, risk assessments, SWOT-analyses, etc.) audits and reviews. These documents can consist of internal or external reports, working material, official environmental product declarations, information brochures for customers, environmental accounts, diagrams and tables for presentations, etc.

4. Technology applied

IBEIM is based on standard technology. Special efforts have been laid on the information platform in order for it to be stable, regardless of implementation of specific modules. Information structure should be left unchanged regardless of choice of methodology, procedures or software. Therefore, the information platform is documented as a conceptual entity relationship model, from which both the relational database design and the STEP exchange file specification has been derived. By choosing relational databases for data storage, there is a wide range of standard operating systems and database management systems that may be used as database servers for the system. STEP is a standard for implementing a data exchange format, as well as the standard describing an implemented format. Currently, IBEIM has only followed the STEP methodology for implementing and describing the exchange file format. It has not been suggested as a standardised format for integrated industrial environmental information management.

The PHASETS reference model is not standard technology, but is based on the principle of the ISO/OSI reference model (responsible body ISO/TC97) which describes data aggregation and communication from a lowest physical layer up to the application layer. PHASETS describes aggregation and communication from definition of a measured entity up to compilation and submission of different environmental reports.

The modularization of the system is made in a standard way through the documentation of the API. This makes any module replaceable and it makes it possible to build and maintain the system into its future needs. By having the API specified, it is also possible to build a copy of any existing system on another operating system platform or to build it as a platform independent system using for example Java™ technology.[1] The system modules are independent of each other and can thus be both developed and used separately.

The system is intended for Internet technology, meaning that users connect to the IBEIM system by their Internet browsers. All user interaction is built to be platform independent and runs at the client, while databases and demanding calculations runs at the servers, establishing a well-optimised client-server environment.

5. Organisation for system

The IBEIM is designed for integration with any business or industrial organisation. Before starting to use the system, it may be configured with descriptions of the organisational units that will make use of the system, the users within these units, and the different relationships between the organisational units and users.

Since the system is based on Internet technology, it is distributed to each different user as web pages. Access rights, user restrictions, and appropriate functionality is prepared for the user, based on login identities. The system is designed for three levels of access rights for each user login: core rights are given for each form or functionality that the user needs for his direct work in the system. A user generally has insertion and updating rights on all core information. Contextual rights are given to a wider area of information and functions, to enable a user to view and analyse a larger information base than is directly needed for the work. The user does not have updating rights on the information with contextual rights. All information outside of core and contextual rights is hidden to the user.

IBEIM supports a number of common and crucial organisational roles. The basis for the system is the information quality management. The responsibility for the total information quality is distributed through the entire organisation, and is strongly supported by the system. (Carlson and Pålsson, 1998a,b). The quality control of each role is considered, from the environmental management and co-ordinators identifying, defining and selecting environmental indicators, the measurement engineers being responsible for defining measured entities and the setting up and maintenance of measurement equipment, through the operational registering of quantitative information, mathematical and systems analysis and compilation of reports. The quality is maintained by standard operations, documentation, and transparent communication.

End users of information can always trace operations and manipulations made on data and information. The management can use IBEIM to delegate new routines for data acquisition, analysis and compilation, and can through the system supervise a correct data handling.

The business' marketing departments, the management and the board, and the product and service development departments can access the system for their decisions or to design special reports displaying specific environmental issues. Such reports may then be edited in for example standard graphical design software, for powerful and credible presentations.

6. System architecture and functionality

IBEIM is a modularised, distributed system designed to support the six phases of environmental data management described by the PHASETS model (Carlson and Pålsson, 2000). Each phase is designed as a software layer in the system, including software that performs well-distinguished tasks (see Fig. 1).

The bottom layer (0) consists of tools for entering documentation describing quantitative entities, such as environmental indicators, and equipment and methods for measuring these entities. The first active layer (1) consists of tools for registering quantitative data and sampling. This can either be user interfaces for manual data insertion, or automatic routines sampling directly from, for example, a measurement system. The second active layer (2) consists of tools aiding the user or the system to perform statistical analysis on sets of individual quantitative data. The third and fourth active layers (3) and (4), consist of systems analytical tools, such as process modelling tools, LCA tools, environmental management systems (EMS) tools, design for environment (DFE) tools etc. With these tools, the user may generate descriptions of the environmental performance of technical systems, subsystems and products. The fifth active layer (5) consists of configurable report generation tools, communicating the contents of the database(s) to different IBEIM information users.

Each layer communicates using the same data model

[1] Java is a trademark of Sun Microsystems Inc.

that defines the database structure. This may be done either by communicating through data exchange at the database, or through direct communication between the layers, using the data model implemented as a STEP (ISO 10303) parts 21 file (ISO 10303-21:1995). Communication within IBEIM and to its environment is regulated by rules described in the fifth layer, basically prescribed as routines for quality assurance regarding preservation of meaning between information sender and receiver.

A formal description of the underlying format makes it possible to use existing techniques for verification of consistency of the format. Tools and modules for the generation and interpretation of documents that comply with the format are already available as elements similar to these commonly used in software compilers for computer languages (C, Pascal, Ada etc.). Such technology has also become commonly used for constructing recognisers and translators for different kind of text processing, such as HTML, SGML and STEP.

An IBEIM system is a network capable unit, which may communicate with other IBEIM compliant systems. For instance, IBEIM may be fully or partially implemented in different organisational units within the same company, and will then work fully and separately for each organisational unit. Any two IBEIM implementations may then communicate, i.e. exchange information and data with each other, to generate for example unifying reports for the management. IBEIM is also designed for supply chain management, which means that companies with business relations may exchange relevant environmental business and product data. In fact, this communication needs only the agreement of communicating the IBEIM prescribed STEP parts 21 files between the companies (Fig. 2).

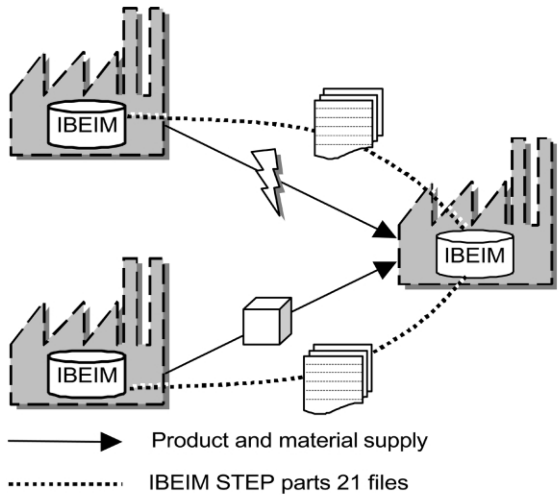

Fig. 2. IBEIM as a network capable unit, enabling environmental supply chain management.

7. Applications for system

IBEIM has been developed to support the industry and other business organisations with an intelligent environmental information management system that will assist these organisations to achieve environmental and economic goals. IBEIM co-ordinates and integrates the various information needs supplying the vast number of environmental management tools used today, such as:

- environmental management system, for example, information regarding the operation of the system, the data aggregation phases, legislative, regulatory, and other applicable policy requirements, such as ISO 14001:1996, EMAS (The Council of European Communities, 1993), environmental assessments, such as risk assessment, life cycle assessment and environmental evaluation of suppliers; and
- environmental records and communication forms, for example, internal and external environmental reporting and environmental labelling.

The system is designed to increase the efficiency and the quality of the information management for any of the above listed tools. The best efficiency, however, is reached by integrating more than one tool with the system. In this way, one may make use of the same information for different purposes, and use the same software modules for different tasks and routines.

A core design feature of the system is the format transformation functions, which translates information and data from the IBEIM internal data format into or from data formats for commonly used environmental information management software. This feature implicates that the IBEIM recommends system users to make use of the most suitable software tools for each environmental information management task, without enforcing any specific tool.

8. Further work

Currently, there are many different environmental information management systems being designed and developed within different industries and other businesses. These systems are integrated with, for example, product data management and computer aided design systems. Within each of these separately designed systems, the environmental information is differently modelled and formatted. Since IBEIM is designed for format translation between different information sources, each new format to translate to and from will imply the need for a new formal translation-routine in the system. Frequent launching of new formats for every new system will, therefore, lead to very high costs for a general IBEIM which can handle all format translations needed.

Unless the continuous launching of new formats for environmental information is halted, costs for environmental management will increase uncontrollably. This may eventually lead to a situation where environmental management cannot be economically sustainable. The only way to avoid this situation is through harmonisation and standardisation of reference models such as PHASETS (Carlson and Pålsson, 2000), and data formats such as ISO 14048 (ISO/CD 14048).

To reach full functionality and efficiency, IBEIM should be integrated with other core business information systems, such as automated manufacturing systems, economical systems, logistic systems, and support systems for purchasing and marketing. Integration with business information systems may be approached from two different directions. One is by expanding IBEIM's format translation functionality to include all relevant information exchange formats needed to communicate with other business systems. As soon as a format is expressed in any standard formal way, a new interpretation unit for the language can be constructed. A requirement is that the format can be given a consistent construction, otherwise it cannot be expressed in a logical manner.

The other approach is to integrate IBEIM models, standards, functionality, and modularity with business systems products available on the market. Basically this would mean that business system vendors develop their own competitive IBEIM solutions. This may be profitable for the vendors when industry standards for environmental information and data has been introduced and successfully used within different industries. Such increased industrial assimilation may initiate a demand for IBEIM compliant and integrated products.

9. Conclusions

In spite of its apparent ambitious scope, IBEIM is relatively inexpensive to technically implement. This is due to the focus directed towards formats, standards and standard technologies. By the application of standards, no additional work is needed for systems development of the core elements, i.e. information requirement analysis and design. IBEIM is also inexpensive to technically implement because of the thorough modelling of the system, especially with regard to the PHASETS reference model and to the format for the environmental information and data.

The successful design of IBEIM is due largely to the PHASETS reference model, in that it supplied a thorough model for information management at different organisational levels and with different information aggregation. PHASETS serves as a design guideline through the development of an information system reaching from the level of physical flows at manufacturing plants, up to strategic organisational levels, such as the executive management board and the marketing departments. It also serves as a high-level software modularization schema, including high-level communication interfaces and task descriptions.

Another valuable component for the design of IBEIM is the underlying model describing the format for the environmental information. This model originates from the work made in the Swedish industry, with the SPINE model and format (Carlson et al., 1995; Carlson and Pålsson, 1998a,b), and on the work made within ISO, with standardising a format for LCA data documentation, the upcoming ISO 14048 (ISO/CD 14048). This work has revealed the important aspects of information describing the environmental performance of technical systems, i.e. production processes, service activities, transports, etc. It has also resulted in a substantially improved understanding of the different and special data quality aspects of such information, and has identified methods for administrating and maintaining the quality of such information systems (Carlson and Pålsson, 1998b). These accomplishments have guided both the development of the PHASETS model, as well as the general design of the IBEIM system. The importance of well described data formats and well-designed transformations between systems cannot be underestimated, and it sets the foundation for the quality of the entire information system.

IBEIM aids users with very fast communication, by making use of computer network technology, i.e. client server components, database servers and centrally published web user interfaces.

By making parts of the IBEIM accessible for both suppliers and customers, environmentally relevant business communication may be as fast and feasible as internal communication.

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Paper IV

AN INDUSTRY COMMON METHODOLOGY FOR ENVIRONMENTAL DATA MANAGEMENT

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ABSTRACT

A methodology for cost efficient quality assurance environmental data management has been developed and is now being implemented in the Swedish forest industry, in collaboration with Chalmers University of Technology. The development of the methodology was run as a two-year project that was initiated and funded by the Swedish Forest Industries Water and Air Pollution Research Foundation (SSVL).

The methodology defines how the industry's production sites can work with environmental data in a common and comparable manner, by structuring acquisition, compilation and reporting of data. It is flexible and can with comparable results be adapted to the desired level of ambition and to the different technical and organisational conditions within different sites. It structures what documentation is needed to achieve verifiable and consequently reusable and credible results. A method report and a manual have been developed, describing the methodology and how to implement it at sites.

The methodology has been successfully tested in six case studies at production sites, representing different types of pulp and/or paper.

The methodology gives the industry, the companies and the production sites an opportunity to meet requirements on environmental information with increasing quality and without increasing cost. The information that are handled are e.g. environmental reports, environmental product declarations, basis for benchmarking, quantification of environmental aspects, internal education and, internal and external information. Also costs to fulfill requirements from authorities can be better controlled, e.g. annual environmental reports, reporting to IPPC (Integrated Pollution Prevention and Control).

INTRODUCTION

The demands for environmental information are increasing. Today, most pulp and paper production plants need to compile and report different types of environmental information. The information is used as basis for different types of decisions, both within the company and externally by customers and other stakeholders. Examples of information needs are:

- *For internal use at production site:* information for process surveillance, Design for Environment (DfE), measuring the performance of the environmental management systems (EMS) [1] etc.
- *Within the company group:* information to perform internal benchmarking of products and processes, and to compile the group's environmental statement.
- *To customers:* information to evaluate and compare the environmental performance of products and suppliers, e.g. through the Paper Profile [2].
- *For authorities:* environmental reporting to local authorities, national EPA and to EU, within Integrated Pollution Prevention and Control (IPPC) [3].

PURPOSE

The purpose of a common methodology for environmental data handling in the forest industry is to:

- *Quality assure environmental data management.* Documented routines for processing, compiling and reporting of environmental data are incorporated into the existing management systems (ISO 9001 [4], ISO 14001 [1], EMAS [5] etc.) and are adapted to the unique prerequisites at each plant.
- *Simplify and co-ordinate the production sites' compilation of environmental data for different needs.* A structured environmental information management system can facilitate and co-ordinate e.g. data for life cycle assessment, environmental labeling, environmental statement and environmental reporting to authorities.
- *Facilitate communication of environmental information to customers and other stakeholders* Environmental information is documented, easily accessible and understandable.
- *Set an industry standard for management of environmental information.* A common methodology supplies a common language and way of working within the forest industry.
- *Allow for the compilation of a common database for the entire pulp and paper industry.* The data for the database is acquired at participating plants with a common and comparable way of working.

DEVELOPMENT OF THE METHODOLOGY

The methodology has been developed in a two-year project collaboration between the major Swedish-related pulp and paper companies and CPM (Center for Environmental Assessment of Product and Material Systems) at Chalmers University of Technology. The project is initiated and funded by the forest industry, through the Swedish Forest Industries Water and Air Pollution Research Foundation (SSVL). The SSVL project board has regularly been updated with the project status.

The following companies have participated in the project: AssiDomän, Duni, Holmen, Kappa, Korsnäs, M-real, SCA, Stora Enso, Södra and Rottneros.

The work in the project has been performed by:

- Case studies at production sites.
- Development of material to support implementation.
- Development of a proposal for maintenance of the results.
- Dissemination of the importance and value of the methodology.

The work was divided into two phases. During the first phase (2000) the methodology based on the PHASETS model [6] was adapted and developed into a practical methodology, to meet the needs of the industry. This was made by performing practical case studies aimed at testing the feasibility of the theoretical methodology PHASETS at Kappa Kraftliner, SCA Ortviken and Stora Enso Skoghall Mill. In parallel with the case studies, a practically useful method report and a manual were authored by the project. These should support the next step of the project, during which the methodology was implemented at new production plants.

In the second phase of the project (2001), the methodology and the manual were evaluated during the implementation at three more plants; Duni Kisa, Korsnäs and M-real Husum. Also, the practical work with testing and evaluating the methodology continued at the plants that participated during the first phase.

During the project, special considerations have been taken into account regarding the feasibility of the resulting methodology, e.g. the necessity for the methodology to be adaptable with the specific organizational, technical and economical conditions within production plants. In practice this meant to use existing routines and to be able to include the methodology in existing management systems. The methodology should also make use of and support relevant international standards. The fact that the methodology is based on PHASETS also enables compliance with scientific consistency, which indicates that the methodology is a stable basis for environmental information management.

THE METHODOLOGY

Overview

The forest industry's methodology for environmental data handling consists of:

- *A common view of documentation* (based on SPINE [7] and ISO/TS 14048 [8])
- *A structured work procedure* (based on the PHASETS model [6])

A structured work procedure supports efficient handling and documentation of environmental data. A common view of documentation assures the quality of the information that is acquired. Together the documentation and the work procedure supply quality assurance of data, in accordance with principles for quality assurance according to quality standards such as ISO 9001 [4].

Common view of documentation

The basis for the quality assurance is documentation of how information is retrieved, compiled and reported. The documentation gives:

- Reviewability and verifiability of the information; for credibility in communication both internally and externally.
- Control and management of the information; a prerequisite to achieve security in decision-making.
- Possibility to reuse the information in different applications; a necessity to efficiently use available resources for environmental data management.

In the project, the SPINE-format has been used for the documentation. The SPINE-format specifies what should be documented and how the documentation should be structured. The SPINE-format is fully compatible with the new technical specification for data documentation, the ISO/TS 14048 Data documentation format [8].

The standardization of ISO/TS 14048 was initiated by Sweden, through CPM. The goal of this work was to reach a standard in line with the practical experiences from the development and use of SPINE.

Structured work procedure

The work flow presented in figure 1 below, describes the work procedure of the practical methodology for environmental data handling in the forest industry.

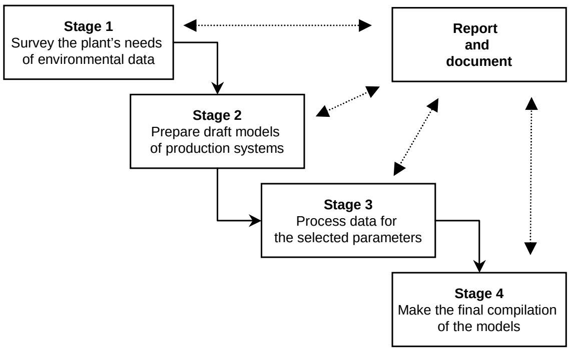

Figure 1 The work procedure of the methodology for environmental data handling in the forest industry.

In *stage 1* the plant's needs for environmental data is surveyed. During this work the stakeholders that request environmental data are identified, as well as their requirements on the data. The survey is used to determine which models that need to be handled, and to prioritize and control the further work.

In *stage 2* draft models of production systems are prepared. These describe the production of the products or product groups that were selected based on the survey of environmental data needs. The production systems can be prepared as either simple or composite systems. In this stage the parameters that should be reported for the systems are also selected.

In *stage 3* data is processed for the parameters that were selected for the draft models. This includes specification of parameters and measurement systems, acquisition of measured values and compilation of measured values into e.g. mean values. Allocation issues for the draft models are also investigated.

In *stage 4* the final compilation of the models is made, based on the information that has been acquired and prepared in the previous stages of implementation.

In each stage *documentation and reporting* should be made, which describes the tasks, reporting paths and routines that have been identified and designed for the work, as well as the results achieved. The documentation and reporting establishes the quality assurance of the environmental data handling. The models that are prepared and compiled should be documented in the SPINE format (this will be replaced by ISO/TS 14048 in due time).

As mentioned earlier, the work procedure is based on PHASETS (PHASEs in the design of a model of a Technical System) [6]. PHASETS structures environmental data handling for different purposes and has been especially designed to be the basis in an efficient and quality assured environmental information system. The structure was developed at CPM, independent of a specific industry sector, based on experiences from the development and maintenance of the Swedish national LCA database [9]. The relationships between PHASETS and industrial organizational routines are described in [10]

MATERIAL TO SUPPORT IMPLEMENTATION

The material to support the implementation of the methodology at production sites includes a manual and a method report. However, at present the actual method report and manual are still working material in the industry group.

The manual describes the practical procedure when introducing the methodology at production plants, and the method report describes the areas of application and the theoretical foundation for the methodology. Much effort has been put to adapt the language and terminology to the forest industry.

CPM can also offer introduction courses in the methodology.

EXPERIENCES FROM IMPLEMENTATION OF THE METHODOLOGY

The practical work at production plants has clearly shown the potential for the methodology to structure environmental data handling. By using the methodology, better control and overview of the information have been achieved. The work has given a thorough overview of how data is handled within the plant. Different levels of ambition and detail have been chosen at the different plants. This clearly demonstrates the flexibility in the methodology.

In the first case studies the methodology was primarily focused on delivering product related environmental information. In the later case studies the scope has been expanded to create an integrated platform for management of all environmental information at a production site. Hence, these systems deal with both product related environmental information and process related environmental information.

The resources for implementation of the methodology depend on:

- The level of ambition and detail for the work, e.g. the complexity of the models, the scope for using the methodology.
- The number of persons involved in the work.
- If the person responsible for work is familiar with the production plant and the methodology.

In the case studies, the working time for implementation has varied from about 24 to 35 mandays.

CONCLUSIONS

The methodology has proven to render environmental information management more efficient and enhance the quality of the information. The costs for generating the information have been unaffected or decreased compared to today’s systems.

The methodology adapts to existing activities within the plants. It is flexible and adapts to various kinds of production sites and meets different needs for environmental information. The methodology has been easily integrated in existing management systems within the plants, e.g. ISO 14001.

The methodology has proven valuable for individual companies, irrespective whether the methodology achieves a broad acceptance within the forest industry. Several of the large companies have started to implement the methodology.

FURTHER WORK

At the time of writing (January 2002) a continuation of the work is being discussed, e.g. how the methodology will be maintained and further implemented in the industry.

To achieve comparability, the methodology needs to be supplemented by policy-agreements within the industry regarding e.g. how the systems should be defined, which environmental parameters that should be accounted for, etc.

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-Åke Gustafson, SCA Graphic Sundsvall
-Ingrid Haglind, AssiDomän
-Roland Löfblad, Södra
-Elisabet Olofsson, SCA Hygiene Products

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Paper V

Defining and managing the quality of environmental information using total quality management

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Abstract

This paper presents a procedure for defining and managing the quality of information for industrial environmental management purposes named TQEIM (Total Quality Environmental Information Management). The procedure is intended to facilitate information management for different methods and tools, for example information for life cycle assessment (LCA), Design for Environment (DfE), environmental management systems (EMS), emission trading, etc. It is based on fundamental principles of total quality management (TQM) and incorporates insights from information quality management for both environmental management and business information systems and databases. Experiences from applying parts of the procedure for environmental information management within industrial organisations is also presented and discussed.

Keywords: Information quality, industrial environmental management, total quality management

1 Introduction

Industry applies different methods and tools to monitor, manage and control the environmental aspects of products and processes. The results from these methods and tools are used to support decisions at different levels. The confidence in the results to support the decisions depends on the quality of the information, i.e. both the quality of the information that is used as input, and the quality of the information that is generated. A widely accepted maxim is that decisions are no better than the information on which they are based [1].

Several approaches for managing quality of information for environmental management have been developed, but they are usually application specific, i.e. developed to support a specific tool or method. They tend to focus on how to perform checks and assessments of the quality of data and information, to for example assess applicability or to estimate uncertainty. Examples are the “pedigree matrices”, where quality and uncertainty of data are assessed through setting quantitative scores for a number of qualitative indicators. Pedigree matrices have been developed for different applications such as assessing quality of environmental models [2], life cycle assessment [3], and emission monitoring [4]. The approaches do not, however, provide much guidance on how to manage the quality of environmental information when it is originally generated. An analysis of the ISO 14000 series of standards, that many industrial organisations use as basis for environmental management, showed that the standards specifies explicit and implicit information quality requirements for the different methods and tools, but there is generally little or no guidance on how to manage the information to ensure that the requirements are fulfilled [5].

This lack of support for how to manage environmental information quality during generation may lead to difficulties in acquiring information in line with quality requirements. Quality management routines need to be developed independently by the organization, which can make it difficult for organizations when planning, implementing and maintaining their environmental information management systems to support the different methods and tools with data and information of appropriate quality. The actual quality of the environmental information will often be dependent on the individuals responsible for generating and developing the information. Hence, the quality and the content of the information that is generated and used for different environmental management tasks will differ based on the knowledge and experience of the individuals involved, and the available resources for managing the information. In practice, the same information may be acquired in different ways by different individuals, resulting in different findings. This may cause that results produced from environmental management efforts lack credibility, which ultimately lead to the fact that the results may be difficult to use as basis for decisions.

In parallel with the developments of environmental management from the 1990s, a number of approaches have been developed for information quality management for business information systems and databases; see for example [6, 7, 8, 9, 10]. These are generally based on the same fundamental principles that have been developed and applied for total quality management (TQM) of products and services. That is, the knowledge and experiences from TQM is utilised, adapted and applied on information and information management. TQM has been widely implemented in industry to effectively and competitively manage the quality of products and services, and there is a large body of literature available, see for example [11, 12, 13, 14].

An insight from TQM is that quality can only be effectively achieved by systematic management of the production. Thus, approaches for managing and improving the quality of the information based on TQM involve management of the information during the different stages of information production. They are based on the fundamental assumptions that information can be seen as information products and that the users of the information are information customers. Central elements in all approaches, which are also central elements according to TQM, are *customer focus* (i.e. understand and define customer information needs and expectations), *well defined responsibility* (i.e. define and appoint responsibility for information quality management) and *manage and improve production process* (i.e. define and manage information as a product from a well defined production process, which includes both information system development and information generation and use).

These approaches are developed to be applicable to any type of business information, but they generally lack descriptions on how they can be applied on a specific domain and how problems that occur when applied to specific types of information should be handled. These approaches, or the general principles of total quality management, are also usually not utilised or acknowledged in the available approaches for environmental information quality management.

This paper presents a procedure for how to implement and maintain systematic management of environmental information quality, based on the general principles of TQM. It is intended to support work with environmental management, by facilitating the management of environmental information.

2 Requirements and assumptions for the procedure

Some basic requirements were formulated that should be fulfilled and incorporated in the procedure, based on experiences from environmental information management in industry. The procedure must be able to accommodate a large flexibility in the level of scope and maturity. It should function equally well when applied to a small part of the environmental information management, e.g. for a specific method or tool for environmental management, as when applied on the entire environmental information management requirements and needs of the organisation. It should also be in line with and be possible to coordinate and integrate with existing management systems that are used within organisations, such as ISO 9001, ISO 14001 and EMAS. Requirements and needs are not static, and organisations need to be able to quickly respond to changes. This fact must be incorporated in the procedure.

The procedure is furthermore based on two fundamental assumptions:

- Environmental information can be seen as information products and the users of the information as information customers
- Established principles for total quality management can be applied and adapted to manage the quality of the environmental information products

These assumptions are based on research for managing information quality of business information systems and databases. The assumptions and their implications on environmental information are described in the following subsections.

2.1 See environmental information as information products

A viewpoint used in the literature describing information quality management of business information systems and databases is that information should be seen as information products, rather than as by-products from different business processes, and the users of the information as information customers. The strategic importance of information to support the business should be recognised [1, 6, 7, 9].

Environmental information products should be well defined. Examples of information products are environmental reports, life cycle assessment (LCA) studies for a specific question, environmental product declarations, etc. The definition of the information product can be facilitated by expressing it in terms of an environmental data documentation format. The format provides a well defined product specification of the information product in terms of content and organisation of the information.

Both final and intermediate information products should be defined and specified. Intermediate information products can be used for generating several different information products within an organisation. This facilitates coordination of process- and product-related information. For example, information about the environmentally relevant inputs and outputs of a production plant can both be used as basis for environmental reports and as input for life cycle assessments.

Seeing environmental information as information products facilitates the understanding and implementation of a customer focus perspective for the information. In this way, the environmental functions within an organization can be considered as information factories that provide the rest of the organisation with information products that are needed to support different types of environmental decisions. The analogy of defining and seeing environmental information as information products also facilitates the understanding of why and how the principles, methods and tools of total quality management can be used and adapted to manage the quality of environmental information.

2.2 Apply and adapt established principles for quality management to manage environmental information

The research on information quality management for business information systems and databases has shown that principles, methods and tools developed for total quality management (TQM) of products and services can be used to effectively manage the quality of information. This knowledge can be applied and adapted to also support environmental information quality management.

There are many descriptions of TQM available, but the common elements can be condensed into six fundamental principles; *customer focus*, *process orientation*, *basing decisions on facts*, *continuous improvement*, *involvement of people*, and *management commitment* [15]. Customer focus implies working actively and systematically to try to fulfil the needs and expectations of the customers, both internal and external. Process orientation implies that the work should be performed in well defined value-creating processes. Basing decisions on fact implies that facts should be well founded and that the performance with regard to quality should be measured and monitored. Continuous improvement implies working systematically to improve the quality of processes and products. A fundamental rule is that “there is always a way to achieve higher quality to a lower cost”. Involvement of people implies to facilitate for employees to participate in the work with quality management and continuous improvement. Management commitment implies that work with quality issues must be based on the commitment and active support from the management.

By applying well known and established principles of total quality management for managing the quality of environmental information, implementation can be facilitated, especially in organisations that have established quality management systems. Much is already available within the organisation in terms of thinking and terminology, and it can be seen as an explicit specification of how the quality management system incorporates and handles environmental information management. Introducing a different way of managing environmental information quality, that is not in line with well known quality management principles, may be both confusing and counterproductive.

3 Procedure for implementing and maintaining total quality environmental information management

This section describes and explains the procedure for implementing and maintaining quality management of environmental information based on TQM principles, named Total Quality Environmental Information Management (TQEIM). The procedure is aimed to increase quality and controllability of environmental information and support long-term continuous provision of information to support environmental management. It can be used as basis for managing data and information for a specific method and tool, e.g. life cycle assessment (LCA), Design for Environment (DfE), environmental management systems (EMS), emission trading, etc., and for establishing and coordinating environmental information management within an organisation. The general idea is to start where you are and with available support and resources and reach results from that point, by working systematically with quality based on the procedure.

Applying and translating TQM principles into quality management of environmental information implies that information customers should be well known, and that information products and quality requirements should be explicitly defined based on their needs. Information products are the result of a well-defined production process and therefore processes involved in generating and managing the information should be understood and well defined, in terms of both individual processes and how they are interrelated as a system. The work should incorporate continuous improvement in the daily work. This requires both a perception and understanding of the current status and a clear strategy for the work. Basing decisions on facts implies that the work should be measured and monitored to ensure that requirements are fulfilled and to provide a basis for work with continuous improvement. Involvement of people and management commitment implies that roles, responsibilities and authorities should be well defined and that sufficient resources should be available. To support the practical work with information quality management training and education is important.

The procedure consists of three fundamental parts:

- Define needs and requirements for environmental information quality. This involves:
    - Understand and identify the needs of information customers
    - Specify and define information products and information quality requirements based on the needs
- Manage information to fulfil defined needs and requirements for environmental information quality. This involves:
    - Assess the current situation with regard to information products and quality requirements
    - Develop strategies for the information quality management work, to ensure that information products are produced in line with quality requirements.
    - Establish, maintain and continuously improve information processes, e.g. change existing processes or introduce new processes based on the strategies that were developed.
    - Establish and maintain measuring and monitoring of the work, e.g. through information review.
- Educate and train involved personnel to support the work with defining and managing environmental information quality, to increase knowledge and understanding and to ensure that the personnel have relevant competence for their job.

The work with the three fundamental parts should be supported by management. Roles and responsibilities in the work should be well defined and known by all involved, and therefore the implementation must involve clear assignment of responsibilities for the different activities in information quality management. Routines should be implemented in existing management systems, such as quality and environmental management systems, to ensure maintenance and that the work will be part of the everyday work within the organisation.

Documentation of information is an integral part in information quality management efforts, to ensure that the relevant information to fulfil the needs and requirements of the information customers is captured. This must be considered all through the procedure.

Integration and coordination of information management for different environmental management purposes, e.g. EMS, LCA, DfE, etc., should also be considered when implementing and maintaining environmental information quality management. Coordination can simplify the handling of information, reduce costs for information and reduce or eliminate some information quality problems. For example, duplication of work where the same information is collected by different individuals, collection of information that is incomplete and that can consequently not be reused for different purposes, efforts with trying to find information that is known to be available but is not easily accessible. Better coordination of information is also in line with e.g. product oriented environmental management systems [16,17].

In the following, the different parts of the procedure are described in detail.

3.1 Define needs and requirements for environmental information quality

Before any environmental information quality management effort is started, one should first identify the needs of the users, i.e. the information customers. The needs should be expressed as information products, e.g. the type of report that is needed, and as information quality requirements for the information products. This establishes the customer focus, from which to base the further work with information quality management. It also determines the scope for the work with managing environmental information quality. Relevant dimensions of environmental information quality and a method for defining information products and information quality requirements are described in [18].

When defining information products and quality requirements, one should seek to implement a process for periodic follow up of needs and expectations, to ensure that the requirements that are applied are up to date and relevant.

3.1.1 Understand and identify the needs of information customers

The information customers and their needs and expectations are the basis for the work with environmental information quality management. Thus, the information customers must be known and their needs and expectations must be identified. The customers of environmental information are both external and internal. External information customers are e.g. customers, suppliers, shareholders, authorities, and trade associations. Internal customers are intermediate and final information customers along the information chain e.g. production, product development, and management.

The process of identifying needs is facilitated by a common understanding of what quality means. Most people have their intuitive perception of what is meant by quality. However, this perception generally differs between different individuals and therefore the understanding should be made explicit and it should be shared and accepted by those involved with environmental information management.

3.1.2 Specify and define information products and information quality requirements based on the needs

Based on the needs of the information customers, information products and explicit quality requirements is specified and defined, that can be managed throughout the information management chain. It is important to maintain a clear customer focus and carefully consider both current and future needs. The environmental information quality requirements should be defined and agreed upon in cooperation between providers and users of the information, to ensure that the quality requirements are feasible to fulfil and that the requirements are sufficient for users needs.

Information quality requirements should be defined as requirements on documentation, to ensure that the relevant information to assess and use the information in line with the needs is captured together with the data. To support the work with documentation, the documentation requirements should be expressed in terms of a well defined documentation format. The format provides a specification of the information product and facilitates a detailed specification of the quality requirements of the information product. The documentation format both serves as a checklist when acquiring and documenting the data, as well as facilitates interpretation and use. The format can also aid for users to explicitly articulate their specific information needs. An example of an environmental data documentation format is ISO/TS 14048 [19]. This format is developed for LCA, but is applicable also for information for other environmental management applications. A framework for structuring environmental information, that can be used as basis for developing and assessing formats are described by Carlson [20].

It should be stressed that information quality requirements can be specified at different levels. The general level is common and agreed requirements on documentation to allow for users to independently form an opinion of the relevance and appropriateness of the information for his or her purposes. Documentation requirements should be defined based on a long term perspective, be flexible and consider both current and future needs for follow up and verification. The next level is to also specify detailed requirements on the content of information in terms of e.g. indicators to be included, required precision of data, system boundaries, etc. This is needed when performing an LCA study or when developing an environmental report. The specification can be done at different levels. For example, when having specified which indicators that should be included, quality requirements can be set for the information that is used as basis for the indicator as well as the indicator result. In this way the controllability is increased, by having both well defined indicators and well defined quality requirements to measure and control the indicators.

3.2 Manage information to fulfil defined needs and requirements for environmental information quality

The defined environmental information products and quality requirements are the basis for developing management of information to fulfil the needs and requirements. The defined information products and quality requirements should be translated into requirements and specifications on the production of the information that can be managed throughout the different stages information collection, storage and communication.

3.2.1 Assess the current situation with regard to information products and quality requirements

Development of environmental information quality management should start from the current situation. An assessment of the current situation is therefore made based on the understanding of the needs and requirements of environmental information in terms of information products and information quality requirements. This is made to identify and assess existing processes for managing information. Also, data and reporting formats that are used should be assessed with regard to their ability to convey the relevant information according to requirements. Deficiencies should be identified and noted.

The assessment provide the basis for deciding whether the processes should be changed in some way or new processes needs to be introduced in order to fulfil the requirements. Thus, the assessment of the current status involves developing an understanding of the information management process, and should include a mapping of available information processes and identification of needs for new processes (see section 3.2.3). The management of environmental information is generally performed by different functions with different roles within the organisation, and the different tasks and communication surfaces within these functions should be identified.

3.2.2 Develop strategies for the information quality management work

The assessment of the current status is used as basis to develop strategies for the quality management work, to ensure that information products are produced in line with quality requirements. They are used for the implementation and maintenance of the quality management work. The strategies should describe how to proceed based on available resources, e.g. how to handle existing data that do not fulfil identified requirements, how to handle missing information management processes for collecting new data, etc..

The strategies should take their starting point in the current situation and be aimed to continuously improve the quality of information. They should involve a specification of how to establish and continuously improve information processes and how to monitor and measure performance. They should also consider and specify needs for education and training to support the work.

The choice of strategy generally depends on the type of information that is managed, e.g. if the data are collected internally or if they are collected from external sources such as suppliers or other stakeholders. For example, for data collected from external sources a strategy can be developed for implementing structured data documentation to ensure that the knowledge acquired from the source is captured for future use. For data collected internally a strategy can be developed for managing the original generation of data within production sites to ensure that they fulfil quality requirements. When developing strategies one must also take into regard practical constraints, such as technical, organisational, and economical conditions. For example, there may be measurement systems and routines missing for needed indicators, there may be organisational barriers that limit access to data, or there may be needed data that are too costly to collect. Possibilities for integration and coordination of information for different environmental management purposes should also be considered.

When developing strategies, there are different levels of management and use of information to consider:

- generation of information that is used as input for environmental management,
- using information in an environmental management method or tool to produce new information, and
- using the information for an environmental control decision.

In each level, the quality of information should be managed.

There are a number of practical methods and tools available within general total quality management that can support the development of the strategies, and aid with identifying sources of quality problems and finding ways to solve the problems. One example is the Deming cycle, which is a well known and widely applied tool. There are different descriptions available but on a general level the cycle involve the elements Define, Measure, Analyze and Improve or Plan, Do, Check, Act [14]. Essentially this involve defining the problem and identifying the causes, develop solutions to solving the problem and perform the solution, control if the measures have led to the desired improvement, and learn from the work to ensure that the same type of problem is avoided. The Deming cycle is used in as basis in the management systems ISO 9001 and ISO 14001.

The strategies should also consider the level of maturity with regard to problem awareness as well as general environmental information quality management commitment within the organisation. The maturity level of the organisation influences how strategies can be developed. Maturity levels are described for general quality management [12] and for software development [21]. These can be used to provide insight also when developing strategies for environmental information quality management.

3.2.3 Establish, maintain and continuously improve environmental information processes

To ensure that the needs and requirements for environmental information products are fulfilled, well defined environmental information management processes should be established, maintained and be continuously improved. Environmental information is generated in different information management processes. To be able to control and manage the quality of the information, it is important that these processes are well understood and defined. This enables work with improvement and facilitates integration and coordination of data collection for different purposes. Sources of quality problems can more easily be identified.

Environmental information management processes have a scope in terms of tasks and activities that are performed, an input in terms of an intermediate information product and an output in terms of a new intermediate or finalised information product. These inputs and outputs should be well defined in terms of content and requirements. Documentation should be established as an integral part of the processes, to ensure that the information is captured at the source when it is generated. It is difficult, costly and sometimes impossible to recreate the information at a later stage. The process in itself should also be documented and should involve a specification of the required input, the work tasks and routines within the process and the outputs, i.e. the results.

The PHASETS model can be used as basis for understanding the different processes and tasks involved with environmental information management [22]. The PHASETS model describes the different phases involved with environmental information management for technical systems. It consists of six phases where each phase describes distinct work tasks in information production with well defined communication surfaces. The model can both be used to benchmark and assess existing processes and as basis to develop and establish new processes. A description of how to implement the PHASETS model for information management in production sites is available in [23, 24]. PHASETS should be combined with process mapping to identify the specific processes involved. Process mapping is tool to get an overview and better understanding of the processes involved in environmental information management and how they are interrelated [25]. A process map provides a visualisation and an overview of the processes, functions and tasks involved, and the specific inputs and outputs of each process. The processes should furthermore be supported by appropriate tools that facilitate documentation and sharing of information. An example for the design for an information system that supports work based on PHASETS is described in [26].

3.2.4 Establish and maintain measuring and monitoring of the work

Measuring and monitoring of the performance of the environmental information quality management should be established and maintained, to ensure that quality requirements are sustained and to provide input to the work with continuous improvement.

Information quality review can be used as a tool to establish checkpoints where the performance is monitored. Review is performed to ensure and maintain that quality requirements are fulfilled, and can provide feedback to the work with information management to be used as basis for improvements. A fundamental idea in the procedure, and quality management in general, is to prevent quality problems at the source, by “doing the job right from the start”, thereby decreasing the need for inspection of quality and the need for rework of identified quality deficiencies. However, since environmental management is dependent on information that is developed in other contexts, and it may be difficult to introduce quality management in all these contexts, some type of quality inspection or review will be needed. A methodology for environmental information review, which can be used as basis, is described in [27]

3.3 Educate and train involved personnel to support the work with information quality management

Education and training is central to support the work with defining and managing quality, to disseminate knowledge and understanding for the different tasks involved in environmental information management and to increase competence. The importance of training should not be underestimated. Different roles in information management and different modes of knowledge are shown to have a great impact on data quality [28], and also different types of skills are important for data quality work [29]. Training sessions and manuals should be developed, and should be directed and adapted for the different functions in the environmental information management process. When introducing environmental information quality management it is important to express the work in the terminology used by the involved personnel and to both explain the purpose and the content of the work.

4 Results and discussion

The TQEIM procedure is intended to support quality management of environmental information for different environmental management purposes. It provides an explicit connection between experiences from the TQM domain and environmental management in terms of information management.

Parts of the procedure have been tested and implemented in research and development projects at the Swedish national competence center CPM, within the research group Industrial Environmental Informatics (IMI) at Chalmers University of Technology. CPM (Center for Environmental Assessment of Product and Material Systems) is a research forum, where research is performed in collaboration between Chalmers University of Technology and industrial companies. This section provides some results and experiences from this work. Experiences from this work have also been used in the description of the different parts of the procedure.

Two projects are especially discussed; the establishment and maintenance of the Swedish national LCA database SPINE@CPM, in the following referred to as the "LCA database project" and a project aimed at implementing a methodology for structured data management within production plants in the forest industry, referred to as the "forest industry project". These two projects have included how to explicitly define environmental quality requirements and how to manage information to fulfil defined requirements. The LCA database project involved defining a general quality agreement in terms of documentation requirements, structured environmental data documentation to manage and document available information from different sources, and information review to monitor performance and maintain quality requirements [30]. The forest industry project involved defining detailed information requirements, and management of production of data and information within production sites, to manage and document data when it is originally acquired and compiled at production sites [31]. The projects have also included developing and providing training and education to facilitate and support the practical work with implementing and maintaining environmental information quality management, see for example [24, 32, 33]. The work in the project has supplied experiences for how systematic work quality management of environmental information can be established and maintained.

4.1 Define environmental information quality

In the LCA database project a quality agreement for the data to be published through the database was defined in cooperation between the industrial partners of CPM and Chalmers University of Technology. This agreement specified quality requirements as detailed documentation requirements, expressed in the SPINE and ISO/TS 14048 data documentation format [34, 35]. The documentation requirements concerned information that needs to be available for users to independently assess the quality and usefulness of the data, and were based on data quality requirements specified in the ISO 14040 series of standards. The agreement established a common platform from which to work, and has been used as a basis for industrial environmental information management for different applications within companies and other organizations. For example, they have been used in the forming of LCA data networks such as the national network Sirii [36], in company internal databases for different environmental management purposes, and for documentation and review in the Swedish system for certified environmental product declarations (EPD) [37, 38]. In this work, they have contributed to improved quality of environmental data in terms of transparency and reviewability. The general procedure have also been used in the development of an information system for toxicology impact assessment OMNIITOX [39]

In the forest industry project, the quality agreement developed in the LCA database project was used as basic requirements on documentation. This was supplemented with a survey of stakeholder needs and expectations, to provide detailed requirements for the information to be produced [23]. Experience from this project showed that it is easy to neglect the importance of a thorough survey of stakeholders and their needs in terms of information products and quality requirements, but if it is not performed well it is difficult to manage the work and acquire relevant information. It is the starting point and basis for the quality management work. A difficulty when identifying needs, however, is that the customers of environmental information are sometimes not well defined. There are information that intended to respond to user needs but that actually do not respond to customer requirements, e.g. EPD (environmental product declarations) is a tool created by environmental experts, that often is referred to as too complex by the actual intended users. Also, it may be difficult to specify information quality requirements, due to the fact that requirements are vague and the actual information customers do not exactly know what they want. Education of the customers can be needed in order to identify relevant requirements.

From the work in both projects it has also been found that there is often an asymmetry between the needs and requirements of the information customers on the one hand, and the information that the providers of the information want to or can provide on the other hand. For example the customers may need detailed information about how the numerical data have been acquired, in order to correctly interpret and use data, but the providers may not have sufficient resources to acquire and document this information. This needs to be acknowledged and handled.

4.2 Manage quality of environmental information

In the two projects, different strategies was used for managing quality of information to fulfil quality requirements; management of information from different data sources through data documentation and managing the quality of data during production of data at production plants. The choice of strategy depends on which part of the data and information management chain that is to be managed, for example when acquiring environmental information from different information sources, or when producing environmental information within production plants to be used as input for different environmental management purposes. The strategies have included systematic work procedures and methods for environmental information management to achieve and improve the quality of information used as basis for environmental assessments.

The PHASETS model was tested in the forest industry project to benchmark and develop information processes within production plants [31]. In the project, PHASETS was used as basis for the development of a work procedure for implementing structured data management. The model was found to be effective for understanding the process of environmental information management in terms of distinct work tasks and communication surfaces. The PHASETS model can also be used to improve current processes and when developing and designing new processes. The process orientation also facilitates for identifying how to coordinate environmental information management for different purposes. The tests increased the control of the environmental information management process and revealed improvement potentials in all plants. This knowledge can be used to improve the process, in order to improve the resulting data. However, improvements may be difficult to introduce due to the fact that some of the processes involved in supplying the information do not primarily have environmental issues in focus, e.g. production monitoring, etc.

Information review to monitor and maintain quality was developed and introduced LCA database project in 1997 and has since then been applied on all datasets published through the SPINE@CPM database. The review is performed based on the quality agreement and has contributed to that the quality of the documentation of published data has been held at a stable level. The review has also provided feedback to the people providing the datasets, which has contributed to support their work with improving quality of documentation. The methodology has also been used within company internal databases as well as basis for establishing the requirements for review in the Swedish system for third party certified environmental product declarations [37, 38].

4.3 Educate and train to support environmental information quality management

Training and education has been a central element in the projects to raise awareness and competence, and have included supervision, specific courses, and manuals to support the work. The efforts have been important to increase understanding of both what information quality means as well as how information quality can be achieved. They have resulted in increased understanding of environmental information quality issues within the participating industrial organisations and have contributed to improved information quality.

4.4 General experiences

Much of the work with environmental information quality management in the projects has been initiated by the practitioners with the responsibility to collect and generate environmental information, based on the fact that quality of the information has been stated as a concern in their daily work. However, they have had difficulties to convince both management and other employees, in the production or other core processes to implement or change their processes to provide environmental information. A general problem for establishing environmental information quality management is a lack of problem awareness at different levels in the company, for example management, production, etc.

It may be perceived that it is cheaper to continue “business as usual” than to implement environmental information quality management. However, some resources for environmental management work are in fact used for getting around poor information quality. For example, resources that are spent on redoing data acquisition that has already been done elsewhere in the organisation, trying to find information that is available but is not easily accessible, efforts with supplementing incomplete information, investigating the basis for the received information due to poor documentation, etc are resources that do not contribute to better environmental management of the organisation. There is, however, a need for a better understanding of the costs and benefits of environmental data quality. For example the overview of data quality costs on a general level, discussed by Eppler [40], could be used as basis also for estimating costs of environmental information quality.

5 Conclusions

The general principles of total quality management (TQM) can be applied for defining and managing the quality of environmental information to support industrial environmental management. The TQEIM procedure described in this paper can be applied for implementing and maintaining quality management of environmental information based on these principles. The procedure is flexible to accommodate different level of ambition, maturity and available resources, and is intended to facilitate systematic work with continuous improvement. It can be applied equally well on a specific environmental assessment method and tool as to the entire environmental information system within an industrial organisation. The full potential with regard to real quality improvement and reduction of costs for information is however envisaged when information quality management for different purposes are coordinated and integrated. The fact that procedure is based on TQM can facilitate implementation in industrial organisations that already have an established and systematic quality management work in line with TQM principles.

Well defined and explicit information products and quality requirements are an important foundation for effective information quality management. The needs and expectation of the involved personnel should be explicitly known, in terms of information products and quality requirements, and requirements should be identified and defined in cooperation between the providers and the users of the information. Based on this, the quality of the information can be systematically managed.

Systematic work with environmental information quality management can increase the controllability of the organisation with regard to environmental issues, resulting in more effective environmental management.

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Paper VI

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Dimensions of information quality for industrial environmental management

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Abstract

This paper aims to provide a description of what environmental information quality means and how it can be described and defined. A review of different approaches to defining information quality is presented, both for specific environmental management methods and tools and for business information systems and databases. A definition in terms of a set of quality dimensions is proposed, which incorporates actual requirements and recommendations in the ISO 14000 series of standards and a user-based empirical definition of quality. The set are intended to be generally applicable for industrial environmental management work, i.e. for both process- and product-related data and information. A procedure for defining information quality requirements using the dimensions is also described.

Keywords: Information quality, industrial environmental management, information quality requirements

1 Introduction

Environmental information is used as the basis for decisions at different levels in the industrial society to steer towards sustainable development. If the information is not of sufficient quality, the ability to steer will be hampered. Thus, the quality of the information impacts the possibility to take sound decisions for prioritisations and measures. In this context, environmental information is defined as quantitative information describing both the environmental performance of a product or a process, and concerns information used as input for different environmental assessments as well as the information generated in the assessment to support decisions.

The quality of information depends on how the information has been managed during the generation of the information. People involved in generating and using information generally have an intuitive perception of what they consider as information quality. However, this perception may differ between individuals and contexts, and often the perception of quality is more or less implicit. This fact creates communication problems between the providers and the users of information. The information provider may generate information in line with his or her perception of quality, which may be based on an intuitive understanding of what the user wants and requires, but it is quite likely that the user's perception and actual requirements differ from the provider's perception.

To facilitate environmental information management and avoid communication problems, the perception of quality must be made explicit, and a common view and understanding of information quality requirements should be established, accepted and shared between the providers and users of information. It is difficult, if not impossible, to work towards and fulfil quality requirements and expectations if they are not explicitly known. Thus, a shared understanding and knowledge of what quality means is needed in order to systematically manage and control environmental information quality in every stage of the generation and use of information. Well defined and relevant quality definitions in terms of dimensions and requirements need to be established.

This paper is aimed to give an overview of existing definitions of information quality and propose a definition that can be used as basis for information quality for industrial environmental management. A procedure for defining environmental information quality requirements based on the proposed dimensions is also described.

2 Views and approaches to defining information quality

There are a number of different approaches for how to describe and define quality for data and information. Definitions are generally based on definitions of product quality adapted to information. On a general level data and information quality may defined as e.g.:

- "characteristics of data that relate to their ability to satisfy stated requirements" ISO 14044 [1], which is based on the ISO 9001 definition of product quality as "degree to which a set of inherent characteristics fulfils requirements"[2]
- "data that are fit for use by data consumers" [3] which is in line with the well known definition of product quality as "Fitness for use" [4],
- "data that meet specifications or requirements" [5] in line with the definition for product quality as "conformance to requirements" [6]
- "consistently meeting knowledge worker and end-customer expectations" [7]

Definitions of quality are based on different viewpoints or perspectives. Garvin identifies five principal approaches to defining product quality [8]. These have reached a wide acceptance in general quality management literature and they are useful also for understanding and describing information quality. Adapted to information quality, the five approaches are [9]:

- *User-based:* information quality lies "in the eye of the beholder". Individual consumers of information have different wants, needs and cognitive styles and the information sources that best satisfy their preferences are the ones they regard as having the highest information quality.
- *Production-based:* information quality is identified as "conforming to requirements". Associated with meeting requirements and with doing the job right the first time within budget and on time.
- *Product-based:* information quality is viewed in precise and identifiable terms. Information quality is directly associated with the characteristics of the information products and can be measurable and quantifiable.
- *Value-based:* considers tradeoffs between competing criteria, where only one of which is information quality.
- *Transcendent:* assumes that information quality is absolute and universally recognizable. Information quality is synonymous with excellence and is both timeless and enduring, with characteristics which rise above changing tastes and styles.

It is important to recognize that these different approaches exist in order to understand what information quality means and how it can be defined. Most definitions of information quality fall within one of the above mentioned approaches. For example, the ISO 14041 definition of data quality (see above) is based on a product-based view, the Wang & Strong definition is based on a user-based view and the Kahn & Strong definition is based on the production-based view.

The different approaches to defining quality can be conflicting, but each has a role since they provide different perspectives of quality, and reliance on a single definition can be a source of problems. Thus, when defining information quality requirements, an overall perception of what quality means can be achieved by combining the different approaches. For example, a user based approach is used to identify quality characteristics that the end-user (information consumer) wants, a product based approach is used to translate these characteristics into requirements on the information, and a production based approach is used to organize the generation of the information product to fulfil the requirements (example adapted from Garvin [8]). The knowledge of the coexistence of these different approaches for defining information quality can be used to ensure that all possible quality dimensions are considered, and to disaggregate the concept of quality, in order to identify specific requirements.

3 Review of information quality definitions for environmental management and for business information systems and databases

In light of the different approaches to defining quality, it is not surprising to find that there is no consensus on a definition of data quality and set of data quality dimensions that are universally applicable. There is a wealth of quality definitions and sets of criteria or dimensions in the literature developed for different applications.

A review was made of different definitions of quality dimensions, from literature describing industrial environmental management methods and tools, and from literature describing information quality for business information systems and databases. Business information systems and databases are relevant for environmental management since environmental information is partly acquired from such, but generally also specific databases and tools for environmental management are used such as stand-alone software supporting a specific assessment method.

Wang & Strong identifies three major ways in which data and information quality is defined in the literature; *intuitively*, *theoretically* and *empirically* [3]. In *intuitive* definitions, information quality dimensions are selected based on the experience or intuitive understanding of one or several individuals and they may combine the different approaches described above, or be based on a specific approach. Most available definitions of quality are intuitive. *Theoretical* definitions are based on the production-based approach of quality, and focuses on how data may become deficient during the data manufacturing process. There are however few such examples available in the literature. *Empirical* definitions are user-based, gathered by asking data consumers what characteristics they use to assess if data are fit for use in their task. They are intended to capture the needs expressed by information customers and thus to capture the voice of the customer.

3.1 Environmental management

Definitions of information quality for environmental management are intuitively defined and application specific, i.e. quality requirements are specified for a specific tool or method such as environmental and sustainability reporting, life cycle assessment (LCA), eco-labelling, Design for Environment (DfE), risk assessment, emission trading etc. Examples are data and information quality requirements specified in the ISO 14000 series of standards and in the Global Reporting Initiative (GRI) guidelines for sustainability reporting. No theoretically or empirically defined definitions have been found for environmental management.

The definitions are generally defined from a product-based perspective, specifying quality characteristics of the data and information that is used and reported. The quality characteristics vary between the different methods and tools and are selected and specified by experts developing the methods or tools, often without a discussion as to why specific characteristics are chosen and why they are relevant, often without a clear definition. An analysis of the ISO 14000 series of standards, which many industrial organisations apply as basis for environmental management, showed that there is a lack of a consistent and coordinated view of information quality for the different methods and tools described by the standards [10]. Table 1 provides a list of quality aspects that have been found in the normative documents in the ISO 14000 series that shall or should be considered when applying different environmental management methods and tools. There is, however, generally no specific guidance or description on how to interpret the aspects for the purpose of the specific tool or method. The list in table 1 is based on the current and available documents in August 2006.

Table 1. Quality aspects for information that shall or should be considered when applying the different systems, methods or tools described by the ISO 14000 series of standards and documents. The number indicates in which standard or document that the aspect is included.

Access to information: 14021	Accuracy:14015, -20, -21, -24, -25, -44, -62, -63, -64 part 1-3	Adequacy: 14031
Adequately explained: 14004	Applicability 14063	Appropriateness: 14004, -15, -20, -44, -63, - 64 part1-3
Availability: 14001, -04, -20, -24, -31, -44, -64 part 2	Clarity: 14044, - 63	Comparability: 14004, -25
Completeness: 14025, -40, -44, -64 part 1-3	Comprehensive: 14040, -44	Consistency: 14001, 04, -25, -40, -44, -63, -64 part 1-3
Credibility: 14025, -63	Integrity 14064 part 3	Known quality: 14024
Meaningful: 14020	Not misleading: 14020, -21, -24, -25, -63	Objective: 14004, -25, 64 part 3
Precision: 14015, -24, -25, -44	Presented in consistent form: 14004, -40	Relevance: 14015, -20, -21, -25, -31, -44*, -63, -64 part 1-3
Reliability: 14001, -04, 15, -21, -31, -40, -44, -63, -64 part 2-3	Representativeness: 14025, -44, 64 part 1	Reproducible: 14004, -20, -21, -24, -25, -44, -63, -64 part 1
Responsive: 14031, -63	Scientific and statistical validity and verifiability: 14031	Security: 14064 part 3
Substantive: 14031, -63	Sufficient: 14015, -20, -31, -40, -44, -64 part 1-3	Suitable presentation: 14063
Traceable: 14004, -63	Transparency: 14024, -25, 40, -44, -63, -64 part 1-3	Truthful: 14063
Unbiased: 14044	Uncertainty: 14025, -40, -44, -64 part 1-3	Understandable: 14004, -20, -31, -40, -44, -63
Useful: 14004, -31	Verifiable: 14004, -15, -20, -21, -24, -25, -31, -64 part 1-3	

* the aspects technology, time related, and geographical coverage in the ISO 14044 standard have been interpreted as *relevance* in relation to the goal and scope

An attempt for a more generally applicable definition of environmental information quality was developed within the work with establishing the Swedish national database for life cycle assessment (LCA) data within CPM. CPM (Center for Environmental Assessment of Product and Material Systems) is a Swedish national competence center at Chalmers University of Technology, where research is performed in cooperation between academy and industry. It describes environmental information quality in terms of a number of dimensions, categorised according to the general information quality aspects reliability, accessibility and relevance [11]. The dimensions were developed for LCA, but have been found to be generally applicable and have been used as basis also when developing information management and information systems for other industrial environmental management applications, such as environmental management systems (EMS) [12], Design for environment (DfE) [13], risk assessment [14], emission trading [15], toxicology impact assessment [16], etc. The dimensions are intuitively simple to understand, and have been used for raising awareness regarding data quality issues in environmental data management within several industries. In these projects, the value of disaggregating the concept of quality has been evident. However, due to the fact that the dimensions are intuitively defined, it is difficult to judge its completeness and representativeness when applied for different types of environmental information.

The consequence of different definitions and requirements is that it is difficult for organisations to generate and coordinate environmental information to support the different methods and tools with data and information in line with the quality requirements.

3.2 Business information systems and databases

Information quality definitions from literature for business information systems and databases are intended to be application independent for any business information and domain. In the available definitions for business information systems and databases, there seem to be an implicit convention where they are divided into two sections; a category section and a criteria or dimensional section, i.e. individual dimensions are grouped into a few information quality categories. Such grouping is useful to facilitate understanding of the individual dimensions and to explain and show interdependencies between different dimensions. Also, the number of dimensions in the definitions is generally limited in order to be manageable.

The categories vary somewhat between the definitions, but four information quality categories can in principle be distinguished, that are more or less common for the definitions found in the literature. Thus, there is some consensus in the literature that these categories are relevant. The categories are (based on Wang & Strong [3]):

- *Intrinsic or inherent quality:* The extent to which data values are in conformance with the actual or true values; i.e. information has quality in their own right, independent of how the information is used.
- *Contextual quality:* The extent to which data are applicable to the task of the data user, i.e. quality must be determined based on the task at hand.
- *Representational quality:* The extent to which data are presented in an intelligible and clear manner, i.e. quality is dependent on how information is represented and presented.
- *Accessibility quality:* The extent to which data are available or obtainable, i.e. that information is accessible for the intended users.

This type of categorisation is generally not used in definitions for environmental management. The definitions in this domain rather specify a list of quality requirements or aspects to be considered.

There are examples of intuitive, theoretical or empirical definitions that all describe different definitions in terms of information quality dimensions or criteria. Notable intuitive definitions are the ones described by two renowned practitioners within the area; Larry English [7] and Tom Redman [17]. With regard to examples of theoretical approaches, Wand & Wang proposes four intrinsic data quality dimensions based on analysis of representation mapping, i.e. if the information is correctly represented in an data format or information system [18]. There are also examples of theoretical definitions where information quality dimensions are derived from semiotics, the branch of linguistics that study signs and how meaning is made and understood [19, 20]. An example of an empirical definition is the one developed by Wang&Strong, where a set of data quality dimensions was developed through a comprehensive survey to identify data quality dimensions that are important to data consumers [3]. This definition has been widely applied in data and information quality literature. Eppler defined data quality dimensions by using the 50 most cited information quality aspects, and consolidating them into four groups, by applying a systematic procedure for reducing the number of dimensions [21].

Although these different definitions are developed to be generally applicable for any business information, they are difficult to apply directly on environmental information. As discussed by different authors, see e.g. [20, 21], intuitive definitions can be adapted to the specific task, but they depend on the knowledge and experience of the practitioner, and the resulting dimensions may not be representative. Theoretical definition can provide rigor, but they generally do not capture the full range of relevant dimensions. Empirical definitions can capture the information users' real requirements, but the correctness or completeness of the dimensions cannot be proven, since the importance of different quality characteristics differs depending on the task in which the information is to be used. The resulting set may not be consistent or free from redundancies. Also, information consumers may not always be able to articulate what information quality dimensions that is important to them.

From an environmental information perspective, some of the general definitions also include some overly technical dimensions, and are described from the perspective of information system professionals, to be used in the design and maintenance of information systems and data formats, rather than from the perspective of the professionals working with the content of the information systems, i.e. the providers and users of the information.

4 Dimensions of environmental information quality

A definition of environmental information quality in terms of set of dimensions has been developed, that are intended to be generally applicable for industrial environmental management. The aim is that the definition can be used as basis for forming a consistent and coordinated view of environmental information quality applicable for environmental management in general. This can be used when developing and implementing environmental information quality management and when setting specific quality requirements. In the development of the dimensions, the following general requirements were formulated. They should be:

1. Based on quality requirements that are applied for information for different environmental management systems, methods and tools
2. Practically applicable and manageable
3. Intuitively simple to understand
4. Independent of format and way in which the information is handled
5. Possible to establish and manage in all stages of information management

The general definitions of information quality for business information and databases do not fulfil the first requirement. They are intended to be generally applicable for any business information and it is difficult to judge their representativeness and completeness, since the importance of different dimensions differs depending who the information customer is and for what the information will be used. Dimensions that are important specifically for environmental information could be overlooked. An alternative approach could be to use the list of identified information quality aspects in the ISO 14000 series of standards, since it does provide relevant aspects to consider for information used in environmental management, but this list is not manageable. It contains many aspects that overlap. Another approach is to use any of the intuitively defined quality dimensions for a specific application within environmental management, and apply them also for other applications, but then there is a risk that important quality dimensions for different methods and tools are neglected.

4.1 Basis for the dimensions

The approach chosen for the development was to combine a relevant general information quality definition developed for business information systems, with requirements and recommendations described in different methods and tools for environmental management. The aim is to capture the actual requirements and recommendations according applied in environmental management and put it into general and coherent definition, by making use of insights from general information quality literature.

The developed set is based on the quality aspects described by the ISO 14000 series of standards (see table 1) and the Wang&Strong user-based definition of information quality [3]. The ISO 14000 series of standards provide environmental information quality requirements for different environmental management methods and tools applied within industry. The documents have been developed in international consensus and they have a broad acceptance. The Wang & Strong definition of information quality was selected as foundation due to the fact that it is an empirical approach aimed to capture the voice of the customer, and it has reached acceptance and has been adopted in several approaches for information quality management. The Wang&Strong definition also includes the general categorisation of information quality, found within the general information quality management literature. As discussed above, the other definitions of dimensions in information quality literature for business information systems and databases are either intuitively defined or contains some overly technical dimensions, primarily aimed for information system development.

4.2 Development of the dimensions

In the development, the quality aspects found in the ISO 14000 series of standards (see table 1) have been interpreted, compiled and grouped based on the Wang&Strong definition. The intention is to ensure that all relevant aspects according to ISO 14000 series are considered and included. Table 2 shows how this has been performed. The first two columns in table 2 show the Wang&Strong categorisation and dimensions, the third column shows how aspects in the ISO 14000 have been grouped, and the last column provides the resulting dimensions based on the comparison and grouping of the two approaches. In the grouping, synonyms or closely related terms have been consolidated into one dimension. For example the aspects “accuracy”, “precision”, “uncertainty” and “truthful” have been interpreted and consolidated as “accuracy”. The number of different standards in which a specific aspect is used has also been considered in the consolidation.

Table 2. Compilation and grouping of quality aspects from ISO 14000 series based on the Wang&Strong general definition of data quality into environmental information quality dimensions

Wang&Strong		**ISO 14000 aspects**	**Proposed dimension**
Category	**Dimensions**	**Grouping**	
Intrinsic quality	Accuracy	Accuracy Precision Uncertainty Truthful	Accuracy
	Believability	Credibility	Credibility
	Reputability	*No direct correspondence in ISO 14000*	Reputability
	Objectivity	Reproducible Integrity Objective Unbiased Not misleading	Reproducibility
		Verifiable Consistency Scientific and statistical validity and verifiability	Verifiability
Contextual quality	Appropriate amount of data	*No direct correspondence in ISO 14000*	Appropriate amount of data
	Completeness	Completeness Comprehensive Sufficient	Completeness
	Relevancy	Relevance Appropriateness Adequacy Applicability Representativeness	Relevancy
	Value added	Useful Meaningful	Useful
	Timeliness	*Corresponds to the relevance aspect time-related coverage in the ISO 14044 standard, and are an implicit aspect also in other standards*	Timeliness
Representational quality	Consistent representation	Presented in consistent form	Consistent presentation
	Interpretability	Transparency Adequately explained Known quality Traceable	Transparency
	Ease of understanding	Understandable	Understandability
	Concise representation	Clarity Suitable presentation	Clarity
Accessibility quality	Accessibility	Access to information	Accessibility
	Access security	Availability Security	Availability

The following aspects in ISO 14000 are not included in table 2:

- The aspect *Reliability* is interpreted as corresponding to the category "intrinsic quality", and is considered as dependent on the other intrinsic dimensions.
- The aspects *Substantive* and *Responsive* belong to the contextual category, i.e. they are determined by the user. They are interpreted as related to specific relevancy aspects of the data, but they are not included as specific aspects.
- The aspect *Comparability* is application specific, i.e. it depends on the purpose whether comparability is an important aspect. This is therefore excluded from the grouping. The quality aspect objectivity is also application specific, and it should be recognized that there are environmental information that can be considered as subjective. This aspect has been kept in the grouping and has been interpreted and grouped as relating to the reproducibility of the information.

The categorization and dimensions described by Wang and Strong were found to be a good foundation for environmental information. However, terms used for some dimensions were replaced by related terms that are used for environmental information, e.g. the term "believability" was replaced by "credibility". One new intrinsic dimension was introduced, "verifiability", due to the fact that it is specified according to several ISO 14000-standards, and can be considered of special importance for environmental information. The dimensions "reputability" and "appropriate amount of data" in Wang&Strong have no direct correspondence in a quality aspect according to any of the documents in the ISO 14000 series. They have still been kept in the definition, due to that these aspects are perceived as important by data consumers. A difficulty in the compilation and grouping was that the dimensions in Wang&Strong and the ISO standards are not very well defined. The interpretation of quality aspects as related terms is made explicit in table 2, but it should be stressed that the result is somewhat dependent on the interpretation and understanding of the author.

This definition incorporates requirements specified in also other environmental management approaches. For example, the GRI (Global Reporting Initiative) guideline is a de facto standard on sustainability reporting developed through stakeholder consultations. Version 3 of these guidelines released in October 2006 includes six principles for defining information quality, to be considered when developing sustainability reports [22]. The principles are: balance, comparability, accuracy, timeliness, clarity and reliability. The "balance" principle concerns that the report should provide an unbiased picture of the reporting organisation´s performance. The definition is also incorporates the dimensions developed and applied at the national competence center CPM (see section 3.1)

4.3 Description of the dimensions

The environmental information quality dimensions derived in the previous section uses the categorisation of quality dimensions that are more or less common for all definitions in information quality for business information systems and databases, described in section 3.2. A description of each dimension is provided in table 3.

Table 3. Description of the dimensions of environmental information quality

Category	Dimension	Description
Intrinsic quality	Accuracy	conformity of the information to its actual (true) value or phenomena.
	Credibility	the believability of a statement and the ability of the observer to believe that statement
	Reputability	the trustworthiness of the source of the information
	Reproducibility	the information is derived using reproducible methods and is unbiased
	Verifiability	the ability of the information to be verified
Contextual quality	Appropriate amount of data	the information is appropriate for the task at hand
	Completeness	all information needed for the task are available
	Relevancy	the information is relevant to the task at hand
	Useful	the information is useful for the task at hand
	Timeliness	the information is delivered in time and the age of data is appropriate for the task at hand
Representational quality	Consistent presentation	the information is presented in a manner appropriate for use, in a way that can be interpreted and understood by the users
	Transparency	the information can be interpreted by the users, through a description of assumptions, etc used in generating the information
	Understandability	the information can be understood by the users
	Clarity	the presentation of the information is clear
Accessibility quality	Accessibility	the information can be accessed and used
	Availability	the information is available to the users

It should be noted that there are interdependencies between the categories and the different dimensions. For example, when assessing the relevance for the task generally the accuracy of the information is important, to be able to assess the relevance and accuracy the information needs to be understandable, and to be able to understand the information it needs to be accessible.

5 Using the quality dimensions in environmental information quality management

The proposed set of dimensions of environmental information quality described in the previous section can be applied to facilitate a broader understanding of what environmental data and information quality means. Such an understanding can facilitate discussions on environmental information quality requirements for different purposes and can aid with supporting users to articulate information needs and expectations to ensure that relevant quality aspects are considered. They can be used as basis for defining and assessing quality requirements for environmental information management and systems, and be used when developing data formats for data collection, storage, and communication.

In the following subsections a procedure is described for how the proposed dimensions can be used for setting specific environmental information quality requirements, e.g. when applying different environmental management methods and tools or for the entire environmental management efforts within the organisation.

5.1 Defining environmental information quality requirements

To systematically manage the quality of environmental information and use available resources for information management efficiently, quality requirements should be well specified and defined, and be well known by all involved in the generation and use of the information. Based on specified information quality requirements, information processes for data collection and processing can be established and maintained that ensures that the requirements are fulfilled. The environmental information quality dimensions described in this paper can be used as basis when setting such quality requirements.

A practical and feasible procedure to support the work with defining environmental information quality requirements is to:

- Identify the users of information and their needs, requirements and expectations
- Translate the identified user needs and expectations into specific information and documentation needs, and express the information needs in terms of a well defined data documentation format, i.e. as documentation requirements.

The procedure is in line with the general idea behind Quality Function Deployment (QFD), which is a quality management tool for translating customer expectations and needs into detailed quality requirements, which in turn is translated into detailed specifications on the product. A description of how the quality of environmental information can be managed using total quality management principles, methods and tools is available in [23].

5.1.1 Identify user requirements and expectations

Environmental information quality requirements should be based on the needs and expectations of the users of the information. The specific requirements and needs of each user should be identified and documented. Both internal and external users of environmental information should be included, e.g. production, product design, customers, authorities, shareholders, etc. The requirements should be set in agreement between users and providers of the information in the context of both parties, to ensure that they both are relevant for use and feasible to fulfil.

When defining requirements it is generally difficult to take all quality dimensions into consideration. Depending on the application of the information, the importance of different dimensions will vary, and a trade-off between different requirements needs to be made due to different constraints, for example organizational, economical, and technical. The trade-off should be made consciously; taking into account the current and future uses of the information and should consider possible consequences from the choice. One should for example consider how the information may be stored and used for follow up in the future, if the information can be used for other purposes than it was originally acquired, etc. Thus, to enable an informed trade-off, priorities with regard to importance of different requirements should also be identified.

It is recommended to establish a co-ordinated view of quality for the environmental management work and the different environmental methods and tools that are applied. The information process with the most rigorous requirements can be used as the target level for all other processes. It should also be recognised that different dimensions have different roles throughout the information chain, in collection, processing, and communication.

5.1.2 Translate identified user needs and quality expectations into information and documentation needs and requirements

User needs and requirements should be translated into specific and concrete information and documentation needs, i.e. as information that needs to be available to fulfil the requirements and allows for assessment of the relevant quality aspects. This provides a clear connection between quality dimensions and requirements and actual information content.

A practical and efficient way of making the information and documentation needs concrete and manageable is to express the information and documentation needs in terms of a well defined data documentation format that is shared by providers and users of information. A data format describes the organization of information according to preset specifications in terms of concepts and relations between concepts. The format provides a common language for the information, and facilitates both documentation and interpretation of the information, as well as review and verification. An example of an environmental data documentation format is ISO/TS 14048 [24].

The data documentation format can be seen as a product specification of an environmental information product. The quality requirements can then be interpreted as desirable properties or characteristics of the content of the information product. It is important that the chosen format allows these properties to be well represented, and that the format can accommodate and handle the defined information and documentation needs, in line with the specified quality requirements. The format should be well structured and yet flexible, be based on the user needs and requirements, and it should facilitate and support the tasks in which the information is collected, used and communicated. If the format does not fulfil these requirements, there is a risk that restrictions and limitations in the format could force users to define and specify quality requirements that are not relevant or sufficient for their needs, or that the format does not support the tasks and consequently information providers and users will have difficulties in using it. Well-defined formats support the work, while badly defined formats that do not accommodate or do not correctly represent the needed information can obstruct quality. A framework for structuring environmental information, that can be used as basis for developing and assessing data formats are described by Carlson [25].

Information quality requirements can be specified at different levels. Common and agreed documentation requirements can be considered as a fundamental level and a prerequisite that enables interpretation and assessment of different quality aspects. The next level is to specify detailed requirements on the content of the information for the specific application, e.g. in terms of indicators to be included, required precision of data, system boundaries, etc.

6 Results and discussion

The set of dimensions proposed in this paper have not yet been used as basis for environmental information quality management in practice. However, the work with applying the intuitively defined dimensions of quality in different information management projects at the competence center CPM (see section 3.1) indicates that such a definition can efficiently support work with environmental information quality management. The value of disaggregating the concept of environmental information quality in terms of specific dimensions has been evident.

The general procedure for identifying information quality requirements and expectations, and based on this define information needs and express them in an data documentation format have been used in different environmental information system and database development projects, such as the Swedish national LCA database [26] and the development of the OMNIITOX information system for toxicology data [27]. In the work with the Swedish national LCA database, quality requirements for the data to be published through the database were identified in cooperation between representatives from the different partners of CPM, based on industrial requirements and data quality requirements in the ISO 14040 series of standards. The requirements were translated into information and documentation needs and specific information and documentation needs were expressed as specific documentation requirements in terms of the SPINE [28] and ISO/TS 14048 data documentation formats [29]. This work has shown that expressing quality requirements in terms of a common and structured data documentation format is an efficient method for users to explicitly express their information needs and to make requirements concrete and manageable. For example, the abstract concept of “technology coverage” in the ISO 14040 series was translated into a detailed documentation requirement that technology should be described in terms of scope and content. This made the work with information quality concrete. By using a common format, communication and interpretation is also facilitated, since the format provides a common language and specification for how to document and interpret the data, and data may easily be communicated between two parties sharing this common language. Relevant information to enable an assessment of the data is communicated together with the data.

7 Conclusions

A better understanding of what quality means is essential in order to be able to discuss and communicate environmental information quality issues, to use as basis for work with systematic management of the quality of information during generation, storage and communication. The viewpoints for defining quality and the proposed dimensions of environmental information quality described in this paper can be used for establishing a coordinated view of quality.

The dimensions can be applied as basis to get an overview of both implicit and explicit information quality requirements, and for establishing explicit and harmonized requirements for information quality for different environmental applications. The requirements should be based on stakeholder needs, both external and internal. With explicit quality requirements it is possible to develop strategies to manage and improve the quality, and use available resources efficiently and effectively. Explicit quality requirements, together with structured management of environmental information to fulfil the requirements, will increase the credibility of the environmental information that is acquired and communicated.

It is in theory possible to generate data and information that fulfils all quality dimensions. However, this is generally too costly to produce, and a trade-off needs to be made. A better understanding is needed of how to make the trade-off between quality requirements with regard to the decision for which the information will be used, and with regard to the resources needed to produce the information. A better understanding is also needed for how to effectively achieve information that fulfils some of the quality dimensions, for example “understandability”. Cognitive science can provide the basis for developing such.

Increased understanding and knowledge of what information quality means can in itself lead to improvements in the quality of information. With this understanding, quality issues can be kept in mind when generating, assessing and communicating information.

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