Life Cycle Assessment Ontology

Marisa Bräscher[1], Fernanda Monteiro[2], Alessandra Silva[3]

[1] University of Brasília, Brasília, Brasil. marisab@unb.br.
[2] University of Brasília, Brasília, Brasil. fernanda.s.monteiro@gmail.com.
[3] Brazilian Institute for Information in Science and Technology (IBICT), Brasília, Brasil. alessandram@ibict.br.

Abstract

In this paper, the domain studied concerns the Follow-up of Life Cycle Assessment (FLCA) which, according to NBR ISO 14040 standard, studies environmental aspects and potential impacts during the life cycle's product, that is, from acquisition of raw material, going through production, use and disposal. From the characterization of domain and identification of knowledge already available, a methodology for elaboration an ontology is proposed, aiming at the information organization about FLCA. The ontology of it has to meet the needs of the project Life Cycle Inventory for environmental competitiveness of Brazilian industry, coordinated by Brazilian Institute for Information in Science and Technology (IBICT). The objectives defined for ontology are: to enable acquisition, representation and handling of FLCA knowledge; to structure and organize knowledge libraries; to disseminate Brazilian terminology standardized in FLCA area, whose methodology follows mainly Uschold and King guidelin. For a test of the methodology proposed, terms have been collected in ISO 14040 standard family and specialized sources in FLCA. These terms are put together according to four FLCA stages: Objective and Scope, Inventory Analysis, Impact Assessment and Interpretation. For each stage basic concepts have been identified. For modeling of FLCA the OWL language was selected, in its version utilized in Protégé tool. In a second stage, FLCA evaluation will be carried out through the parameters: clearness – human checking of the definitions in order to be sure whether they are clear and without ambiguities – ; congruity and coherence – automatic checking of the ontology verifying whether it is internally congruen t–.

Keywords: Follow-up of Life Cycle Assessment, ISO 14040, LCA ontology methodology.

Resumen

En esta comunicación el dominio estudiado se refiere a "Follow-up of Life Cycle Assessment (FLCA)" o evaluación del ciclo de vida de los productos que de acuerdo con la norma brasileña (NBR) ISO 14040, estudia aspectos ambientales e impactos potenciales durante el ciclo de vida del producto, que va desde la adquisición del mismo en bruto hasta su *producción, uso y disposición. Partiendo de la caracterización del dominio y de la identificación del conocimiento ya disponible, se propone una metodología para la elaboración de una ontología dirigida a la organización de la información sobre FLCA. Dicha ontología tiene que cubrir las necesidades del proyecto sobre competitividad medioambiental de la industria brasileña "Life Cycle Inventory for environmental competitiviness of Brazilian industry", coordinado por el Instituto Brasileño de Información en Ciencia y Tecnología (IBICT). Los objetivos definidos por la ontología son: posibilitar la adquisición, representación y manejo del conocimiento FLCA; estructurar y organizar el conocimiento en las bibliotecas; difundir terminología brasileña normalizada relacionada con el área FLCA, cuya metodología sigue principalmente la establecida por Uschold y King. Para testar la metodología propuesta se han recolectado términos de la familia de la norma ISO 14040 y de fuentes especializadas en FLCA. Estos términos se han reunido en cuatro etapas FLCA: objetivos y alcance, análisis de existencias, evaluación del impacto e interpretación. En cada estadio se han identificado conceptos básicos. Para modelar el FLCA se ha seleccionado el lenguaje OWL en la versión utilizada en el software Protégé. En una segunda etapa se lleva a cabo la evaluación de FLCA utilizando los siguientes parámetros: claridad –se comprueban las definiciones con ayuda humana para asegurar su claridad y ausencia de ambigüedad-; congruencia y coherencia –se prueba automáticamente la ontología para verificar si es coherente internamente-.*

Palabras clave: Evaluación del ciclo de vida del producto, Follow-up of Life Cycle Assessment, ISO 14040, Metodología, Ontologías.

1 Framework and Objective

In an information system, the quality achieved in accessing content depends substantially on the way information is organized. In the 60s, Montgomery (1969) had already stated that the core of an information retrieval system is the module that controls the representation of the content. This idea is also emphasized by Salton (1990) who stated that any advanced model for information retrieval must deal with the problem of language analysis, since texts and documents contents necessarily control the retrieval activities.

The objective of information organization is to allow information, or organized knowledge, to be retrieved afterwards. To put it in effect, it is necessary to organize the content according to criteria preferentially familiar to the user. Therefore, in order to guarantee the desired results, the standards of organization to be adopted must be defined from the very beginning, that is, since the conception of an information retrieval system.

Knowledge representation schemes – such as Classifications, Thesauri, Taxonomies and Ontologies – play a critical function in the organization of knowledge, for they provide a vocabulary of terms and relations with which one can model this domain. Since these schemes delimit the usage of terms and define concepts and relations of a certain field of knowledge, in a shared and consensual way, they ensure that, in a community, everybody will use the same language to organize, store and present information.

These schemes of representation unfold the knowledge of a domain and make possible: the indexation, organization and retrieval of information as well as other types of objects; the construction of knowledge maps; the navigation for searching information; and the creation of new knowledge from the existing one.

In the scope of the Life Cycle Assessment for the Brazilian Industry Environmental Competitiveness project, coordinated by the Brazilian Institute for Information in Science and Technology (IBICT), one will find a proposal on developing an ontology aimed at the organization and retrieval of information, and at the contribution for a consensual vision of this domain.

2 The Life Cycle Assessment (LCA) domain

Understanding which domain is being approached is a vital part of knowledge representation in order to draw up definitions, create relations and structure a scheme of conceptual representation. For this purpose, firstly, the standards of the ISO 140001 family have been investigated. This family encompasses the Environmental Management System standards, which aims at supporting organizations according to sustainable development concept. Nevertheless, other specific sources were utilized as well, not only for understanding the domain, but also for harvesting terms and definitions that compound the Life Cycle Assessment Ontology (LCAO). In order to make clear the basics considerations and tunes related to a LCA domain, a succinct explanation is suitable.

2.1 LCA

Every product resulting from human labor causes impact in one way or another on the environment. Such impact may occur during the extraction of raw material utilized in the manufacturing and fabrication processes, in the productive process itself, in its distribution or transportation, in its use, or in its final disposition. These consecutive and interlinked stages constitute the Life Cycle Assessment of a product, in other words, the history of a product from its birth, encompassing its production stage, distribution, the use of the product by the consumer, until its transformation into garbage or residue (from cradle-to-grave). For instance, when evaluating the environmental impact caused by a car, one must consider not only the extraction of raw material for its construction, but also the possible damages its fabrication process may cause: the energy usage, the production of its different components such as tires, glass and fuel, the pollution caused by residues emission, its use and final destination.

LCA is a “technique for evaluating environmental aspects and potential impacts associated with a product” (ISO 14040), used in environmental management. This technique consists on a study comprising different stages which involve the entire life cycle of a product.

2.2 LCA Phases

Since LCA is a complex analysis comprising many variables, it is divided into phases which outline a methodological structure. Each of these phases is described below, according to information from ISO 14040, ISO 14041, ISO 14042 and ISO 14043 standards.

[1] A set of standards developed by ISO Technical Committee 207 (TC 207) as a response to the worldwide demand for a more reliable environmental management, in which the environment has been brought in as an important variable in business strategy.

2.2.1 Goal definition and scope

The goal must be clear and detail the desired application, the motivation reasons and the persons interested in the results of the study. It is from this point that LCA steps are determined. Based on the proposed objectives, the scope must provide a set of information which comprises parameters and outlines the study. Among other details, this scope must describe precisely:

- The functions of the product system, that is, the set of units of the production process that, when interlinked, complete one or more functions;
- The product system boundaries considered for the study determining which units of the process must be included in the LCA. The criteria that influence this limitation must be identified and justified;
- The data quality requirements relevant to the study, considering, for instance, timing and geographic area covered, as well as data sources and data representativeness.

2.2.2 LCI Analysis

This step requires the study of a LCI previously elaborated, its analysis and the interpretation of its results. The Life Cycle Inventory – object of this phase of study – is the set of data collected and quantified related to the input and output of a product system. That is, it is basically the mass and energy balance in which all flow of data must correspond to an output flow quantified as product, residue or emission.

2.2.3 Life-cycle Impact Assessment

The impact assessment makes use of the LCI data in order to infer which potential environmental impacts may occur during the LC of a given product. Moreover, it is possible to make a comparative analysis of products or processes. Since LCA is utilized for such an end, this stage not only recommends which products should be environmentally preferable, but also identifies opportunities for improving the environmental performance in the LC of both products and processes. In this stage, it is also included a critical analysis of the goals and scope of the LCA study to verify their adequacy.

2.2.4 Interpreting the Results

Here, the results of the inventory or impact analysis are verified in order to provide conclusions and recommendations to decision-makers, in accordance with the goals and scope of the study. The recommendations derived from this assessment may be reviewed one more time. Similarly, the quality and nature of data can be submitted to an interactive process of critical analysis and revision. It is important to emphasize that measures subsequent to the considerations obtained from the LCA are not part of the study scope.

3 Methodology for elaborating the Life Cycle Assessment Ontology (LCAO)

In order to establish the LCAO methodology, some proposals by different authors have been studied: Gruber (1993); Grüninger; Fox (1995); Sowa (1999); Uschold (1996); Uschold; King (1995); Uschold et al. (1998). The LCAO methodology is structured according to the steps described below, which were defined by the group coordinated by Mike Uschold.

3.1 Identification of scope, objectives and potential users

In this step of the methodology, one may define the scope of the domain to be modeled, the ontology goals and the potential users.

To define the domain to be modeled – Life Cycle Assessment (LCA) – it is adopted in this methodology the concept of LCA as described in the ISO 14040 standard: "The LCA studies the environmental aspects and the potential impacts during the lifetime of a product (that is, from "cradle-to-grave"), from the extraction of raw material, encompassing production, usage and disposal. The general categories of the environmental impacts that need to be considered include the use of resources, human health, and ecological consequences".

The LCA ontology must attend to the requirements of the project "Life Cycle Inventory for the Environmental Competitiveness of the Brazilian Industry". Considering that, the following objectives were defined for the ontology:

- to make possible the acquisition, representation and manipulation of knowledge on LCA, by means of a consistent set of basic modeled concepts;
- to structure and organize knowledge libraries, which allow organized access to the contents of the ISO 14040 family of standards and to the specialized documentation;
- to disseminate the standardized Brazilian terminology on LCA;
- to support the LCA learning process by using the ontology as instructional material;
- to improve the shared comprehension and view on LCA.

The ontology must provide a set of terms and definitions that encompass adequately and precisely the relevant concepts for modeling the LCA domain. By following the principles defined in the methodology, other more specific terms, can be included further.

Considering the proposed objectives, the LCA Ontology is characterized as a semi-formal ontology, according to Uschold (1996) concept: an ontology expressed in a restrict and structured form of natural language, clearly and avoiding ambiguity. The definitions in natural language are collected and registered in the Ontology and serve as a basis for the construction of definitions in restrict and structured natural language, which can be translated into a formal language further.

Concerning the scope, the LCAO is characterized as a domain ontology, according to Uschold`s concept (1996) – that is, ontologies modeling subject areas such as Medicine, Geology or Finance, considered separately from the problems and tasks related to them.

One of the ways to define the scope of an ontology is to specify some competence questions, which are questions that a knowledge base, supported by the ontology, must be capable to answering. In an informal ontology, such questions are utilized in the ontology assessment stage.

We defined the following competence questions for the LCAO:

- Which concepts are related to the different phases of the LCAO?
- Which elements must be considered in the LCA goal definition and scope?
- What defines the limits of a product system?
- How is a process unit constructed?

- How are the environment impacts characterized?

The definition of the ontology objectives, types of user and scope orientates the other stages for building the ontology. These parameters are utilized to delimit the set of terms to be collected and the level of specificity of these terms, in order to define the types of relations to be established among concepts and to proceed the ontology assessment.

3.2 Information collection

In this stage, it is carried out the collection of terms and identification of basic concepts and of the relations of LCA domain, regardless of the codification language.

Besides the terminology in Portuguese language, the LCAO presents their correspondent terms in English. The sources of each information collected is registered: Portuguese term, English term, definitions and usage context.

The definitions in natural language found in the documents are registered in the LCAO for documentation purpose. From each of them it is produced a precise definition text – free of ambiguities – for the concepts and relations, which is registered in the ontology as "semi-formal definition".

By analyzing those definitions, it is possible to identify the basic level concepts and the categories for organizing the ontology systematically. A critical revision of these definitions must be carried out by experts from all over the world in order to verify its clearness, completeness and degree of formality.

3.3 Categorization and modeling

In this stage, the terms collected are grouped in subject categories related to LCA. For this, one may adopt LCA stages as categories of this domain. This choice of categories were also approved by experts in the area. Thus, the concepts modeled in the ontology refer to LCA phases as defined in ISO 14040 standard:

a) Goal definition and scope: puts together concepts relating to the LCA phase in which one defines, undoubtedly, the intended application, the reasons for carrying out the study and the target audience, that is, for those one intends to communicate the results of the study (e.g.: Process unit, Process flow chart; Functional unit).

b) Inventory analysis: puts together concepts relating to the LCA phase that involves data collection and calculation procedures in order to quantify inputs and outputs of a given product system (e.g.: Input, Output, elementary Flow, Mass balance, Allocation, Data collection).

c) Impact assessment: puts together concepts relating to the LCA phase that involves the assessment of potential environment impacts significance by using the results from the life-cycle inventory analysis (e.g. Impact category, Characterization, Classification, Human toxicity).

d) Interpretation: puts together concepts relating to the LCA phase in which the assumptions of the inventory analysis and of the impact assessment, or – in case of studies on life cycle inventory – only the results of the inventory analysis are consistently combined with the objective and scope defined, aiming at reaching conclusions and recommendations (e.g.: Integrity testing, Sensibility analysis, Consistency check).

Within each subject category it was identified the basic level concepts, according to the solution adopted by Uschold and King (1995), which are based on Lakof.

The basic level of concepts is constituted of concepts which are in the intermediary level of an hierarchy, that is, they are not higher or lower level concepts, for instance: MATERIAL (superordered concept); RAW MATERIAL (basic level), SECONDARY RAW MATERIAL (subordinated concept).

One of the features of the basic level concepts is that they gather the most part of the members of the category attributes to which they belong in order to make the domain modeling easier. The top-down approach requires the use of very general level terms – leading to the risk of imprecision and re-work – while the bottom-up one can demand the definition of a lot of specific terms, with the risk that many of them may not be important for the Ontology.

In order to support the adoption of the basic level approach, Uschold and King (1995) state that:

a) The basic concepts seem to be the most important and will be used for defining the others (for the definition of the others).
b) The concepts that are not basic will normally be defined in terms of the basic concepts.
c) The use of these concepts is desirable in order to augment the ontology clearness, specially for the not- expert audience.

Concerning LCAO, these are some examples of concepts considered as being of basic level: product system, process unit, material, energy, input, output, flow, among others.

The organization of concepts in categories or classes, the definition of their attributes and the establishment of relations among the concepts define the conceptual model of the domain that is being structured in the ontology. The explicit representation of this conceptualization in any formal language is the ontology codification. This codification involves the accordance with any meta-ontology, the choice of the representation language and code creation.

In order to model the Ontology, a meta-ontology was not defined *a priori*, neither was an specific tool. According to Uschold (1996), it may restrain thoughts and lead to incomplete definitions.

After grouping the concepts based on subject categories, and after a preliminary analysis of the natural language definitions collected, the software Protégé was selected in order to model the LCAO.

3.4 Evaluation and test

In the analyzed methodologies, different criteria for ontology evaluation are defined. For an the LCAO, the following evaluation parameters are to be used:

- Clearness: human verification of the definitions which checks if they are clear and without ambiguities. This verification must be carried out with a help of an specialist belonging to the area.

- Consistency and coherence: automatic verification of the ontology which checks if it is internally consistent, that is, without circularity. This automatic verification is attained by means of a software called RACER, whose function "Classify Ontology" executes the inconsistency check in the ontology structure.

The evaluation will be also carried out by verifying the competence questions, by analyzing whether the ontology has knowledge to answer them. The evaluation and test processes must count upon the participation of LCA specialists.

4 Achieved results

In the scope of LCAO development project, the following issues are already defined: the objective and scope of the ontology application; the categories of LCA domain for grouping concepts and the standards concerning terms presentation (singular or plural usage, compound terms, classes and slots). It has been collected and registered 132 terms, with their definitions and equivalences in English language, and grouped according to their corresponding domain categories. These data are registered as slots of the classes and subclasses. The methodology for LCAO elaboration is already delineated and it is being applied for structuring terms and concepts previously collected. Figure 1 presents an example of the "flow" class relationships, extracted by the plug-in TGVizTab.

5 Final considerations

In order to model an ontology it is necessary to make an exhaustive survey of the concepts related to the domain to be modeled, as well as to have a general knowledge about the structure of this domain. Concerning the LCAO, there was a preliminary training stage on LCA by means of courses and study groups, which brought a general view of the domain to the team. Without such a view, would be impossible the development of the ontology.

One of the difficulties usually faced on modeling the ontology is to define the starting point to structuring classes and subclasses. Hence, the identification of basic level concepts supports the ontological structure, for it is from these concepts that other concepts are identified, favoring the mapping of the whole domain to be modeled.

The LCAO modeling experience reveals that there is still a lot to be discussed concerning the practice of ontology elaboration. The methodologies are still very new, and there are very few reports about their applications. In the practice of developing the LCAO, some barriers have been identified concerning the delimitation of necessary attributes to answer the competence questions and to accomplish the objectives addressed to the ontology. In the development of the ontology, it was noticed the need of outlining, in a more detailed way, the criteria to elaborate the semi-formal definition and the criteria to draw the relationships boundaries of the ontology classes and subclasses.

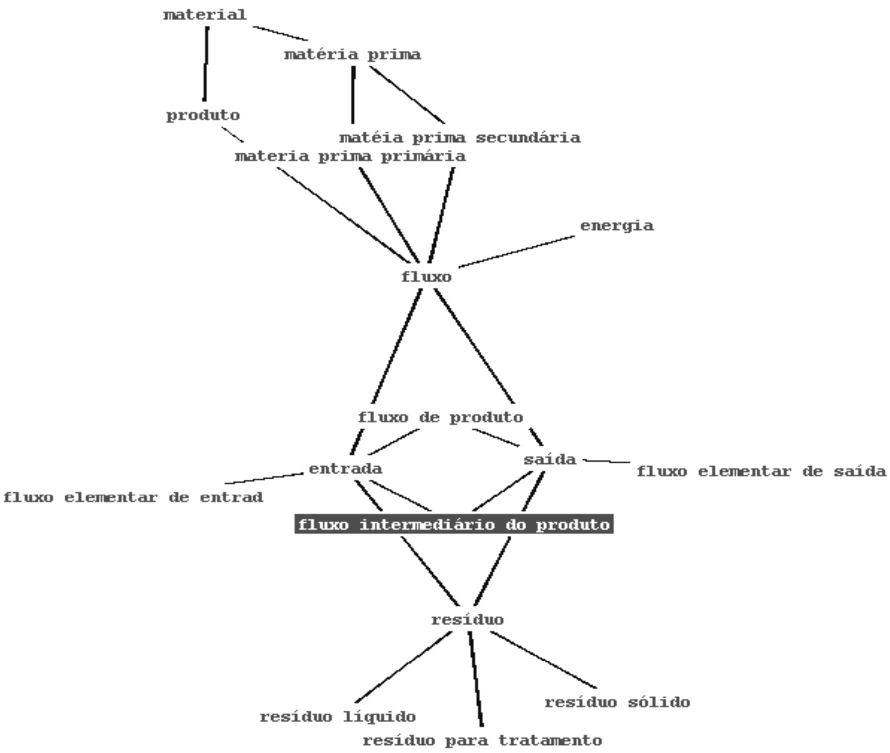

Fig. 1. Example of the “flow” class relationships, extracted by the plug-in TGVizTab

References

GRUBER, T. R. Toward principles for the design of ontologies used for knowledge sharing. *International Journal Human-Computer Studies*, 1993, vol. 43, p. 907-928.

GRUNINGER, M.; FOX, M. S. *Methodology for the design and evaluation of ontologies*, 1995 [electronic resource]. <http://citeseer.ist.psu.edu/cache/papers/cs/1337 > [Consulted: 20 jan. 2006.]

ISO 14040. Gestão ambiental – Avaliação do ciclo de vida – Princípios, 2001.

MONTGOMERY, C. A. Automated language processing. *Annual Review of Information Science*, 1969, vol. 4, p. 145-174.

SALTON, G.; McGILL, M. J. *Introduction to modern information retrieval*. New York: McGraw-Hill Book Company, c1983, p. 448

SOWA, J. F. Building, sharing and merging ontologies [electronic resource]. *Tutorial, 1999*. <http://users.bestweb.net/sowa/ontology/ontoshar.htm>. [Consulted: 12 dec. 2005.]

USCHOLD, M. Building ontologies: towards a unified methodology. In: *Annual Conference of the British Computer Society Specialist Group on Expert Systems (Cambridge: 1996).*

USCHOLD, M.; KING, M. *Towards a methodology for Buildng Ontologies*. Edinburgh: Artificial Applications Institute, 1995, p. 13 (AIAI-TR-183)