2014 47th Hawaii International Conference on System Science

A Web-based Smart Inference System to Support Automated Generation of LCA Simulation Models

Sarfraz Ul Haque Minhas
BTU Cottbus-Senftenberg
minhas@tu-cottbus.de

Ulrich Berger
BTU Cottbus-Senftenberg
ulrich-berger@tu-cottbus.de

Abstract

The decision on most eco-efficient production scheme for producing customized products is highly time consuming and error-prone as it depends on several factors most notably the geographical locations, legal requirements, materials characteristics and process related parameters. Furthermore, the planners must be experienced with the simulation tools as well as related terminologies, environmental laws and standards to conduct precise assessments. The limited functionalities of decision making tools as well as non-automated exchange of information and data, absence of environment related knowledge and non-standardized interfaces between the simulation tools and ERP/PLM systems make planners incapable of reaching quick decisions on eco-efficient choices.

This paper proposes a web-based inference system seamlessly connected with the LCA simulation tools and legacy systems. The web-based software automatically analyzes the input on manufacturing alternatives to produce customized products and generates automatically the corresponding LCA simulation models. These models can be used inside LCA tools.

1. Introduction

The globalization process, accompanied by the rapid dissemination of information, has led to opportunities for new markets. Although consumption varies eminently from one region to another, the global consumption rate is accelerating on average, with increasing expectations and better quality of life. The increased focus on the political, legal, social and environmental issues has emerged the concepts such as sustainable production and industrial ecology [1]. To ensure sustainability, the production sector, in particular, should be able to ensure economic development and competitiveness. This emphasizes the use of natural resources in a rational manner and managing those being used in the best possible way with minimal impact on environment in the following:

a) Products and services: safety and minimizing environmental impact during the entire life cycle considering design for remanufacturing / recovery / recycling.

b) Processes and operations: design and management for waste reduction and on-site recycling, for minimizing the use of those physical/chemicals substances that are potentially harmful to human health as well as to the environment, for reducing power consumption, maximization of the utilization coefficients and the re-use of available resources. It also stresses the need of identifying and following those guidelines throughout the supply chain that support sustainable development of the production processes. The sustainability is directly linked with the environmental impact of the production processes as well as the service related activities. It includes generation of pollutants on one side and on the use of resources such as fossil fuels, water and land on the other. The long sustainability demands effective reduction of pollutants and emissions from the productions systems by limiting the environmental load and optimal consumption of natural resources. Peeping into the automotive sector, the contributions made by this sector in elevating the world GDP are being counterbalanced by significant environmental impact of the products and processes. There are 0.75 billion cars on the roads world-wide and each year, the number of produced vehicles (passenger cars & commercial vehicles) has reached by more than 73.10 million units. The current car product rate project nearly two billion cars on the road by 2050. Consequently, the environmental impact of manufacturing will be elevated significantly and sustainable production will not be achieved unless our planning decisions are made on eco-efficiency. At the same time, the increasing production rates due to expanding markets lead to huge consumption of resources, which have direct impact on the environment and the sustainable development. Further, the decentralization of production systems, mass

978-1-4799-2504-9/14 $31.00 © 2014 IEEE
DOI 10.1109/HICSS.2014.109

customization of products and changing strategic, business and social goals have complicated the decision making on selection of optimal among several potential alternatives for manufacturing of customized products in decentralized manufacturing networks. The decisions are mostly uncertain due to absence of knowledge and knowledge management systems. The following section presents a review on decision support systems and the role of knowledge management in intelligent decision making by exploiting technologies from the artificial intelligence domain.

2. Knowledge management and decision support: a review

Though there is no commonly accepted definition of decision support system (DSS) [2][3][4][5], it plays a crucial role in decision making [6]. It is "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting solutions for non-structured management problem and improved decision making" [7]. In any enterprise IT infrastructures, a huge change has been witnessed over the last decade namely from centralized to decentralized client/server architecture, from desktop versions to remote access and from conventional databases to dataware houses. These things can be observed more closely in several enterprises in which legacy tools for instance Product Lifecycle Management (PLM) systems, Enterprise Resource Planning (ERP) systems are based on such IT infrastructures. These systems offer substantial assistance to planners in sharing their cognitive load in complex decision making situations. Though, decision support systems already in place have enabled them to utilize enterprise information system for better decision making through close human computer interaction. Yet the issue remains open as how to utilize or reuse the knowledge generated during interaction with such systems or with distributed resources.

The decision support systems have been classified by Alter [8], [9] into seven types namely File drawer systems, Data analysis systems, Analysis information system, Accounting and financial models, Representation models, Optimization models and Suggestion models. Power [10] categorized the decision support systems as Model-driven DSS, Data-driven DSS, Communications-driven DSS, Document-driven DSS, and Knowledge-driven DSS. The Communication-driven DSSs have got more attention in distributed and networked decision making, particularly at the higher management level where, for instance, video conferencing is required to define action plans or resolve certain conflicting issues among the collaborating partners. The communication-driven DSS is effective only when the collaborative partners have background knowledge or skills of the relevant problem area. In case of uncertain situation or unskilled planners, the knowledge driven DSS contains functionalities of recommending actions to the users besides retrieving knowledge for solutions or guidelines to any particular problem. Additionally, it can make decisions partially or fully dependent upon the strength of the incorporated intelligence and problem solving capabilities. This enhances the prospects of exploiting technologies from artificial intelligence field such as semantic web, multi-dimensional models, data cubes and Online Analytical Processing for decision making tool. At this point, some researches identify lack of software based information tools. For example, management information tools and content based tools provide storage and administration of information and knowledge in the organizational knowledgebase. These tools are thoroughly useful as supporting tools for enhancing the knowledge management processes in companies. However, they strongly miss functionalities for systematic consolidation of know-how regarding employees skills. This can be further elaborated by insufficient organizational conditions and instruments for an accelerating know-how creation (e.g. defined activities, straight instructions, and lessons learned workshops for training the personnel in the field of problem solving skills). Typically, documentation of implicit knowledge of employees is neither suitable nor appropriate. Therefore, formal procedures based on methods like Delphi surveys/experts workshops have been adopted to collect expert's knowledge. The very significant portion of the knowledge, which is generally not documented and hence lost, is generated during interaction between the software tools and the skilled users.

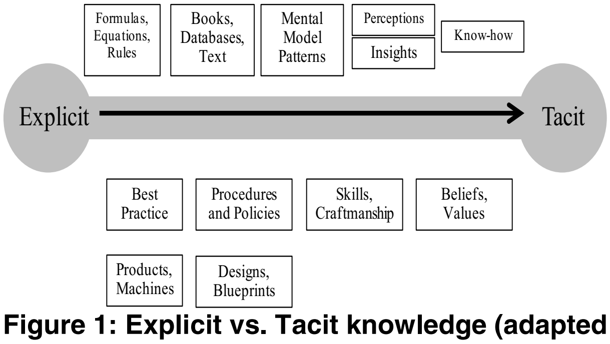


Figure 1: Explicit vs. Tacit knowledge (adapted from [11])

From the literature, no research publication has addressed this issue so far. Connecting a link with the theoretical concepts, Figure 1 shows the highlighting means for guiding actions and informing decisions along the knowledge continuum [12]. The interesting fact is the interest of companies getting much of their knowledge documented rather than containing them in brains. It emphasizes the need for penetration of knowledge management concepts in all the enterprise related business activities particularly the manufacturing. Several approaches have proved that the efficient knowledge management is very essential in dealing with inherent complexities in manufacturing whether it is at planning level or even at the shop floor control level. The customized production requires constant interaction through exchange of information between the collaborating partners [13]. It involves distribution of explicit knowledge in several enterprise departments. The tacit knowledge is quite difficult to share and exchange among various in both closely and loosely connected departments in the absence of formal procedures and interoperable tools capable of exchanging it. Hence more cooperation is required [14] which demands willingness of skilled employees, to share their knowledge through formal means. Higher levels of knowledge dissemination and information exchange leads to a considerable decrease of technical uncertainties in the mass customization knowledge driven process. Thus knowledge management strategies must be adopted as they provide the baseline for the development of knowledge management system. As reported in [15], two prominent strategies namely codification and personalization allow systematic structuring of enterprise knowledge and make it useful for the enterprise through smooth flow of information from centralized resources to various departments inside as well as outside of an enterprise. This systematic flow of information leads to better knowledge sharing. The more systematic is the sharing, the higher will be the chance for its visibility and usability in decision making. As reported in [16], there are certain mechanisms for origination of this process. The first one includes diffusion which means that employees of some enterprise select and communicate existing information without being oriented towards a particular problem. The second refers to the information retrieval, which means whosoever demands certain information for solving any problem; must be provided by the person who carries it. The third is the pooling of information which refers to the collaborative working of skilled employees to pool their knowledge. The extent of such sharing is not limited to the factual information but also to suggestions and instructions related to any particular problem of the domain concerned. The fourth mechanism is the collaborative decision making which generates new knowledge potentially mature enough for storage. The knowledge can only be exploited by enterprises as long as it has access and sharing possibility [17]. Thanks to large-scale high speed computer networks that have made access to information possible, however, the processing and interpretation of retrieved information is still a topic of research due to the heterogeneity of data. The heterogeneity of data can be syntactical, structural or semantic [18]. The syntactical problems are resolved if suitable interfaces, for the integration of information sources, are developed. The structural problems can be solved by one to one structural mappings provided the scale of sharing information is small. Semantics of the information must be considered in large scale information exchange in order to see in what way different information sources are connected together. Thus, the semantic interpretation of knowledge can ensure better pragmatic use of knowledge in the decision making process.

3. Pilot case definition

In the scope of this paper, the production of customized hood assembly in decentralized manufacturing is considered to demonstrate the concept for web-based smart inference system. It includes a knowledge management system based on ontologies and inference system seamlessly connected with the legacy tools such as ERP/PLM systems through open source interfaces and with the simulation tools in server-client fashion, thus relieving part of cognitive workload on planners in executing decision related tasks and solving problems.

4. Problem statement and objectives

Taking into account the presented trends, the traditional key performance indicators such as cost, time, and quality are no more sufficient upon which optimal production plans are generated and decision making to achieve sustainable production. The environmental impact of the potential solutions has to be determined before deciding on the optimal choices for manufacturing processes, resources, manufacturing locations and transportation means in the whole decentralized production scheme. The commercially available PLM and ERP solutions do not support holistic consideration of potential environmental impact in the evaluation of potential production schemes and eventually in decision making process. The decision making process is extremely time consuming and non-trivial as the selected options have to be simulated using the conventional simulation tools and then results are shared through non-standardized interfaces with the other simulation tools/planning tools. Additionally, the planners have to rely on LCA experts to conduct simulations and deliver results back to ERP/PLM planners. The exchange as well as the processing of this information takes place generally through manual means, which makes the decision making even more difficult when the resources are placed in a distributed fashion and the communication and exchange of information intensively rely on company's IT infrastructure. The distributed resources however, furnish more intensive inter and intra departmental collaboration along the whole product development cycle. However, one of the challenging problems related to them in the manufacturing environment is to connect them semantically and infer required knowledge, which facilitates planners with the comprehensive decision making. Foreseeing the environmental assessment of customized products and of manufacturing networks as a daily based activity, the concept for inference system must be formalized considering the following objectives:

a) Development of product independent taxonomies for manufacturing and environment related domain knowledge, which is required for environmental simulations in LCA tools and for decision making.

b) Development of Ontology based knowledgebase to enable storage of knowledge generation from or through interaction with the LCA simulation tools.

c) Enriching ontologies with the semantic rules for product and process classifications and mapping to the environmental concepts, to infer simulation models for the LCA tools.

d) Navigation through ontologies using standardized query formats and searching algorithms.

e) Seamless exchange of information from the legacy tools and automatic generation of queries for synthesizing simulation models for LCA simulations.

The architecture for the web based tool must support the development using state of the art web technologies, knowledge representation format, data exchange formats to deliver easy to use, easy to access, domain independent and location independent solution.

5. Concept formulation

5.1. e-Custom project

Before going into the concept details, the authors want to highlight the fact that the proposed concept is devised by assuming this module as an add-on to the web-based collaboration platform (see Figure 2) developed in the scope of EC FP7 Project e-Custom. The e-Custom architecture is based on two main software parts i.e. the user adaptive design system and the decentralized manufacturing platform. The decentralized manufacturing platform interconnects other software modules namely Optimization Heuristic Module, Dynamic Network Module and Environmental assessment module. The Optimization Heuristic Module-I takes the personalized product information (customized order) and then formalizes the order details into an XML schema and finally generates a customized Bill of Materials (BoM). The XML scheme is stored in a tree structure that contains detailed information about the product. The schema contains the geometric characteristics of the personalized parts of the product, the materials, the colors, the textures, the weight and the dimensions of each component, and the relations between the components, subassemblies and raw materials. The second part of the module i.e. Optimization Heuristic Module-II afterwards maps the customized BoM into several possible alternative Bill of Processes (BoP) The alternative BoPs include alternative processes for manufacturing and transporting the components of the product over the network.

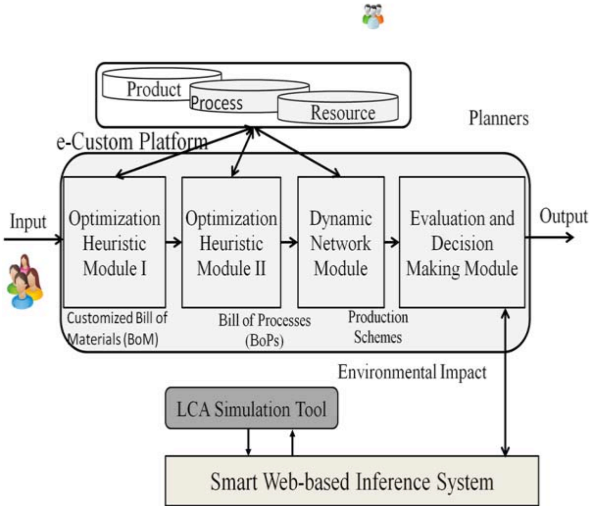


Figure 2: e-Custom decentralized manufacturing platform

Based on the BoP, the platform retrieves from the database, the resources (machines) that are capable of producing the components. The dynamic network tool, taking into consideration the assembly sequence, the required operations and the suitability of the resources to perform these operations, forms the feasible alternative production and transportation schemes. Each alternative comprises a network configuration that is capable of producing the personalized product. The selection of the best / good production scheme can be performed by the decision making using heuristics and intelligent search algorithms.

5.1. Smart web-based inference system

Taking in account the pilot case, the objectives and requirements concerning software architecture and the e-Custom Platform, the concept for smart web-based inference system is presented in Figure 3. At this point, it must be mentioned that the input to the decentralized manufacturing platform comprises of specifications of the customized order and the output is the optimal customized production scheme. The production scheme formally describes specifications related to the decentralized manufacturing network for producing the customized product as an xml schema. These specifications are related to products, processes and resources of all the selected manufacturing and supply locations against the customized order. This multilevel and cross connected information file needs to be parsed which is used afterwards for generating queries in compliance with the W3C standards. The query generator takes each node and generates queries against each node mentioned in the production scheme.

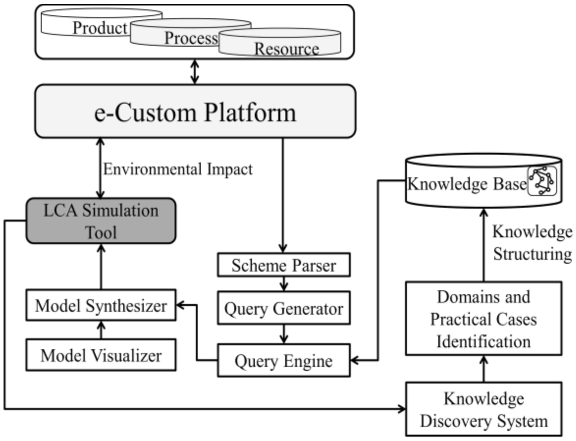


Figure 3: Smart web-based inference system

The query engine searches for relevant environmental impact related information from the knowledgebase and delivers results concerning possible I/O model for environmental simulation tools and the relevant instructions. Likewise, the knowledge concerning other nodes is generated and sent to the model synthesizer. The model synthesizer accumulates the results and generates the simulation model against the production scheme afterwards. The user can visualize the simulation model of the customized production scheme and can make alterations in the model before exporting it to the LCA simulation tool. The knowledge generated as a result of interaction between the simulation tool and the LCA planners is used to create new taxonomies or enrich the existing ontologies. The implicit knowledge of domains experts must be translated into the additional rules to infer the practical solutions for decision making. The ontologies must be described in a formal way complying with the W3C standard. The following workflow illustrated in Figure 4 is followed to create ontologies. For navigation inside the ontology graph through keywords or free search, search algorithms are required. These algorithms must be capable of using standard query structures to navigate inside the user queries.

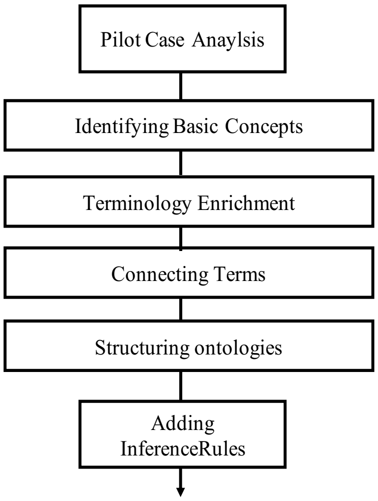
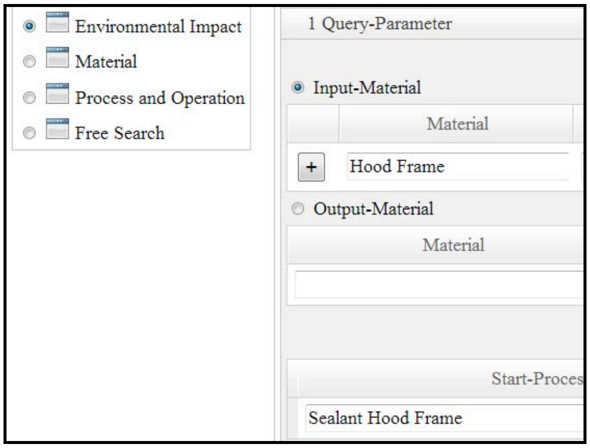


Figure 4: Workflow for ontology creation

6. Implementation

The concept is implemented using ZK, which is java based open source web application framework. It provides a powerful java based user interface platform capable of handling large scale data-driven business applications. The storage of business logic at the server side enables increased security for the application.



● Environmental Impact
○ Material
○ Process and Operation
○ Free Search

1 Query-Parameter

● Input-Material

Material

+ Hood Frame

○ Output-Material

Material

Start-Proces

Sealant Hood Frame

Figure 5: Web-based smart inference user interface

Furthermore, the ontologies are developed using RDF structures which allow large number of RDF triples to be efficiently stored on the storage devices. Jena Framework has been used to develop APIs for reading, processing and writing RDF data in XML formats, handling OWL/RDF ontologies and for development of query engine compliant with the latest SPARQL specifications. For inference, Jena engine is used to implement inference rules and get reasoning services for the OWL/RDF ontologies. As shown in Figure 5, the users can access the Inference System through web-browser and can navigate through the knowledgebase by several means i.e. through manual input in the form of formal queries or key words as well as user can upload an xml file describing the production scheme for manufacturing customized products.

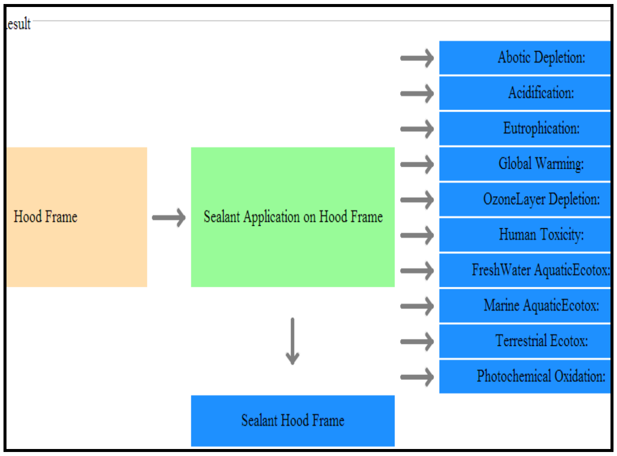


Figure 6: Output from the knowledge base

The inferred input/output model for LCA simulation can be visualised in Figure 6.

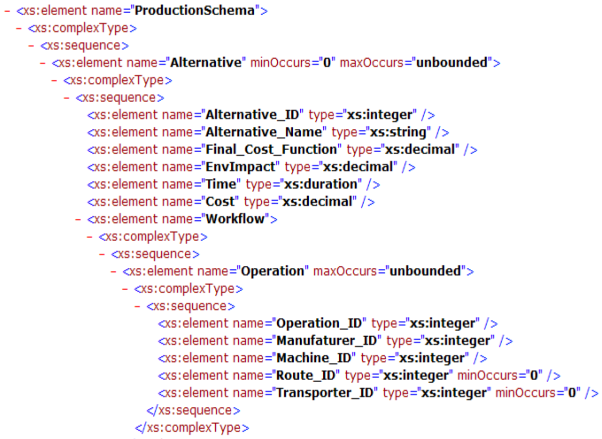
This development will facilitate the integration of unskilled and inexperienced planners in decision making on selection of the most eco-efficient production schemes. Furthermore, it will also enable skilled planners to use the same tool for enriching their experiences in the knowledgebase. Hence it is available for reuse in inferring simulation models for the LCA simulation tool and providing guidance to the unskilled ones.

7. Case validation

To test the processing of explicit and tacit knowledge generated during the decentralized manufacturing planning process, the example of customized/individualized manufacturing of car hood is selected as a case for the concept validation.

The selected case is sufficient to demonstrate the concept enabling users easily understand the product and process structure with or without customization. It also supports free manipulation of explicit knowledge (e.g. technical information) and tacit knowledge without violating the confidentiality of manufacturer related information/knowledge. As mentioned earlier, the product, process and manufacturing information is generated as a production scheme (see Figure 7) against each of the customized product.

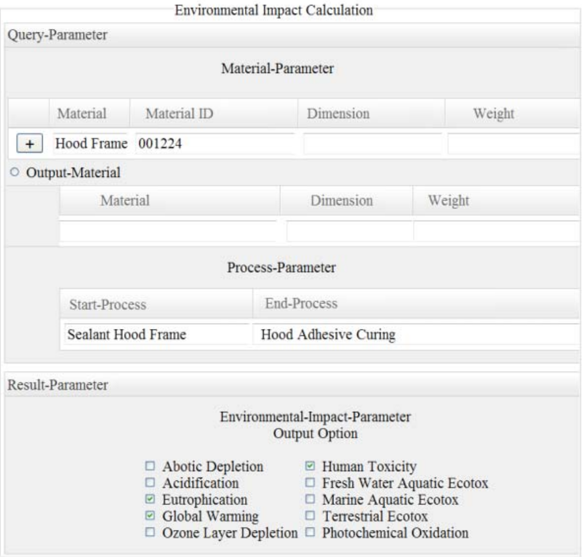
The smart web inference system takes this production scheme as an input and parses each manufacturing node in a sequential manner which is used later on for query generation. Thus knowledge is retrieved in a seamless and automatic manner.



```
- <xs:element name="ProductionSchema">
 - <xs:complexType>
  - <xs:sequence>
   - <xs:element name="Alternative" minOccurs="0" maxOccurs="unbounded">
    - <xs:complexType>
     - <xs:sequence>
        <xs:element name="Alternative_ID" type="xs:integer" />
        <xs:element name="Alternative_Name" type="xs:string" />
        <xs:element name="Final_Cost_Function" type="xs:decimal" />
        <xs:element name="EnvImpact" type="xs:decimal" />
        <xs:element name="Time" type="xs:duration" />
        <xs:element name="Cost" type="xs:decimal" />
      - <xs:element name="Workflow">
       - <xs:complexType>
        - <xs:sequence>
         - <xs:element name="Operation" maxOccurs="unbounded">
          - <xs:complexType>
           - <xs:sequence>
              <xs:element name="Operation_ID" type="xs:integer" />
              <xs:element name="Manufaturer_ID" type="xs:integer" />
              <xs:element name="Machine_ID" type="xs:integer" />
              <xs:element name="Route_ID" type="xs:integer" minOccurs="0" />
              <xs:element name="Transporter_ID" type="xs:integer" minOccurs="0" />
             </xs:sequence>
            </xs:complexType>
```

Figure 7: Production scheme (output from e-Custom platform)

On contrary to this automatic approach, the users can search manually through a restricted search approach followed in Figure 8. The queries are generated automatically using manual input from the users/planners for knowledge search as shown in Figure 8.



Environmental Impact Calculation

Query-Parameter

Material-Parameter

	Material	Material ID	Dimension	Weight
+	Hood Frame	001224		

○ Output-Material

Material	Dimension	Weight

Process-Parameter

Start-Process	End-Process
Sealant Hood Frame	Hood Adhesive Curing

Result-Parameter

Environmental-Impact-Parameter
Output Option

☐ Abotic Depletion
☐ Acidification
☑ Eutrophication
☑ Global Warming
☐ Ozone Layer Depletion
☑ Human Toxicity
☐ Fresh Water Aquatic Ecotox
☐ Marine Aquatic Ecotox
☐ Terrestrial Ecotox
☐ Photochemical Oxidation

Figure 8: Web-based GUI for knowledge navigation (restricted search)

The input given by a user through the web-based graphical user interface (see Figure 8) is taken by the query generator, which synthesizes queries aligned with the knowledgebase structure. The tool is used by describing a case example of knowledge retrieval of customized hood assembly. Suppose a user wants to look for knowledge concerning the possible environmental impact of the hood assembly of any customized order. The user insert material, the process parameters particularly the whole or section of the process chain indicating the start process node to the end process node and can also indicate the expected environmental impact or its value.

As illustrated in Figure 8, the user intends to explore the knowledgebase for environment impact of Hood Frame during a section of its whole process chain (i.e. from sealing hood process to the adhesive curing of hood). The query controller takes the input and generates SPARQL based queries to search in the knowledgebase. The knowledgebase comprises of material, process and environmental related ontologies. The material ontology describes the materials as final products, products in processing phase and raw materials. Figure 9 shows the ontologies of materials and members of these ontologies such as hood assembly parts, intermediate parts and components, operations related to hood assembly processes.

The process ontology (see Figure 9) covers two main associated and closely related sub-concepts i.e. operations and resources. The operations related to the manufacturing of customized hood as well as the machines used are stored as instances in the knowledgebase. The tacit knowledge from the LCA experts as well as from the manufacturing planners involved in hood manufacturing was added to the knowledgebase as production rules and inference rules. This enables concrete search helpful for providing recommendations to the planners as well as suggested LCA simulation model and hence determine the eco-friendly manufacturing processes and routes. The simplest example of such rules is the supply of optimal quantity of hood frames from suppliers at a certain location to any of the manufacturing location using the available transportation routes and resources without exceeding the allowable limit of CO_2 emissions. In this example both the experience of LCA experts as well as the other planners is involved. The tacit knowledge concerning this case is programmed as production rules/inference rules to enrich the knowledgebase. Figure 6 is a graphical input output model (Car Hood Assembly) for LCA simulation model of the query generated against each node mentioned in the production scheme of customized hood. The information from the generated input output LCA model is exchanged with the LCA tool to get simulation results (environmental indicators and their values).

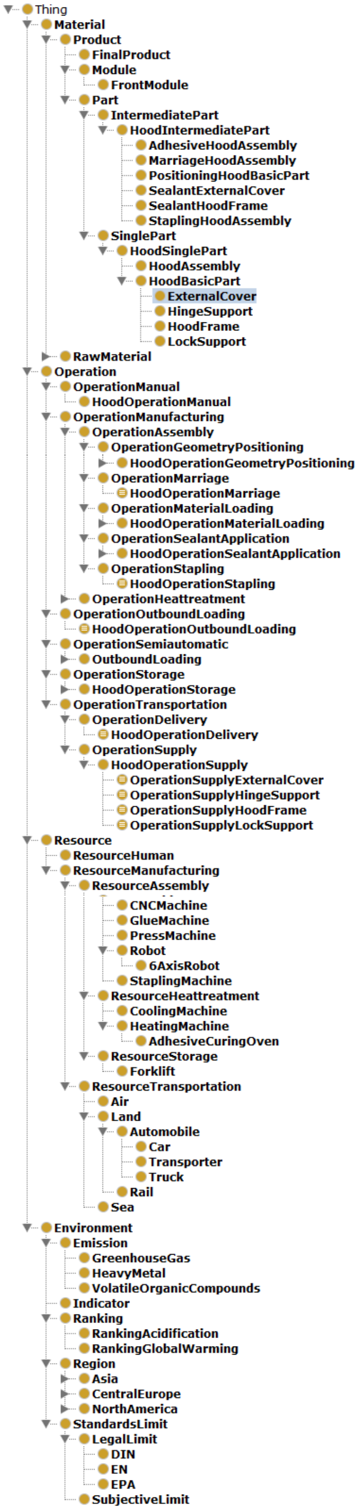


Figure 9: Material, Process and Environment Ontologies

The tool infers the LCA simulation models of manufacturing of customized products through seamless generation of SPARQL based queries. It allows easy navigation inside the knowledge base for possible emissions and their values (if available, see Figure 10).

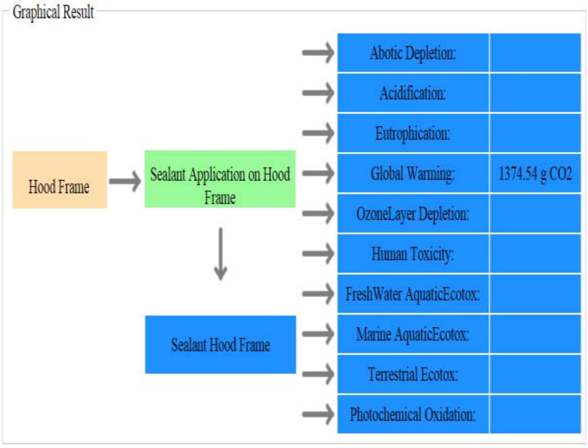


Figure 10: Query Results (Graphical Output)

The tool facilitates inclusion of tacit knowledge from planners and the LCA experts for enriching the knowledgebase. However, at the moment, it does not support automatic extraction of tacit knowledge from the LCA experts and manufacturing planners through formalized means.

8. Conclusions and future outlook

The expanding role of knowledge management in the planning and other associated processes in production networks is a key to achieve quick, reliable decision making in uncertain situations. A concept for extracting and reusing the knowledge from the planners as well as the planning related software has been developed and validated through automotive pilot case. This knowledge has been used to infer LCA simulation models for new manufacturing cases. Web-based software solution comprised of customized user query interface, ontology based knowledge-base and Scheme parser is implemented and validated. The software is programmed to allow input through two means i.e. direct from users through customized user queries or by simply uploading the production scheme information. This query is generated after the user has customized his input information through textual input or through keyword using free search functionality. In case of an xml based data file (refers to the customized production scheme) as input, the information contained in the data is first parsed through scheme parser and queries are generated in a sequential manner against the parsed information. The query engine is used to search information from ontologies. This information is delivered to the model synthesizer for inferring LCA based simulation models. The generated results have been used to enrich the knowledgebase for better inference capabilities. As an outlook, new functionalities like processing of natural language queries with smart context will be added, navigation capabilities will be enhanced and testing of Semantic web Information Management with Automated Reasoner (SMART) with the system will be carried out. The validation scenario will be expanded to assist eco-efficiency based decision making in manufacturing of products such as customized orthotics, assisted components for elderly people.

9. Acknowledgements

The research work reported is this paper is partially supported by the European Commission Project e-Custom FP7-2010-NMP-ICT-FoF 260067 “A Web-based Collaboration System for Mass Customization”.

10. References

[1] Ehrenfeld J., Industrial ecology: a new field or only a metaphor?. Journal of cleaner production, Vol. 12, pp. 8-10, 2004.

[2] Lee K.W., Huh S.Y., A model-solver integration framework for autonomous and intelligent model solution. Decision Support System, Vol. 42, pp. 926–944, 2006.

[3] Bhatt G.D., Zaveri J., The enabling role of decision support systems in organisational learning, Decision support system, Vol. 32(3), pp. 297–309, 2002.

[4] Shim J.P., Warkentin M., Courtney J.F., Power D.J., Sharda R., Carlsson C., Past, present, and future of decision support technology. Decision support system, Vol. 33, pp. 111–126, 2002.

[5] Zeleznikow J., Nolan J.R., Using soft computing to build real world intelligent decision support systems in uncertain domains. Decision Support System 31, pp. 263–285, 2001.

[6] Turban, E., Decision support and expert systems: management support Systems, Macmillan series in information systems, Prentice-Hall International, N.J., 1993.

[7] Turban, E., Decision support and expert systems: management support systems, Prentice-Hall International, N.J., 1995.

[8] Alter, S.L., Decision support systems: current practice and continuing challenge, Reading, MA: Addison-Wesley, 1980.

[9] Mallach, E. G., Understanding decision support systems and expert systems, Irwin Professional Publishing, Burr Ridge, Ill, 1994.

[10] Power, J., Decision support systems: A historical overview, Chapter 7, Handbook on decision support systems -1 Basic Themes, International Handbooks on Information Systems, Springer, 2008.

[11] Braunstein, Y., Basics of knowledge management, lecture on knowledge management, June 2004.

[12] Smuts, J. L., Towards comprehensive knowledge management system architecture, Nov. 2008.

[13] Calabrese, G., Managing information in product development, Logistics information management, Vol. 12, 6, pp. 439-450, 1999.

[14] Calabrese, G., Communication and co-operation in product development: a case study of a European car producer, R&D Management, Vol. 27, Issue 3, pp. 239-252, 1997.

[15] Berends, H., Van der Bij, H., Debackere, K., Weggeman, M., Knowledge sharing mechanisms in industrial research. In: R&D Management, Vol. 36, Issue 1, pp. 85-95, 2006.

[16] Hansen, M.T., Nohria, N., Tierney, T., What is your strategy for managing knowledge?, Harvard Business Review 77, 2, pp. 106–116, 1999.

[17] Choo, C.W., The knowing organization: How organizations use information to construct meaning, create knowledge and make decisions. In: International Journal of Information Management, Vol. 16, 5, pp. 329-340, 1996.

[18] Stuckenschmidt, Heiner; van Harmelen, Frank, Information Sharing on the Semantic Web. Springer-Verlag Berlin Heidelberg Germany, 2005.