Ontology Based Environmental Knowledge Management

A System to Support Decisions in Manufacturing Planning

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Abstract: The environmental efficiency based decision making to decide for optimal manufacturing routes in the decentralized production, has become very complicated. The draining of skilled workers, limited functionalities of decision support tools, localisation of information resources, unavailability of adequate environmental knowledge, systematic management of the same and non automated information exchange between various information tools are among the causes that generally hamper the decision making process. The complexities can be resolved if the mechanism for environmental data collection, structuring and retrieval over a web environment is developed so that both collaborative and individual decision making is possible. This paper discusses the case study from the automotive manufacturing area and the development of environmental knowledge management tool capable of providing planners and production managers the knowledge related to the potential environmental impact of the manufacturing choices in a distributed manufacturing scenario.

1 INTRODUCTION

There has been tremendous increase in environmental pollution due to frequent manufacturing activities around the globe in evolving distributed manufacturing systems interlinked with product specific supply chains. Besides, newly introduced stringent environmental regulations and shift towards mass customized production have given the manufacturers only option to adopt more environmental friendly practices inside as well as outside their factories. This is the one of the main aspect for achieving sustainability, which has become a very crucial factor for competitiveness in the global market. The latter needs efficient management of manufacturing indispensable to target the ambitious environmental objective envisioned by the European Commission (EC) in its Horizon2020 program and in the Organisation for Economic Co-operation and Development (OECD), to embark on the journey of sustainable manufacturing and eco-innovation. Further, the manufacturing landscape is distinguished by decentralization in manufacturing systems, mass customization of products and changing strategic goals. At the same time, increasing production rates due to expanding markets are resulting in huge consumption of resources thereby influencing environment quite sharply. In the context of manufacturing networks and supply chains, this requires following those procedures in planning supply chains that guide towards sustainable manufacturing minimizing the impact on environment and ensuring competitiveness. However, the insufficient knowledge support and unsystematic management of the information related to environment hinders or cease the decision making for eco-efficiency in manufacturing. The following section presents a review of approaches reported in the scientific literature for eco-efficiency based manufacturing planning.

2 ECO-EFFICIENCY BASED MANUFACTURING PLANNING

The research on developing planning strategies for eco-efficiency in manufacturing has got wide

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importance in literature. Several initiatives have been taken by legislative authorities European Commission (EC), UNEP etc. These initiatives emphasize on adopting methodologies and tools to facilitate eco-efficient decision making in manufacturing system. This would lead to incorporation of environmental management strategies in the whole factory more specifically in the manufacturing planning ensuring better environmental operational performance on the factory floor. Sroufe et al. 2002 made a detailed analysis on scientific literature that establishes relation between environment management and the operational performance of the manufacturing system. Several models have therefore been investigated linking the environmental emissions with operations performance and listed in (Sroufe et al. 2002) thereby highlighting its importance in evaluating manufacturing performance based on environmental impact (Figge et al. 2002) (Schaltegger et al. 2000). The incorporation of this criterion in decision making is a big challenge for enterprises particularly the SMEs. Such system is not yet implemented there possibly due to development costs (Golinska and Romano, 2012). However, the cost factor changes when a manufacturing planning is viewed from the hierarchical perspective. In (Sroufe et al. 2001), the researchers have grouped environmental management related practices at operational, tactical and strategic levels in a performed case study. This study shows that the manufacturers are now emphasizing on adopting environment related decisions at the operational level. These practices include scheduling, sequencing and capacity planning. Apart from introduced methodologies to evaluate environmental impact in distinct areas of the manufacturing, numerous tools have been reported in the literature which uses eco-efficiency related performance indicators in the manufacturing planning particularly in the efficiency evaluation of supply chains. For example, the efficiency of the supply chain is based on how well the material requirements planning is made, which is primarily dependent upon effective tools addressing all the necessary strategic and the derived operational objectives and performance indicators of the company. Melynk et al. 2001 introduced a Green material requirement tools to incorporate environmental issues in material requirement planning. It is one among many preliminary concepts that targeted minimization of environmental impacts of waste stream generated in manufacturing processes. A model based on fuzzy set theory for the assessment of environmental hazards in manufacturing is introduced in (Hui et al. 2002). The big issue in such assessment is the uncertainty of the information used. A case study was performed (Hui et al. 2002) manifesting the fuzzy set based approach as a lever to minimize uncertainty in the information being used for environment assessment of manufacturing processes. Manufacturing processes generally consume huge amount of energy which directly affects the environment. Therefore, research literature principally addresses issue of evaluation of energy performance in manufacturing systems, defining strategies to reduce energy consumption and the environmental impact of manufacturing processes. The environmental impact reduction through energy performance improvement has been targeted and several solutions have been proposed. A common measurement framework for guiding the company managers and external stakeholders to adopt eco-efficiency as means for environmental sustainability has been introduced in (Verfaillie et al. 2000). This framework provides assessment of environmental impact during product creation and during service based on five prominent indicators i.e. energy consumption, water consumption, material consumption, Green house gas emissions (GHG) and Ozone depleting substance emissions (ODS). Hence this way, the framework provides a flexible framework that is widely used, broadly accepted and easily interpreted in the environmental measurement framework. Therefore, more environmental sustainability can be ensured once the guidelines mentioned in this framework are followed. However the quantification of sustainability needs assessment methodology that can be practically used widely in the industry. One of the methodologies for such quantifications is the Life Cycle Assessment approach. It is termed as the grouping and assessment of potential environmental impact of products and services along the life cycle, enabling determination of the environmentally aggressive stages in the product life cycle. Preuss (2005) emphasized the need for environmental management system for greening the supply chain. Several methods were outlined e.g. allowing manufacturers laying focus on eco-efficiency of the material acquired from the suppliers, including the criteria of eco-efficiency in the selection of suppliers, incorporating better environmental monitoring procedures based on environmental standards like ISO 14001 and by establishing environmental management system in a manufacturing company. Bojarski et al. 2009 introduced optimization based on environmental impact using IMPACT 2002+ methodology. Decisions are made on determining the most eco- friendly manufacturing location and processing technology. In (Guillén-Gosálbez and Grossmann, 2009), the supply chain design problem take into account the presence of uncertainties in the life cycle inventory connected to the operation of supply chain network. A bi-criterion stochastic mixed-integer nonlinear program was developed to achieve maximization of the net present value and the minimization of the environmental impact for any given probability level. An LCA based Eco-indictor99 method was used to compute the environmental performance of the supply chain network. The stochastic model is transformed into deterministic model by re-defining the probabilistic constraints needed for computing the environmental impact. The capabilities of this model and the solution procedure using two case studies for determining the solution by trading off between the environmental impact and the profit has been elaborated. The solutions provide guidance to the decision makers for selecting the more eco-friendly supply chain in uncertain situations. A mixed integer model is developed that minimizes emissions throughout the supply chain by considering environmental sourcing (Abdallah et al. 2012). Life cycle assessment was made considering a case study. This case study covers three different scenarios based on different carbon emissions costs. The model helps manufacturers in choosing suppliers with better environmental performance. The above approaches provide models and methods how environmental performance can be included in the decision making. They however, do not focus on information systems needed for supporting environmental based decision making. The information system for supporting decision making based on environmental impact are known from the chemical industry in which energy and material flows are considered (Funk et al. 2009).

In various projects like OPUS (Bullinger et al. 2000), CARE, INTUS the environmental accounting instruments in the ERP systems were created as described in (Funk et al. 2009). However, these projects could not deliver a comprehensive tool or reference architecture of the information system model for the incorporation of environmental impact/eco-efficiency as a criterion in decision making. Further, they did not address issues related to information representation complexities in environmental based decision making. Möller et al. 2006 investigated the role of Information Technology (IT) systems to support environmental management accounting in ERP supported decision making processes. They also emphasized on well-defined data exchange between the ERP systems and the environmental information systems to help better storage of best practices of business processes in the ERP systems. Rautenstrauch 2007 described environmental management information solutions already made in the integration of the ERP with other management tools such as material flow management. The feasibility of integration of environmental management system with the ERP systems was investigated, which has got a very limited implementation scope. Funk et al. 2009 proposed calculation of environmental impact in ERP systems using environmental related information from external databases. Wohlgemuth et al. 2008 provided the basic architecture of software platform for environmental management information system. This platform supports the customized development of software tools as a plug-in application for material flow management but it does not provide any information system that could support in decision making in manufacturing planning based on the necessary key environmental criteria. Knowledge-based approaches have been tested in several distinct manufacturing planning areas for solving a number of individualized problems e.g. in (Cakir and Cavdar, 2006), a knowledge-base system is proposed to get recommendations on optimal cutting parameters in machining operations like milling, drilling and turning etc. However, knowledge management system has been limited to the development of information portals where environmental knowledge has been kept in inoperable fashion.

3 CASE STUDY AND PROBLEM DEFINITION

The presented literature review summarizes that the environmental based assessment of manufacturing processes is a necessary key performance assessment criterion in the manufacturing planning. This implies that the environmental impact of 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 manufacturing setups. The commercially available Product Life Cycle Management (PLM) and Enterprise Resource Planning (ERP) solutions do not cover holistic consideration of potential environmental impact in the evaluation of potential production schemes and eventually in the decision making process. The decision making process is a time consuming and non-trivial as the selected options have to be simulated using the conventional simulation tools and then the results are shared through non-standardized interfaces with the other simulation tools or even through manual means. Additionally, the planners have to rely on the LCA experts to conduct simulations and deliver results back to ERP/PLM planners. The exchange of information takes place in manual ways, which make decision making even more difficult when the resources are placed in a distributed fashion and intensive reliance of software 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 distributed systems in the manufacturing environment is to connect them semantically and infer required knowledge that facilitates planners with the comprehensive decision making. The question arises as to how it can be practiced actually in the manufacturing industry.

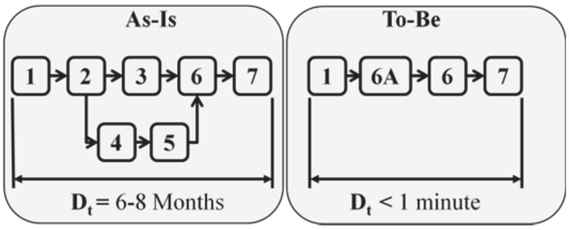

Figure 1: Environmental based decision making work flow (As-Is Versus To-Be).

In Figure 1, the nodes are numbered to represent the following

1. Order preparation/request for assessment
2. Correspondence & approval
3. Data collection (from inventory)
4. Hiring of LCA expert
5. Signing confidentiality/contractual agreement

6A. Environmental knowledge retrieval

6. Conduction of LCA study/environmental assessment
7. Reporting to planning department & final decision

D_t represents time to reach decision.

Considering the case of automotive industry, the work flow for environmental based decision (As-Is) is shown in Figure 1. The product for which the environmental impact has to be assessed is done in the following order (Referring to Figure 1).

1. The planning department requests for the assessment of potential environmental impact of the particular product.
2. Next the correspondence is made with the inventory department for the acquisition of product related information and negotiations are made to determine who will be selected for the LCA assessment.
3. Environmental related data as well as the product information is collected from the respective departments.
4. Afterwards, the LCA expert is hired to conduct such assessments. The assessments are made by internally or externally hired LCA expert.
5. In case of an externally hired LCA expert, a confidential agreement is generally made.
6. The assessment of environmental impact is made with the aid of commercially available life cycle assessment tools.
7. Finally the results are communicated to the planning department about the potential environmental impact of product under the LCA study

The total duration of this process is generally six to eight months depending upon the complexity of the product and the associated process chains under study. Moreover, the duration can be prolonged upto 18 months if the LCA study is made externally through sub-contracting. This situation reflects that the environmental based decision making cannot be incorporated in the company's operational performance due to time consuming workflow in mass customization scenario. As the mass customization has engulfed our manufacturing landscape, the environmental assessment of customized products and of manufacturing networks will become a part of operational planning. The environmental management system based on knowledge-based must therefore be devised to reduce this workflow substantially as shown in Figure 1 (To-Be). The objectives of environmental knowledge management system are the following:

i) 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.

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

iii) Enriching ontologies with the semantic rules for product and process classifications and mapping to

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the environmental concepts, to infer simulation models for the LCA tools.

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

v) Seamless exchange of information from the legacy tools and automatic generation of queries for synthesizing simulation models for the LCA simulation. The architecture for this web based environmental knowledge management tool must support the development using state of the art web technologies, knowledge representation formats, data exchange formats to deliver easy to use, easy to access, domain independent and location independent solution.

4 CONCEPT AND IMPLEMENTATION

Considering the case study, the problem formulation and the required objectives, the concept for environmental management system for environmental based decision making is presented in Figure 2.

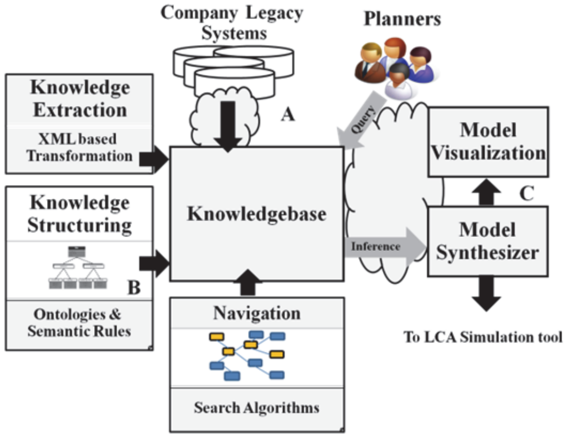

Figure 2: Overall concept of the knowledge management system.

The architecture concept for environmental management system comprises of the main modules namely the knowledge extraction sub-module, knowledge structuring module, navigation module, model synthesizer module and model visualization module. The knowledge is generated by both ways i.e. through interaction with simulation tool as well as the results generated from LCA simulation tools. The knowledge is extracted either through manual means formalized in the form of documented statements and by linking the tags. The knowledge is structured through formal representation using ontologies. These ontologies are used for knowledge extraction as well as for knowledge retrieval. The topics from the manufacturing and environment need to be conceptualized and articulated as several ontologies. The domain ontologies are constructed using standard ontology editor namely Protegé available as an open source aims at development of ontologies. The knowledge generated as a result of interaction between the simulation tool and the LCA planners is used to create new taxonomies or to populate the existing ontologies. The implicit knowledge of domains experts are translated into additional rules that would infer practical solutions for decision making. The ontologies are described in a formalized way complying with the W3C standards. The production scheme, which describes the details of decentralized manufacturing network for producing the customized product in an xml format, is imported in the knowledge retrieval portal. These specifications are related to products, processes and resources of all the selected manufacturing and supply locations against the customized order. This multi-level and cross connected information file needs to be parsed which afterwards is used for generating queries in compliance with the W3C standards. The query generator takes each node one by one and generates respective queries against each node mentioned in the production scheme.

5 VALIDATION

The implemented tool was tested based on the pilot case: the example of customized/individualized manufacturing of car hood assembly is selected to validate the concept. While it consists of simple multi-level bill of materials i.e. four parts and two customized additional parts, it is sufficient to demonstrate the concept, which facilitates users in understanding the product and process structure with or without customization easily. It also supports free manipulation of explicit knowledge (e.g. technical information) and tacit knowledge without violating the confidentiality of manufacturer related information/knowledge. The environment knowledge management system takes production scheme as an input (see Figure 4) and parses each manufacturing node in a sequential manner. This information is later on used to generate relevant queries. Thus knowledge is retrieved in a seamless and automatic manner. On the contrary, users can

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also search manually through a restricted search approach. The input given by the user through this web-based graphical user interface is processed by the query generator, which synthesizes queries complying with the knowledgebase structure.

For validation, the retrieval of environment related knowledge through the knowledge portal (web-based graphical user interface), the production of customized hood assembly in decentralized manufacturing is taken as an example. It includes a knowledge management system based on ontologies and inference system seamlessly connected with legacy tools. A wrapper is developed that connects the knowledge base system with the LCA simulation tool.

```
- <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 4: The XML representation of production scheme (Node A in Figure 2).

Suppose a user wants to search 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 select for the possible environmental impact indictors. For example, the user can 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 engine takes this input and generates SPARQL based queries to search the relevant information in ontologies.

The knowledgebase comprises of material, process, resource and environment related ontologies. The material ontology describes materials as final products, products in processing phase and raw materials. The Figure 5 shows the taxonomies of ontologies of materials, processes, resource and environmental related ontologies.

```
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#MaterialObjectProperty -->
<ObjectProperty rdf:about="&untitled-ontology-5;MaterialObjectProperty"/>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#MaterialObjectPropertyMaterial -->
<ObjectProperty rdf:about="&untitled-ontology-5;MaterialObjectPropertyMaterial">
  <rdfs:subPropertyOf rdf:resource="&untitled-ontology-5;MaterialObjectProperty"/>
</ObjectProperty>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#MaterialObjectPropertyRawMaterial -->
<ObjectProperty rdf:about="&untitled-ontology-5;MaterialObjectPropertyRawMaterial">
  <rdfs:subPropertyOf rdf:resource="&untitled-ontology-5;MaterialObjectProperty"/>
</ObjectProperty>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#OperationObjectProperty -->
<ObjectProperty rdf:about="&untitled-ontology-5;OperationObjectProperty"/>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#OperationObjectPropertyEnvironment -->
<ObjectProperty rdf:about="&untitled-ontology-5;OperationObjectPropertyEnvironment">
  <rdfs:subPropertyOf rdf:resource="&untitled-ontology-5;OperationObjectProperty"/>
</ObjectProperty>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#OperationObjectPropertyMaterial -->
<ObjectProperty rdf:about="&untitled-ontology-5;OperationObjectPropertyMaterial">
  <rdfs:subPropertyOf rdf:resource="&untitled-ontology-5;OperationObjectProperty"/>
</ObjectProperty>
<!-- http://www.semanticweb.org/ontologies/2012/7/9/untitled-ontology-5#OperationObjectPropertyResource -->
<ObjectProperty rdf:about="&untitled-ontology-5;OperationObjectPropertyResource">
  <rdfs:subPropertyOf rdf:resource="&untitled-ontology-5;OperationObjectProperty"/>
```

Figure 5: Excerpt of manufacturing related ontology (Node B in Figure 2).

The process ontology 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 additional production rules.

This enables concrete search helpful for providing recommendations to the planners as well as suggested LCA (Life Cycle Assessment) 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 additional rules to enrich the knowledgebase.

Figure 6 is an example of the graphical input output model (Car Hood Assembly). This model shows the environmental impact of the requested

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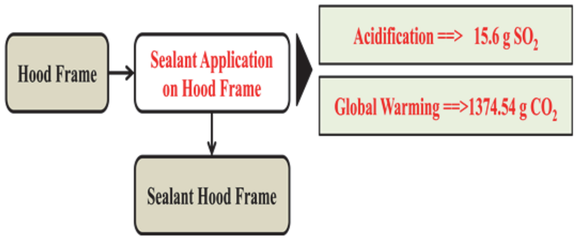

Figure 6: Generated knowledge related to part of the manufacturing operation in customized hood assembly (Node C in Figure 2).

operation in customized hood assembly, generated against a respective operation node mentioned in the production scheme (see Figure 4). The tool infers environmental knowledge related to the 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 in the knowledgebase). The tool facilitates inclusion of tacit knowledge from both planners and the LCA experts.

4 CONCLUSIONS

The environmental knowledge management is needed to work seamlessly with the company planning software tools to support reliable, precise and much quicker decision making than those practices already in place. A concept for environmental knowledge management system is implemented and validated through the pilot case from the automotive industry. With the help of this pilot case, the knowledge from manufacturing and environmental domains is implemented using ontologies in compliance with the W3C standards. A Web-based software solution is developed for customized user query interface, ontology based knowledge-base is implemented and validated.

The environmental knowledge management tool allows input by two means: directly from users in the form of customized user queries or by simply uploading the production scheme data generated by legacy tools. This query is generated after the user has customized his input information through text input or through keyword using free search functionality. The query engine allows searching of information from ontologies, which is delivered to the model synthesizer inferring LCA based simulation models. The generated results are used to enrich the knowledge base for better inference capabilities. As an outlook, new functionalities like processing of natural language queries with smart context will be added. Additionally, the extraction of environmental related information and automatic population of ontologies will be made, seamlessly linking both the company legacy tools information and as well as the LCA tool outputs linked with the environmental knowledge management tool.

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