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Optimize Energy Efficiency in the Supply Chain of FMCGs with the use of Semantic Web Technologies

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Abstract

Supply Chain Management is a critical domain for Fast Moving Consumer Goods (FMCGs). This domain is known for its complexity. New standards and regulations regarding Energy Efficiency and Environmental Aspects in general, as well as customer demand, make the analysis, modeling and design of the Supply Chain more and more complicated. Partners involved in these processes are numerous and of diverse background. To help solving this problem, common understanding of the domain and exchange of information among partners involved in the Supply Chain is of high importance. An ontology capturing the knowledge of the domain was created. To achieve maximum efficiency of the domain operations in terms of cost, quality of service and environmental impact, concept definitions from multiple sources were gathered. An advanced software solution that leverages semantic web technologies, enables users to link data from multiple Excel spreadsheets and relational databases together in real-time for data collection, collaboration, and reporting. In this framework, a new way for collaboration throughout the supply chain with the use of an underlying ontology, semantic technologies and visualization technics is introduced. The proposed approach is applied in the context of the FP7 European project e-SAVE.

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Keywords: Energy efficiency; Supply chain; FMCGs; Ontology; Semantic Web Technologies; Domain definition

1. Introduction

In this paper we present new techniques for information visualization using a semantic framework and an underlying ontology to represent various data collected at different stages of the product lifecycle. The type of data

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generated and its relevance varies throughout the product lifecycle thereby affecting the supply chain design. The modern supply chain must be dynamic enough to match product characteristics and customer requirements which vary throughout the lifecycle of the products. The focus of this paper is on the supply chain of non-durable, low margin FMCG products. These low margin goods require an extensive distribution network and often result in high stock turnover, thereby making the supply chain a critical to minute changes during the product lifecycle. In such a dynamic business environment real time data acquisition, information sharing and decision-making tools play an imperative role in the design of an efficient supply chain. Knowledge sharing, real-time market analysis, acquisition, management and representation of product related data further complicates the analysis, modeling and design of the Supply Chain. Due to vast multitudes of systems acting at various levels, knowledge exchange, processing and interpretation requires a mutual machine understandable knowledge representation framework. The proposed framework presents special capabilities with respect to knowledge extraction, data storage and binding and information visualization during different stages of the product lifecycle. With an ontological core, we employ existing features and tools of semantic technologies to retrieve, identify and display relevant information from product data which helps us design an energy efficient supply chain.

Ontologies have proven to be a very efficient tool for knowledge structuring and exploitation. They have been largely used in supply chain to represent different supply chain networks. Ye et al. [17] propose an ontology-based architecture for addressing the problem of semantic integration in supply chain management aiming to serve as an interlingua between heterogeneous information systems. Fayez et al. [5] present an ontology model that aims to support the building of supply chain simulation models and thus assist in the decision making across the supply chain. The approach integrates several supply chain views as well as models with all the necessary distributed knowledge for the simulation models.

The TOVE ontologies aim to create an enterprise infrastructure concerning an overall industrial environment that extends beyond the supply chain domain. The proposed supply chain ontologies try to capture the resources and the structural concepts of a manufacturing enterprise, as well as an overall top-level ontology. Furthermore, Lu et al. [11] propose an approach for developing a product-centric supply chain ontology to support networked enterprises interoperability by extending a Product Ontology, with the SCOR model.

Ye et al. [18, 19] present a supply chain management ontology model which is constructed in a modular way, aiming to enhance its reusability and maintainability. The IDEF5 schematic language is used to visually represent the core concepts and relationships and Ontolingua is used to define the syntax and formal semantics of the ontology and serve as a translation mechanism between representation languages. Moreover, Zdravković et al. [20] present the SCOR-FULL ontology, which semantically enriches the SCOR reference model using the OWL specification in an attempt to overcome semantic inconsistencies and incompleteness of the SCOR model. Lastly, the Enterprise ontology provides a foundation for modeling an overall enterprise and provides concepts that can be the basis for modeling also the supply chain.

The amount of data in the world has been exploding in the past decades. Such large amounts of both structured and unstructured data makes it very difficult to process with traditional database software and IT services. Li Da Xu [17] reviews state of the art information management tools for supply chain quality management. Analyzing very large sets of data (most often unstructured), in order to continue to support productivity growth and innovation is becoming a key competition factor. However the growth of tools to analyze the data has been marginal. A big challenge today is the design of software which can utilize domain specific knowledge to effectively query, interpret and visualize the acquired data throughout the lifecycle of a product. An extensive survey of available techniques and their shortcomings has been presented in Keim et al [9]. Shaw et al [14] propose a systematic methodology for managing marketing knowledge and designing efficient decision support systems. Cheung et al [8] present a knowledge based customization system for supply chain integration to design an efficient supply chain.

Semantic enrichment using ontologies opens a possibility for automatic reasoning and inference, which leads to automatic generation of new knowledge. With the evolution of the web 3.0, semantic technologies are now being utilized to extracting the knowledge contained in big data. Owing to their focus on the "meaning" of the data, these technologies provide altogether different scope for storing, querying and visualizing data. The three underlying standards of the semantic web are Resource Description Framework (RDF), SPARQL and OWL (Ontology Web Language). These standards are utilized to develop the linked data methodology for publishing and sharing structured data. In this methodology each data entity is tagged with a Universal Resource Identifier (URI) and linked to each other to establish a graphical topology in the data. In order to provide integration for different platforms the data is modelled using RDF. Berners-Lee et al [1] completely describe the scope of this technology. Semantic data visualization is another distinct advantage of web semantic technologies. Visualization is employed in tools that support the development of ontologies such as ontology extraction tools and ontology editors. These tools employ schema visualization techniques that primarily focus on the structure of the ontology. Major uses of such visualization techniques are in analyzing data pattern, comparison between different datasets, data querying and information exploration. A detailed description of such tools is presented in Fluit et al [6].

Product Lifecycle Management (PLM) can be defined as a business activity of managing, in the most effective way a company's products all the way across its lifecycle. PLM as a knowledge management system helps in sharing product related information and innovation by gathering information through the product lifecycle. Sudarsan et al [15] have proposed an information modelling framework for PLM. Borsato [2] proposes an ontology that overcomes interoperability issues between applications throughout the product lifecycle. Closed loop PLM can be defined as a strategic business approach for effective management of product lifecycle activities by using product data/information/knowledge which can compensate for PLM to realize for product lifecycle optimization in closed loops with support for PEIDs and product knowledge and data management system. A holistic view of PLM covers all aspects of the product lifecycle from Beginning of Life (BOL) through Middle of Life (MOL) and End of life (EOL). Detailed information and material flows are required for creation of the detailed holistic lifecycle model. A successful creation of such a model will enable creation and transmission of performance characteristics and establish backward flow of information to the associated life cycle actors. Kiritsis [10] presents some imperative semantic technologies for closed loop lifecycle management.

Evidently interoperability and information exchange between various companies is critical for a successful lifecycle management of the products. In this paper we exploit sematic web technologies for transparent data management. These tools provide significant advantages in terms of time, cost and maintainability by addressing data integration and classification challenges. Fabian et al [4] propose an infrastructure for controlled sharing of semantic data between different stakeholders involved. Data integration and classification challenges are imperative in product life cycle analysis wherein gathering information and making the information "smart" instead of static is a key aspect of the analysis. The focus of this paper is on knowledge extraction and visualization from data retrieved during the supply chain phase of the product life cycle. Information sharing is an essential aspect in achieving supply chain integration and efficient collaboration between partners leading to an improved supply chain performance. Madenas et al [12] provide a critical review of the existing techniques for information sharing through the supply chain. A major success factor is the ability to extract, manage, share and visualize relevant information. We exploit the properties of the semantic tools to manage content dynamically and develop a platform to allow interoperability for data exchange between different players of the supply chain. A semantic system designed specifically for logistics part of the supply chain, focusing on business to business integration has been proposed by Preist et al [13]. Kalogerakis et al [8] propose a semantic framework for development of interoperable visualization application using domain knowledge of different domains. Applications such as AmiGo [3], PageMan [16] use an ontological back end for knowledge extraction and visualization but in life sciences domain. Huang and Lin [7] propose a solution for sharing knowledge with semantic web thereby addressing the problem of interoperability in a supply chain. In this paper we present a semantic ontology driven architecture to collect, extract and visualize data throughout the product lifecycle. The inherent goal of the designed framework is to be able to access all the information coming from historical and real time data regardless of format, structure, or location of the data.

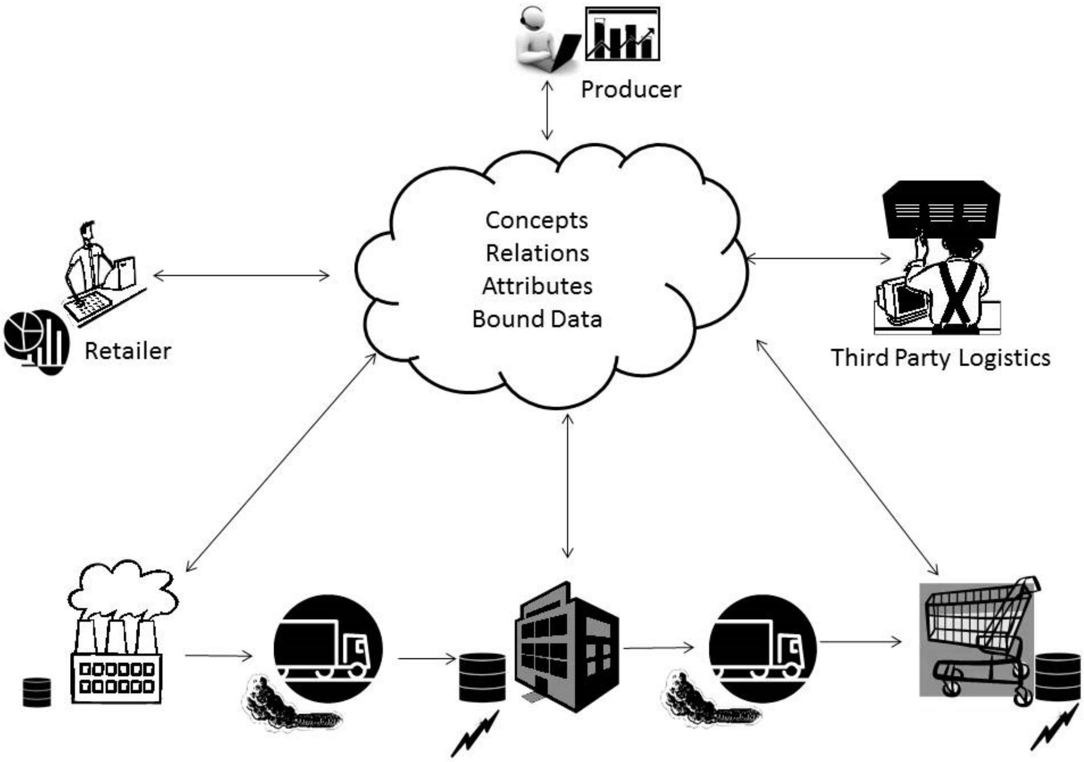

Fig. 1. The proposed view of a collaborative supply chain of FMCGs.

2. Tools

In the case of this study, several tools were necessary to model the ontology and map the data. Firstly, in order to develop the ontology of the e-SAVE environment, Web Ontology Language (OWL) was used. OWL is used when processing the content of the information rather than just presenting it. It permits a greater machine interpretability than other languages such as XML, RDF, etc. The engineering tools used are listed below.

Protégé (http://protege.standford.edu/) is an open platform for ontology modeling and knowledge acquisition. Protégé was used to edit the original ontology of the e-SAVE domain.

The main Protégé functions are: load and save OWL and RDF ontologies; edit and visualize classes, properties, and SWRL rules; define logical class characteristics as OWL expressions; execute reasoners such as description logic classifiers; and edit OWL individuals for Semantic Web markup.

Protégé is available in different versions, each including different plug-ins, whose main difference is the ontology language that they support:

• Protégé version 3 supports OWL 1.0, RDF(S) and Frames.
• Protégé version 4 supports OWL 2.0.

We use Anzo Enterprise to link and visualize data. Anzo Enterprise (http://www.cambridgesemantics.com/products/anzo-enterprise) is “an open platform and set of tools for building and deploying Unified Information Access (UIA) solutions.” It permits the virtualization of any structured or structured set of data into a unique information structure, the analysis of the environment with easy to create dashboards, and operationalization of data with automated actions and sharing. Anzo Enterprise was used to link the data sets to the ontology and visualize and analyze it with the Anzo web application.

Furthermore, WebProtégé is used in order to support collaboration for Ontology Engineering and to make the Ontology publicly available. The e-SAVE Ontology can be found and downloaded under http://esave-dev.intrasoft-intl.com:8080/webprotege/ .

3. Data Collection

In this section we outline the steps essential to collect, gather and link data to the ontology and display the relevant knowledge in the data. Ontologies act as a schema definition for the relation of various things within the knowledge domain. Through its graph structure, it is possible to find, trace and relate the relationships between things. If these connections and relationships make sense — that is, if the ontology is coherent — then there is a consistent logic model for searching and organizing information within the domain. Hence after the development of the ontology the immediate step is to collect and link data with the relevant concepts of the ontology. Through the European project e-SAVE several components for data collection were developed. The developed framework allows for the dynamic and automatic computation of the carbon footprints of the activities and products of the supply chain through the development of a dynamic LCA engine, and the bridging of the tool with existing information through web- services. It is based on formulas-based allocations of the carbon footprints of the activities along the supply chain to the products going through this supply chain over a specific period. Automatic exchange of the generated carbon information with other components of the proposed framework that may facilitate supply chain management, Reporting and Environmental Impact Assessment (Simulation) is also possible.

4. Link data to Visualize, Analyze, Share and Reuse information

We now link all the available measured data to our ontology. To do so, we use anzo enterprise which allows us to link datasheets to the concepts of our ontology. For instance, for a class called Product we could link data to its attributes such as its EAN Code, its name, its Product Category, its Packaging, etc. These set of tools permits us to link numerous datasheets coming from a variety of databases, spreadsheets, CSVs and more to our shared ontology. In doing so, it allows any collaborator to link relevant data that he may have to the model and share it instantly with all other users constantly enriching the overall model. In the case of this project, we linked two different databases to our e-SAVE ontology. One of the databases included measurements made by the company studied itself and the other was a database for common environmental impacts for vehicle types. The linked data can be then visualized through dashboards, charts, tables, etc. Data linking process is as follows. We first log on to the anzo server and are displayed a window depending on the users' role. We use the database connect tool to create a new data base connection depending on the database type. In case we use spreadsheets or csv we use the excel plugin provided by anzo. We perform sql queries in order to retrieve related data. Finally, we load the relevant ontology for the exposed dataset and we map the available data to the ontology.

5. Information Visualization and Analysis

In this section we discuss about the use of business intelligent tools which utilize ontologies to extract information for both structured and unstructured sources and analyze it by linking the data to personalized web dashboards where all changes are instantly updated. This permits us to link and share information from all supply chain partners, customers, and other web sources by extracting them from a Big Data repository. Another positive aspect of the sharing opportunities of ontology modelling is the standardization of field definitions in order to suppress issues of understanding between partners of the environment. For instance, when defining the concept of Product (class), the editor can assign specific properties to it making standardized data form for the products in the environment. This will then make it easier for collaborators to share their own data on products by giving data which will be comparable to the one of others. Though maintaining the agility and freedom of an open model, applying the lows of natural selection.

Finally, sharing the ontology bring opportunities for users to extend the model as one can easily add new concepts and properties without losing any of the previous data. All of the data of the dashboard is then kept in synchronization meaning that any update on the model will be instantly taken into account by all devices connected to the model. Any form created by any user will be automatically updated with the relevant data.

All of these reasons make data analysis through ontology sharing more reliable and always kept up to date between partners of the environment, hence reducing the degree of subjectivity.

We now showcase the designed assessment tools which automatically evaluate the environmental performance of a supply chain and its actors (linked corporate carbon footprints) as well as to deliver the environmental profiles of the products going through this supply chain (large-scale automatic generation of products' carbon footprints). Such tools were created with the intention to reduce time and cost to generate carbon footprints (corporate and products) over any period of time. This is particularly true for the carbon footprints of products which can be generated on a massive scale, e.g. for product labelling. They can also assist in the analysis and identification of potential actions of carbon emissions reduction and possible actions to monitor these actions. Once the ontology has been evaluated and validated with the data available to all the users, we now visualize and analyze the gathered information. Anzo gives access to the users to numerous visualization and analysis tools: one can chose to present the data in different forms (column or bar charts, pie charts, tables, etc.), create filters on data in order to visualize specific parts of the model and create a dashboard giving users "an easy to read, often single page, real-time user interface, showing a graphical presentation of the current status and historical trends of an organization's key performance indicators to enable instantaneous and informed decisions to be made at glance," (Peter McFadden, What is dashboard reporting, 2012).

The list below summarizes the features of such a solution of Supply Chain analysis:

- Modifying one value will synchronize in no time the data base on the cloud storage;
- KPI charts can be configured and shared with anyone by giving the link of the charts;
- These KPI charts are updated automatically if an entry has been changed or added. It is possible to block the KPI charts if someone does not want it to be updated;
- Agents can fill data forms from web applications or from datasheets. This results in both cases in updating data and updating the KPI charts;
- The ontology model can be exported in tabular form, which is the act of mapping;
- Various tutorials as descriptions or some pop up to prevent errors (hints, alerts, etc…) can be done and shared;
- Everything has a Uniform Resource Identifier (URI) which means it can be shared by link and in a group;
- There are confidentiality parameters that the owners can define to improve the security;
- By using filters, one can focus on the parameters or concepts in which he is interested in.

Below are presented a few examples of the information which could be extracted from our model. As the client is looking to optimize energy efficiency and carbon footprints of its supply chain, we thought it is interesting to show some example of the CO2 impact per product category, functional node, or functional section. Each of these example will serve to present some of the visualizing tools available to the users.

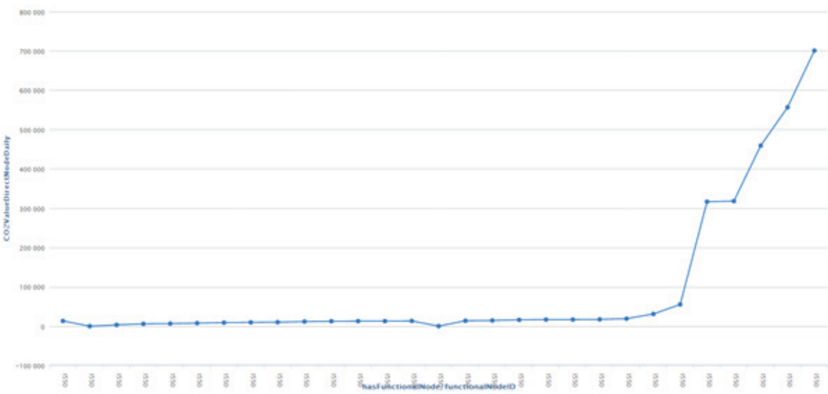

Fig. 2. Evolution of CO2 direct value for Node l550 during April 2012.

This first graph shows the evolution of the CO2 direct value of one functional node during one month. This figure was built from a datasheet including CO2 direct values for all functional nodes, during the full year of 2012. By creating a date range filter we were able to show the evolution only for one specific month while filtering on a single functional node. This graph shows that CO2 emissions for this node are mostly close to zero, but rise greatly towards the end of the month.

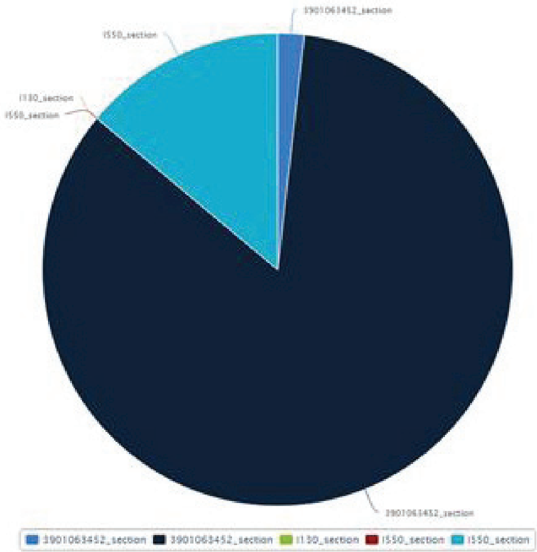

Fig. 3. Evolution of CO2 direct value for Node l550 during April 2012.

After showing the evolution of CO2 direct values for one month in functional node l550, it can be interesting to see which section of that node has the greatest impact daily. In the above pie chart, we can visualize the proportion of CO2 impact of each section, filtered on the same range of date as previously or another. In this chart, in order to change functionalities, the date was filtered on one single day: the 11th of July, 2012.

Finally, having analyzed which section has the most impact, it now could be interesting to see which product category has the most impact for the previously studied node.

Many more KPI Charts could be created and made available to all users of the model. All of these opportunities of visualization and analysis of the data make it easier for companies to study supply chains in their totality offering a very wide range of optimization plans. It seems obvious that these tools make this new method of collaboration between partners of the supply chain a very powerful and complete one. This is why, nowadays, many efforts are made all throughout the world to enhance the use of underlying ontologies, semantic technologies, and visualization techniques.

6. Conclusions

This project was an approach to understanding the benefits of the use of ontology modelling for Supply Chain Management for FMCGs. From the work done, it is clear that such an approach can only be enriching for all partners of the chain. Nevertheless, this project was completed as a simple study background and should therefore be deepened in order to have satisfying results. One of the main concerns is to gather missing data for the ontology. For instance, as mentioned before, nodes, products and vehicles do not have human readable names in the databases. Moreover, a lot of concepts developed in the ontology do not yet have data mapped to them. The first future step would then be to situate precisely which concepts lack data and contact the appropriate collaborators to gather and share that information.

Secondly, a lot of the information gathered remains unused because of inconsistent or missing IDs between concepts from one partner of the project to another. The next step should then once again be to situate which concepts that should be linked together are not in order to assign consistent IDs between the different data sources taking all the available data into consideration.

Finally, once both previous steps are completed, the model should be evaluated by all of the partners of the project in order to produce for example a company dashboard showing all the relevant data in different visualization forms. This instantly updated dashboard could then be shared will all partners of the supply chain constantly demonstrating new ways to optimize the chain's energy efficiency, or even reduce costs and increase service levels.

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