# Ontology Driven Approach for Intelligent Energy Management in Discrete Manufacturing

Hendro Wicaksono[1], Sven Rogalski[2] and Jivka Ovtcharova[2]
[1]*Intelligent Systems and Production Engineering/ Process and Data Management in Engineering,*
*FZI Research Center for Information Technology, Haid-und-Neu Str. 10-14, D-76131, Karlsruhe, Germany*
[2]*Institute for Information Management in Engineering, Karlsruhe Institute of Technology,*
*Zirkel 2 Building 20.20, D-76131, Karlsruhe, Germany*

Keywords: Energy Efficiency, Energy Management, Knowledge Acquisition, Machine Learning, Manufacturing, Ontology.

Abstract: In recent years ontologies have been used for knowledge representation in different domains, such as energy management and manufacturing. Researchers have developed approaches in applying ontologies for intelligent energy management in households. In the manufacturing domain, ontologies have been used for knowledge management in order to provide a common formal understanding between the stakeholders, who have different background knowledge. Energy management in a manufacturing company involves different organizational entities and technical processes. This paper proposes an approach to applying ontology for intelligent energy management in discrete manufacturing companies. The ontology provides a formal knowledge representation that is accessible by different human stakeholders as well as machines in the company. This paper also demonstrates the methods used to construct and to process the ontology.

## 1 INTRODUCTION

Facing a politically challenging future - determined by environmental targets, the finite nature of fossil energy and a constant population increase - energy and resource efficiency has developed into one of the most crucial issues of the 21st century. Following industrialisation, especially in countries with emerging markets, there has been a significant increase of energy demands in the past decade.

Besides the ecological and social motivation, costs also play a decisive role. Products with many variants have made processes more complex. These are often very energy intensive and therefore expensive. This implies that on one hand, manufacturers need to be flexible in order to satisfy these diverse demands. On the other hand, customers demand high quality and often more precise products (Kinkel, 2005). In addition, increasing energy prices reduce the revenue span. Hence, energy efficiency in accordance with the economization of production costs is an important competitive factor in the energy-intensive industries, such as manufacturing.

A suitable solution to address this problem is the introduction of corporate energy management. This can be established depending on the size and energy intensity of the company. Energy management defines the sum of all processes and measures which are developed and implemented to ensure minimal energy consumption with the given demand. An energy management system (EnMS) is a systematic way to define the energy flows and serves as a basis for decisions to improve energy efficiency. An EnMS includes the implementation of organization and information structures that are necessary for energy management, including the required tools for this purpose (Kahlenborn et al., 2010). The standard ISO 50001 describes the requirements for energy management systems for industrial companies.

Most manufacturing companies face problems in implementing the energy management standards. There are often no standardizations in their operation portfolios (plants, sites, etc.). The energy consuming production processes, building infrastructures, as well as power plants are documented and managed separately and in an unstructured manner.

Management has little insight into the usage of energy in the operation, due to the knowledge gap between managers and operators. Managers do not

Wicaksono H., Rogalski S. and Ovtcharova J..
Ontology Driven Approach for Intelligent Energy Management in Discrete Manufacturing.
DOI: 10.5220/0004141601080114
In *Proceedings of the International Conference on Knowledge Engineering and Ontology Development* (KEOD-2012), pages 108-114
ISBN: 978-989-8565-30-3

have the tools to manage the energy usage over different vertical and horizontal levels of the organization. Operators often do not realise whether their activities and decisions create excessive energy usage or demand. Best practices to avoid energy wastage are only known by some employees, but the other employees do not have access to this knowledge.

An important step in energy management is to measure the energy consumption at different levels of granularities. This can be done using data acquisition systems. The framework of a data acquisition system contains signals, sensors, signal conditioning, hardware and a computer with software. Due to the various technologies of data acquisition systems, connectivity and standardization are important issues to establish an automated energy management system. Most of the meters have to be read manually and thus it presents problems in accuracy.

The energy data acquisition systems are not integrated with other IT systems, such as Enterprise Resource Planning (ERP) or Material Execution System (MES). It is difficult to relate the energy consumption and demand with manufacturing operations, employee activities and business processes. It causes an inaccuracy of energy cost allocation to the produced goods or services.

This paper proposes an ontology based approach to solve the problems mentioned above and at the same time providing a knowledge base that can be accessed by intelligent systems.

## 2 THE APPLICATION OF ONTOLOGIES IN ENERGY MANAGEMENT AND MANUFACTURING DOMAINS

For the last ten years researchers have been applying ontologies as knowledge representation in various domains, such as medicine, agriculture, biology, software engineering, etc. Ontology has proven to be a solution to the shared understanding problems among people and even software. It is used to harmonize the knowledge gap between customers and manufacturers during the requirement elicitation in the pre-contract phase of the product lifecycle (Wicaksono et al., 2012). An ontology driven approach is also used to detect semantic ambiguities, uncertainties and contradictions in business and IT service management, therefore it overcomes the business gap between many IT service providers (Valiente et al., 2012).

In the energy management domain, ontology has been utilized as a representation of the knowledge base for an intelligent system that monitors and controls the energy consumption in a household (Wicaksono and Rogalski, 2010). The rules represented in SWRL are integrated in the OWL-Ontology. Wicaksono, Rogalski, and Kusnady (2010) developed an approach to allow the semi-automatic generation and instantiation of ontology elements using a machine learning algorithm (Wicaksono et al., 2010). Ontology is also used to classify home electrical appliances produced by various home appliance vendors and manufacturers to allow a comparative analysis of their energy consumptions (Shah et al., 2011). Furthermore it is also used to represent functionalities of heterogeneous devices from different technologies used for home energy management (Rossello-Busquet et al., 2011).

In the manufacturing domain several studies have already been conducted on the application of ontology to structures and the integration of knowledge from the different systems or stakeholders. It begins with an approach from Lemaignan et al., (2006), which proposed an upper OWL ontology for manufacturing domain and presented two applications in cost estimation and multi-agent systems (Lemaignan et al., 2006).

Lin and Harding developed an approach to support information autonomy that allows the multi-disciplinary, inter-enterprise stakeholders to use their own terminology and information model and simultaneously facilitate the communication and information exchange among them (Lin and Harding, 2007).

In chemical industries, ontologies are also used to model different types of work processes. It allows the formal representation of operational processes throughout the plant life cycle (Hai et al., 2011). Panetto et al., (2012) proposed an approach for facilitating a system's inter-operability in a manufacturing environment based on an ontological model for inter-operating, all-application software that shares information during a product lifecycle. The approach tried to address the difficulties in managing heterogeneous information scattered within organizations. It focused on the concept that a product should embed the information about itself (Panetto et al., 2012).

Until today, there have been no researchers who have developed approaches in the use of ontology to support energy management in manufacturing. In this paper we propose an approach that adapts the

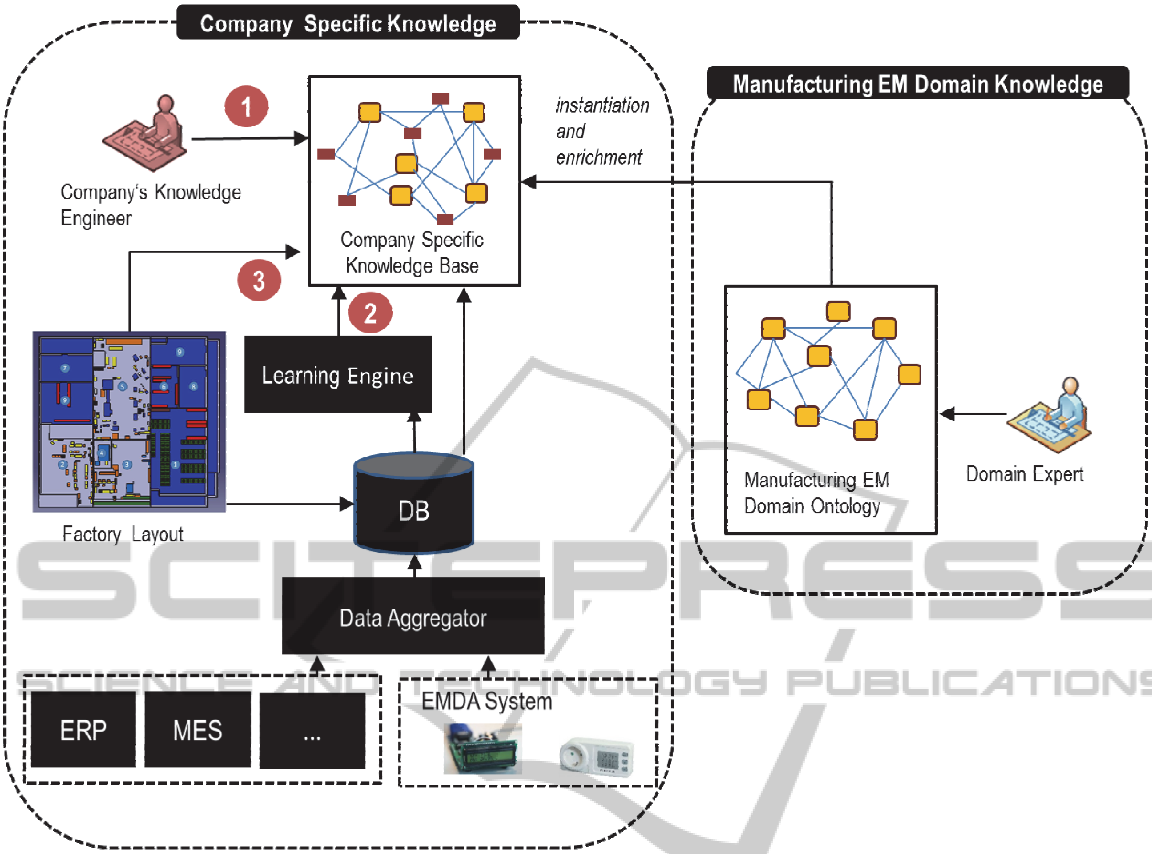

Figure 1: Architecture overview of intelligent energy management in manufacturing using ontology.

home energy management ontology to the manufacturing domain, resulting in manufacturing energy management ontology. We present some methods to generate the ontology as well.

## 3 CONCEPT OF ONTOLOGY BASED INTELLIGENT ENERGY MANAGEMENT IN MANUFACTURING

In our work, we use OWL – Web Ontology Language to express the knowledge model. OWL is originally a mark-up language for publishing and sharing ontologies on the web (Bechhofer et al., 2004)

The ontological classes as well as their attributes and relation definitions representing automation devices; for instance sensors, energy meters, building environments, production facilities, products and resources; are created manually by experts. The ontology containing these hand-crafted elements builds the knowledge base corresponding to the manufacturing energy management domain knowledge. It contains only the ontological classes or *Tbox* elements that describe the knowledge structurally and terminologically. It provides a common conceptual vocabulary in the manufacturing energy management domain. It does not contain any ontological individuals or *Abox* components.

The domain knowledge represents the meta model of a manufacturing energy management system, therefore it owns the validity for any manufacturing company and does not contain any instance-specific information. It also includes SWRL rules corresponding to common practices of energy management in manufacturing. SWRL is a mark-up language that combines OWL and RuleML (Rule Markup Language) and enables the integration of rules in OWL ontology (Horrocks et al., 2004).

The domain knowledge is added with company-specific rules. Some rules are created by the knowledge engineers in the company. Other rules are created semi-automatically by applying machine learning algorithms. The algorithms generate association and classification rules from the hidden

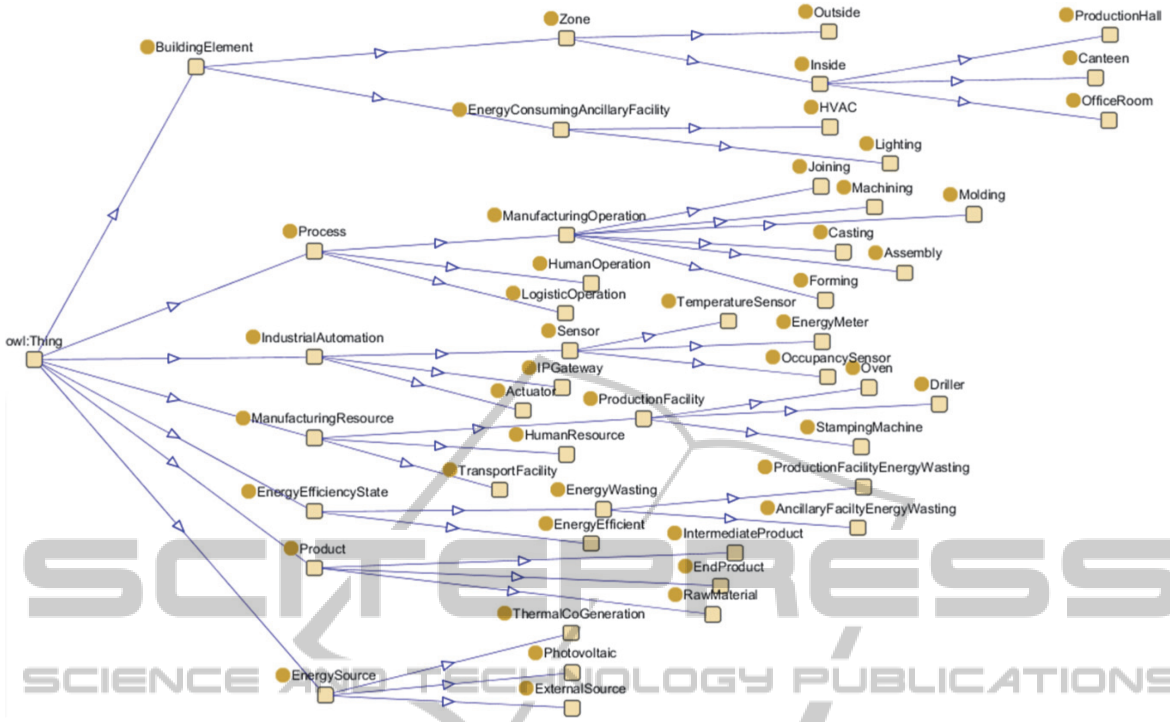

Figure 2: Class hierarchy of manufacturing energy management domain ontology.

knowledge that is extracted from the collection of energy, production and energy-related infrastructure data. The rules are converted to SWRL format and integrated into the ontology.

The *Abox* knowledge elements are created semi-automatically based on factory configuration and layout. For this purpose, we have developed a method for interpreting the semantic information from building and factory construction drawings (Wicaksono and Rogalski, 2010). This will result in an instance of the manufacturing energy management domain ontology containing company-specific knowledge elements. Figure 1 depicts the architectural overview of our approach for developing the intelligent energy management system.

## 4 THE ONTOLOGICAL KNOWLEDGE DOMAIN MODEL

Raza and Harrison (2011) have developed an ontological knowledge model for Product Lifecycle Management (PLM) in the automotive industry, based on relationships among products, processes and resources (Raza and Harrison, 2011). In our approach, we propose a similar method and add knowledge elements representing energy management related knowledge such as ancillary, transport or intra-logistics and energy conversion facilities.

Figure 2 depicts the class hierarchy of the manufacturing energy management domain ontology. At the highest level of ontology under the concept `Thing`, we put the classes `Product`, `Process`, `ManufacturingResource`, `BuildingElement`, `EnergySource`, and `EnergyEfficiencyState`. `Product` represents the discrete products, such as the purchased materials or products, the intermediate products that are manufactured within the factory and the end products that will be sold to the customers. We define energy relevant properties on the concept Product, for instance `hasVolume`, `hasWeight`, `hasMaterialType`. Based on these properties, it can be decided which machine the product should be manufactured with and how much energy it consumes.

We develop the process hierarchy similar to the one in the MASON approach (Lemaignan et al., 2006) consisting of `ManufacturingOperation`, `HumanOperation` and `LogisticOperation`. All of those processes can affect the energy consumption in the company. For the sake of simplicity, in this paper we present only several main manufacturing operations classes, for instance, `Forming`, `Joining`, `Assembly`, `Machining`, `Molding`, and `Casting`. The `Process` class has the property `hasEnergyConsumption`. We put the object property `produces` in `ManufacturingOperation`, to relate it to `Product` and `operatedOn` to `ProductionFacility`. The concept `LogisticOperation` represents the intra-logistic operation or transport between production facilities. It has the properties `hasOrigin` and `hasDestination` with `ProductionFacility` being the range of both properties.

The class `ManufacturingResource` consists of the subclasses `ProductionFacility`, `TransportFacility`, and `HumanResource`. It has a relationship to `Process` through the object property `operates`.

`EnergySource` represents the energy generation sources that are possibly used by the company. They can be from a utility company or internally generated, such as photovoltaic or thermal co-generation. We add the object property `supplies` with the classes `ProductionFacility` and `EnergyConsumingAncillaryFacility` as the ranges, in order to allow the modelling of the energy flow within the company.

The class `EnergyEfficiencyState` corresponds to energy efficiency that should be achieved and energy wasting or peak loads that have to be avoided within energy management activities. Through this class we can classify which practices or constellations could improve the energy efficiency, or which cause energy inefficiency. We consider a peak load as a state that should be prevented, since it can instantaneously cause high energy allocation, thus causing higher energy costs.

The class `BuildingElements` models the building structures, such as rooms, production halls, canteen, offices, as well as the energy consuming facilities that indirectly affect the production processes, such as lighting and HVAC systems. By using the approach in interpreting the factory layout drawing, the ontological elements of the classes can be generated semi-automatically (Wicaksono and Rogalski, 2010).

The class `IndustrialAutomation` represents the integrated application model for different industrial automation technologies. The actuator for controlling the production or ancillary facilities is modelled as a sub class. The energy consumption meter, temperature sensor, occupancy sensor and other sensors are also included as subclasses. The object property `isAttachedOn` is created to relate them to production and ancillary facilities.

## 5 COMPANY SPECIFIC KNOWLEDGE BASE

As shown in Figure 1, there are three ways to generate a company-specific knowledge base. The first is through the manual generation by knowledge engineers in the company. If necessary, the knowledge engineers can enrich the domain ontology with sector-specific ontological sub classes. For example, for a metal or stainless steel industry, the sub classes `Forging`, `HeatTreatment` and `Milling` are added as the sub classes of `Forming`. The energy efficient or inefficient practices are modelled with SWRL. An example of a condition, which describes energy wasting conditions of ancillary facility, is if an oven is active during a heat treatment process and the heating system located in the same zone or hall is still turned on, then it is considered as an energy inefficiency condition. Equation (1) illustrates the SWRL representation of such a condition.

```
Oven(?o)∧ HeatTreatment(?ht) ∧
operates(?o,?ht)∧ isActive(?ht,
true)∧ HeatingSystem(?hs) ∧
hasState(?hs, true) ∧ Zone(?z) ∧
isLocatedIn(?o,?z) ∧
isLocatedIn(?hs,?z)→
AncillaryFacilityEnergyWasting(?hs)
```
(1)

The knowledge inferred from the SWRL rules in equation (1) can be retrieved using Semantic Query-Enhanced Web Rule Language (SQWRL). SQWRL is a SWRL-based query language that supports SQL-like operations like negation, disjunction, counting, and aggregation (O'Connor and Das, 2009). The SQWRL shown in equation (2) can be used to retrieve all the ancillary facilities that are in under energy wasting conditions.

```
AncillaryFacilityEnergyWasting(?h)→
sqwrl:select(?h)
```
(2)

Since ontology is both human and machine readable, the knowledge base can be connected to an alerting or messaging system. If the SQWRL in Equation (2) returns some elements, a message can be generated. This can sharpen the awareness of employees in order to improve the energy usage efficiency within the company. The energy efficient/inefficient conditions that are formalized and stored in the ontological company's knowledge base, allow simple access and query from any employee as well. This accelerates the knowledge transfer among the employees in practicing energy management.

The second method is to semi-automatically generate the SWRL rules using machine learning algorithms. In the manufacturing sector, companies have to deal with large amounts of data from different systems. There is often knowledge hidden in the data that cannot be directly identified due to the complexity of the data. The Knowledge Discovery in Database (KDD) process extracts the knowledge from the data using machine learning techniques. As shown in Figure 1, the product, process and resource data from different IT systems, such as Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) are accumulated in a software module for data aggregation. The module is also responsible for performing the data pre-processing, such as data cleaning, selection and transformation. The energy related data from the Energy Monitoring and Data Acquisition (EMDA) system are incorporated by the module and they are finally stored in a relational database.

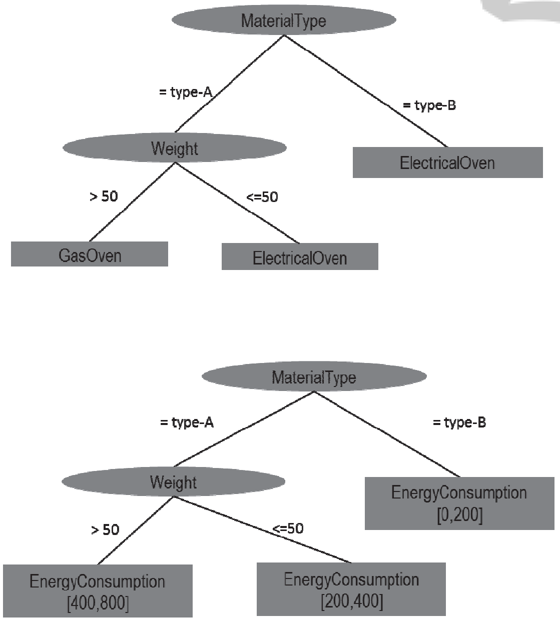

Figure 3: A result example of machine learning algorithm.

In our work, we develop a learning engine module containing machine learning algorithms to generate rules from the database. Figure 3 shows an example of a result of a machine learning algorithm that determines on which machine a product with the particular characteristics, i.e. weight and material type, should be heat treated and how high the energy consumption is. We develop a classification algorithm to generate rules for this purpose. Rules generated by the algorithm are then transformed into SWRL rules. Equation (3) gives an example of a SWRL rule arising from the algorithm results illustrated in Figure 3.

Based on the algorithm result shown in Figure 3, it can be concluded that if the weight of the product is less than or equal to 50 kg, the heat treatment process has to be performed in an electrical oven. It will consume energy between 200 and 400. That means, if it consumes more energy than 400, it can be considered an energy inefficient condition or anomaly.

```
  Product(?p)∧ hasMaterialType(?p,
    “Type-A”) ∧ hasWeight(?p,?w) ∧
      swrlb:greaterThan(?w,50) ∧
 ElectricalOven(?o) ∧ HeatTreatment
     (?h) ∧ operates(?o,?h) ∧            (3)
        produces(?h,?p) ∧
    hasEnergyConsumption(?o,?e) ∧
      swrlb:greaterThan(?e,400) →
ProductionFacilityEnergyWasting(?e)
```

By querying the ontology using SQWRL, it is possible to ascertain which machines or production facilities currently operate energy-inefficiently. Therefore a quick operative action can be performed to solve the problem. Since the ontology represents the semantics of the manufacturing energy management and allows a shared understanding among stakeholders, the management can have an overview of the state of their factory with respect to energy efficiency. An alarm system can be built based on the knowledge base.

The ontological individuals of the class `Product` are generated based on the data from the order management system and ERP (see Figure 1). The energy consumptions are assigned with data from EMDA system.

The third method is to generate ontological elements from building construction drawings and factory layouts. This method is not further presented in this paper. This paper focuses only on the knowledge representation using ontology and how the knowledge is generated.

## 6 CONCLUSIONS

This paper presented an approach to an intelligent energy management system in discrete manufacturing using ontology as the knowledge representation. We developed domain ontology for manufacturing energy-management. It consists of

OWL classes and SWRL rules representing common constellations of energy (in) efficiency. It is further instantiated and enriched, resulting in the company-specific knowledge. This paper explained three ways to generate the company-specific knowledge, i.e. manual generation by a knowledge engineer, semi-automatic SWRL rule generation using machine learning, and semi-automatic ontological element instantiation from building construction drawings and factory layouts.

The relationships among different energy related elements such as products, processes, resources, building elements and energy sources built in the ontology, enable a holistic analysis for any stakeholder on which factors can affect the energy (in) efficiency in the company. The knowledge gap among employees or between operative employees and management can thus be overcome. The approach allows the integration and standardization of different IT and EMDA systems within the context of a corporate energy management system.

However, to implement the approach, the role of the knowledge engineer and domain expert to generate the knowledge is still vital. Knowledge modelling could be a time-consuming, error-prone and inefficient task. The approach proposed in this paper could be further developed by applying ontology learning from text documents to automatically generate the ontological classes.

## REFERENCES

Bechhofer, S., van Harmelen, F., Hendler, J., Horrocks, I., McGuinness, D. L., Patel-Schneider, P. F. and Stein, L. A., 2004. *OWL Web Ontology Language Reference*. Retrieved on 15 April 2012, from http://www.w3.org/TR/owl-ref/.

Hai, R., Theissen, M. & Marquardt, W., 2011. An ontology based approach for operational process modelling. In *Advanced Engineering Informatics*, no. 25, pp. 748–759, Amsterdam, The Netherlands: Elsevier Science Publishers B. V.

Horrocks, I., Patel-Schneider, P., Boley, H., Tabet, S., Grosof, B. and Dean, M., 2004. *SWRL: A Semantic Web Rule Language Combining OWL and RuleML*. Retrieved on 14 April 2012, from http://www.w3.org/Submission/SWRL/.

Kinkel, S., 2005. *Anforderung an die Fertigungstechnik von morgen - Wie verändern sich Variantenzahlen, Losgrößen, Materialeinsatz, Genauigkeitsanforderungen und Produktlebenzyklen tatsächlich?*. Nr. 37. Karlsruhe: Fraunhofer Institut ISI.

Lemaignan, S., Siadat, A., Dantan, J. Y. and Semenenko, A., 2006. MASON: A Proposal For An Ontology Of Manufacturing Domain. In *Proceeding IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications*, pp.195-200. Washington, USA: IEEE Computer Society.

Lin, H. K. & Harding, J. A., 2007. A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration. In *Computers in Industry*, no. 58, pp. 428–437. Amsterdam, The Netherlands: Elsevier Science Publishers B. V.

O'Connor, M. & Das, A., 2009. SQWRL: A Query Language for OWL. In *Proceeding 6th International Workshop on OWL: Experiences and Directions (OWLED 2009)*, Chantilly, VA, United States.

Panetto, H., M. Dassisti, and A. Tursi., 2012. ONTO-PDM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment. In *Advanced Engineering Informatics*, no. 26, pp. 334-348. Amsterdam, The Netherlands: Elsevier Science Publishers B. V.

Raza, M. B. and Harrison, R., 2011. Ontological Knowledge Based System for Product, Process and Resource Relationships in Automotive Industry. In *Proceedings of the 1st International Workshop on Ontology and Semantic Web for Manufacturing*, pp. 23-36. Heraklion, Crete, Greece.

Rossello-Busquet, A., Brewka, L., Soler, J. and Dittmann, L., 2011. OWL Ontologies and SWRL Rules Applied to Energy Management. In *Proceeding 13th International Conference on Modelling and Simulation*, pp. 446 - 450. Washington DC, USA: IEEE Computer Society.

Shah, N., Chao, K. M., Zlamaniec, T. and Matei, A., 2011. Ontology for Home Energy Management Domain. In *Digital Information and Communication Technology and Its Applications - International Conference*. Berlin, Heidelberg: Springer.

Valiente, M. C., Garcia-Barriocanal, E. and Sicilia, M. A., 2012. Applying an ontology approach to IT service management for business-IT integration, In *Knowledge-Based Systems*, vol. 28, April 2012, pp. 76-87. Amsterdam, The Netherlands: Elsevier Science Publishers B. V.

Wicaksono, H. & Rogalski, S., 2010. Ontology Supported Intelligent Energy Management System in Buildings. In *Proceeding of IEEE International Conference on Industrial Engineering and Business Management (ICIEBM)*, pp.637-642. Yogyakarta, Indonesia.

Wicaksono, H. Rogalski, S. and Kusnady, E., 2010. Knowledge-based Intelligent Energy Management Using Building Automation System. In *IEEE IPEC, 2010 Conference Proceedings*, pp. 1140-1145, Singapore.

Wicaksono, H., Schubert, V., Rogalski, S., Ait Laydi, Y. and Ovtcharova, J., 2012, Ontology-driven Requirements Elicitation in Product Configuration Systems. In *H. ElMaraghy (ed.), Enabling Manufacturing Competitiveness and Economic Sustainability*, pp. 63-67. Heidelberg: Springer.