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Resource selection ontologies in support of a recipe-based factory design methodology

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Abstract

Factory (re) design involves the appropriate utilisation of product, process and resource knowledge in the determination of suitable configurations of physical factory facilities which have the potential to meet industrial and organisational requirements. Different independent semantic modelling standards exist for products, processes and resources but to automate and facilitate the selection of factory resources, there is the need to semantically integrate resource capabilities with product and process requirements. This paper defines a 'recipe-based' approach to designing factories and it is based on the assumption that capabilities and competences of reusable components (or building blocks) of factory resources can be semantically modelled and matched with product-process requirements. This approach will enable Factory Designers and Engineers to decide on relevant resource systems within finite, valuable and defined sets of requirements.

Keywords: Semantic modelling, Digital factory design, ontologies, resource selection

1.0 Introduction

Manufacturing Enterprises (MEs) are faced with intense competition arising from internal and external changes, which induce dynamics directly or causally on products, processes and their associated resources (Agyapong-Kodua and Weston, 2011, Ajaefobi et al., 2010, Weston et al., 2006). Many causally and/or temporarily related factors may induce these changes and lead to complex and difficult to predict dynamics (Agyapong-Kodua, 2009, Sterman, 2000, Richardson, 1999, Wolstenholme, 1999, Scholz-Reiter et al., 2004). Currently, in factory design scenarios, life cycle engineering of production systems is required to fully understand the changes that are likely to impact the various phases of products, processes and resource systems design (Weston et al., 2009). This is necessary to ensure that MEs:

(i) remain competitive during their lifetime, by realising high value added products in a timely and cost effective way

(ii) extended their useful lifetimes (thereby mitigating investment risks) despite general industry trends

To achieve this, several factory design methods have been reported (Pahl et al., 2007, Kroes, 2002). Clearly, there have been many advances in factory design technologies stemming from the use of mathematical and graphical simulation models (Chung, 1999, Heragu and Kusiak, 1988, Kim and Kim, 2000, Hamann and Vernadat, 1992); artificial intelligence (Mir and Imam, 2001, McKendall and Shang, 2006, Balakrishnan et al., 2003) and other knowledge-based tools (Grubic and Fan, 2010, Todorova and Stefanov, 2009, Fernández López, 1999, Schreiber et al., 1999, Horrocks and Harmelen, 2001, Dean et al., 2002, Grüninger et al., 2010, Fallside and Walmsley, 2004, McGuinness et al., 2000, Ribière and Charlton, 2000). Despite these advances:

1. Existing factory design approaches largely depend on the skill of the designer and can be very expensive. Although this is the case, very good examples of factory designs already exist and when these are aligned with product requirements, lots of time and investment on factory development tools can be saved. This can however be achieved if knowledge related to: 1) products; 2) processes and 3) resources is captured and semantically integrated to generate first stage high level needed factory solutions
2. There is limited interaction between stakeholders of the factory design process leading to long design lead times
3. As a result of (2), decisions are not concurrent, leading to potential errors in factory design decisions

4. The causal impacts of products, processes and resource changes on each other can be phenomenal
5. Limited alternative resource analyses is usually conducted rendering the design process ‘static’ because the true capabilities of resources are not carefully modelled.

To support resource systems analyses, literature (Byer and Weston, 2003, Cui and Weston, 2010, Ding and Weston, 2007, FP6-DIFAC, 2006, Ajaefobi and Weston, 2005) reports several techniques for developing conceptual and detailed models of resources. Some of the reported resource systems modelling approaches are based on scientific management techniques; socio-technical systems modelling techniques; approaches centred on modelling human behaviours; enterprise modelling linked to modelling functional elements of resources; developing ‘resource-based views’ as part of a ‘dynamic capabilities approach’; modelling ‘competency resource aspects of individuals’ (CRAI) (Ajaefobi et al., 2010, Weston et al., 2009). Despite the potential of these present-generation resource systems modelling approaches, there is limited application when reasoning about and/or predicting possible future behaviours of resources under changing workload conditions (Agyapong-Kodua et al., 2012).

The impetus for developing the recipe-based factory design approach therefore came from three related observations, namely:

(1) Many complex factory models exist today which address aspects of the factory design process. Also a number of standards and proprietary models attempt to cover the whole development cycle. These standards and models are too complex to be applicable in Small and Medium Enterprise (SME) domain. They are further not available for information sharing between different application providers.
(2) To develop a useful factory model, in general, it is necessary to model (qualitatively and quantitatively) ‘products’, processes’ and ‘resource systems’ aspects of the factory and to consider current and possible change requirements and impacts that arise from these changes.
(3) Current factory modelling tools especially the resource systems toolkits provide modelling constructs that enable modelling manufacturing systems in context but are less advanced with respect to:
    (i) Explicit specification of all resource sets: humans, machines and IT systems; more especially integrating the capabilities of these resource components into a unified resource system meeting factory design requirements.

(ii) Adjusting virtual resource systems dynamically to changing process requirements

(iii) Computer executing semantically selected resource systems and their behaviours in real production environments.

Based on the above observations on state of the art factory design solutions, this paper proposes that at least first hand virtual factory models can be developed by capturing and semantically describing ‘models of requirements’ of products and processes to maintain consistency in concepts and logic. At a second stage, resource systems are also modelled independently giving close attention to their capabilities and/or competences. Based on these separate models, resources can be selected and matched with the product-process requirements and vice versa. This will enable candidate resource systems with certain attributes to be selected to meet specified requirements. This is what has been described in this paper as the ‘recipe-based’ factory design approach.

As a way of demonstrating this approach, the paper focuses on semantic models of resource systems that can be matched at a conceptual level, then computer executed in support of stages of systems engineering via use of a suitable platform. The paper applies the ontoBroker (Ontoprise, 2011) as the main connecting platform whilst the resource systems are described with the objectLogic language in the OntoStudio environment (Ontoprise, 2011). Further to this, relationships, rules and logics for products, processes and resource integration have been built into the models so that useful results can be achieved by querying the semantic model.

2.0 Some advances in digital factory design methods

Research into product design methods has led to the development of design methods such as Design for Manufacture (Stoll, 1986, Scarr, 1986, Kobe, 1990, Boothroyd and Dewhurst, 1986); Design for Assembly (Boothroyd and Dewhurst, 1986), Design for Disassembly and Recyclability (Kuo et al., 2001), Design for Maintainability (Vujosevic et al., 1995), among others. Most of these methods consist of a set of sequential processes which need to be realised for optimal design output. Clearly, product design impacts on facility design and vice versa, hence product and facility design are causally related.

Factory design consists of the design and implementation of physical facilities and organisational infrastructure in view of realising products (Tong et al., 2003). It therefore consists of the congruent design of processes, resources and flows associated with products. Tong, et al. (2003), however, argue that factory design extends beyond product design requirements and must include the actual physical facilities' design, process definition, sequence selection, organisational infrastructure design and implementation, required for the product realisation process (especially the internal processes) of several types of products in a specialised area. Thus, it is not limited to the specification of product realisation sequences alone but instead the detailed specification of processes, resources and systems required for economic realisation of products (AMICE, 1993). This may therefore involve the extensive consideration of an entire supply chain with key focus on the design and location of internal facilities to help realise enterprise goals. As a result, proponents of business process re-engineering (Davenport, 1993, Bernus and Nemes, 1996, Gunasekaran and Irani, 2010, Vernadat, 2002, Hammer and Champy, 1993) have indicated that it is always necessary to model the conceived business case in a virtual world; experiment and modify resources and flow sequences until optimal solution is obtained (Gunasekaran and Kobu, 2002, Agyapong-Kodua et al., 2009, Agyapong-Kodua et al., 2012). Other researchers have indicated that being able to achieve this in an efficient, timely and cost effective manner requires the use of a coherent set of well experimented modelling tools focussed on products, processes, resources, information, cost, value, etc (Agyapong-Kodua et al., 2009, AMICE, 1993, Chen and Tsai, 2008, Lohse et al., 2006, Agyapong-Kodua et al., 2012).

A number of factory design methods (Iqbar and Hashmi, 2001, Sheth, 1995, Wiendahl et al., 2002) and techniques (Womack and Jones, 2003, Bicheno, 2000, Kosanke, 1996, Hines et al., 2004) have evolved over time with the objective of rapid design, coherent integration of processes and resources, virtual simulations and layout optimisation. These techniques and methods have led to the development of technologies such as applied in 3D and digital factory mock-up tools like Tecnomatix FactoryCAD (Siemens, 2000) for the representation of factory objects and simulation of performance of different arrangements of production resources. Also reported is the use of FactoryFLOW (CIM Technologies 2000) to optimise manufacturing facilities based on material flow requirements, distances between resource centres, cost, material and resource travel times. Other products from Tecnomatix help in the full animation, and 'walk through' and 'inspect' functions of Engineers. Different ergonometric analysis can be performed with the Mockup and Flythrough software (Siemens, 2000). Other tools from Tecnomatix which provide support for aspects of the overall factory design process are JACK and Factory OPT. Similar applications exist in the Delmia (Dassault Systemes) suite of software for the design of factories. A number of discrete event simulation tools have also aided the design and analysis of facility layouts. Further literature on this can be found in (Rahimifard and Weston, 2007, Chatha and Weston, 2005, Ajaefobi, 2004, Agyapong-Kodua et al., 2012, Ajaefobi et al., 2010, Khalil and Weston, 2010). Also immersive virtual reality has being used to provide a new working and assessment environment for the planning and design of factories (Wiendahl et al., 2002).

Further to the above tools, mathematical and artificial intelligence modelling techniques have been used for the design and optimisation of factory layout solutions. Literature has specified the use of artificial neural networks (Chung, 1999, Heragu and Kusiak, 1988, Kim and Kim, 2000); construction heuristics such as CORELAP (Lee and Moore, 1967) , ALDEP (Seehof and Evans, 1967), COFAD (Tompkins and Reed, 1976), SHAPE (Hassan, 1994); improvement heuristics such as CRAFT (Armour and Buffa, 1963), FRAT (Khalil, 1973) and DISCON (Drezner, 1987); tabu search algorithms (Chiang and Kouvelis, 1996), simulated annealing algorithms (Chwif et al., 1998, McKendall et al., 2006), genetic algorithms (Pierreval et al., 2003, Dunker et al., 2005, Balakrishnan et al., 2003), slicing tree (Shayan and Chittilappilly, 2004, Wu and Appleton, 2002), space filling curves (Wang et al., 2005), ant colony algorithms (Solimanpur et al., 2005, Baykasoglu et al., 2006) and hybrid genetic algorithms (Mir and Imam, 2001, McKendall and Shang, 2006, Balakrishnan et al., 2003).

Clearly, these mathematical and artificial intelligence methods are suitable for optimising factory designs. The main challenge however is that they do not provide mechanisms for checking poor designs and they sometimes only end up optimising poor designs. It is therefore appropriate to enact methods which will facilitate the development of good factory designs which can be optimised at a later stage.

Another approach commonly reported in the literature deploys process mapping technologies (Womack and Jones, 2003, Bicheno, 2000, Hammer and Champy, 1993, Hines et al., 2004). Serrano et al. (2008) after evaluating the performance of process mapping tools in manufacturing systems design indicated that in broad terms, ‘static’ process engineering tools which can support the design of factories can be broadly classified into flow diagram charts; structured systems and architectural systems. He classified value stream mapping (Womack and Jones, 2003, Duggan, 2003, Lee, 2005, Hines et al., 2004) and all the process mapping tools such as process activity maps (Hines and Nick, 1997, Bicheno, 2000), Customer maps (Bicheno, 2000, Hines and Nick, 1997), product variety maps (Bicheno, 2000), cost flow maps (Bicheno, 2000, Hines and Nick, 1997, Hines et al., 2004), etc as flow diagram charts. IDEF0 (Icam DEFinition Zero) (NIST, 1993), SADT (Structured Analysis and Design Technique) (Marca and McGowan, 1988) and SSADM (Structure

System Analysis and Design Method) (Ashworth, 1988) were classified as structured systems whilst GRAI (Graphes a` Resultats et Activite´ s Interrelie´ s) (Doumeingts et al., 1998) , CIMOSA (Open System Architecture for CIM) (Kosanke, 1996, AMICE, 1993, Vernadat and Berio, 1999, CEN/ISO, 19440), PERA (Purdue Enterprise Reference Architecture) (Williams, 2002) and the other enterprise modelling tools were classified as architectural systems.

These process mapping and enterprise modelling tools capture processes associated with the development of products but do not directly associate product and process requirements. More critically, they are functional in modelling operation activities and not fully deployed in the factory design phases. Integrated semantic requirements for resource and process coupling are not fully defined. Because most of these tools are research-based, they have had limited applications in industries worldwide.

Most recently, based on the European Factory of the Future (FoF) agenda, some research activities focussed on various aspects of the future factory have emerged. Some with promising outcomes include 'Modular Plant Architecture' (FP5-GROWTH, 2000), 'A configurable virtual reality system for Multi-purpose Industrial Manufacturing Applications'-IRMA (FP5-IRMA, 2010), 'Digital Factory for Human-Oriented Production System'-DiFAC (FP6-DIFAC, 2006) and 'Virtual Factory Framework'-VFF (VFF, 2009, Pedrazzoli et al., 2007). Work in these projects have led to the termed "Digital Factory" which is used to refer to the network of digital models, methodologies and applications required for the realisation and integration of activities within the full life cycle of a factory (VFF, 2009). The main objective behind the digital factory model is that perceived operations and controls in a factory must be modelled and experimented until expected key performance indicators such as cost, quality and lead time are favourable.

In the context of achieving this goal, the product-process-resource interfaces and dependencies must be fully understood to enable flexible, fast and reactive integration. In the past, attempts to achieve this have been faced with challenges associated with data which was vast, incompatible, dispersed and complicated. Hence combining, managing and integrating them was difficult. There is therefore the driving need to develop and integrate tools for appropriate data integration and reflection.

Despite these advances, the interplay between product, process and resource design is still under consideration. Most product design activities do not extend to facility design; therefore systems are currently designed separately. More critically, products and facilities can be designed by different stakeholders without a common database, making appropriate overall design solutions difficult to obtain. In current manufacturing systems, product designs may be required to fit into existing manufacturing systems with limited changes to the facilities. This means that knowledge of available manufacturing resources and their capabilities or competencies must be readily available for the use of system designers.

3.0 Recipe-based factory design method

From the above review, the authors and their co-teams (COPERNICO, 2010, VFF, 2009) have perceived that models for efficient design, control and management of digitised virtual factories require:

1. Explicit characterisation of data with their semantic relationships
2. Support for inter–document references (cross-references) to ensure proper referential consistency.
3. Efficient modelling and management of distributed data so support the realisation of (2)
4. Efficient integration of different knowledge domains (Factory, Building, System, Resource, Process, Product, Strategy, Performance and Management).

To achieve this and also help solve some of the problems outlined in section 2.0, researchers on the Cooperation Environment for Rapid Design, Prototyping and New Integration Concepts for the Factory of the Future project (COPERNICO NMP-2008-3.4-1 Rapid design and virtual prototyping of factories) have proposed and tested a ‘recipe-based’ approach to modelling digitised factories.

Apart from the general semantic requirements described through the COPERNICO and VFF projects (COPERNICO, 2010, VFF, 2009), the authors and their colleagues (Agyapong-Kodua et al., 2013) have reported that from a methodological perspective, to rapid-prototype a digital virtual factory, there is the need to (COPERNICO, 2010): 1. capture user requirements; 2. develop a library of ‘factory-recipe’ solutions; 3. support semantically matching of factory requirements with the populated factory solutions; 4. conduct further factory simulation and analyses for optimal performance.

The paper considers therefore that factory design methods have provided useful knowledge sets on factory layouts and the associated resources, therefore these good examples of layouts and their resources can be captured and aligned with their production requirements. This will help reduce the amount of effort required for planning of new or reconfigured factories. By doing so factory design knowledge can be captured and reused to facilitate the design process. This is the thinking behind the recipe based factory design approach. Basically, the concept relies on the derivation of a library of ‘pre-defined layout and configuration recipes’ which are semantically matched carefully to a set of production system requirements, so that based on semantic rules, logics and appropriate matching of ‘concepts’, possible solutions can be pulled from existing databases of recipes and their associated modelling libraries. A factory recipe refers to predefined ‘patterns of solutions’ matching the product and process requirements of a production system. The basic idea behind such an approach is to provide current and future factory designers with abstract descriptions of reusable components (or building blocks) of factories and also allow them to select among predicted suitable sets of resource systems (people, machines and computers). Most importantly, when production system requirements change, these resource systems can dynamically be reconfigured to meet the requirements. To a larger extent, recipes of factory solutions comprise various systems of layouts, people, production and assembly machines, utility systems and computers which are often configured based on different organisational structures, constraints, demand, and data so that they function appropriately to meet production systems requirement.

To ensure the generation of useful patterns of solutions (recipes), a systems engineering approach consisting of the decomposition of production system requirements into ‘lower modular requirements’ termed as ‘sub and sub-sub requirements’, and then matching it with similarly hierarchically decomposed factory recipes, is deployed. This approach has a number of benefits because depending on the level of granularity, different levels of solutions can be achieved. In traditional systems engineering approaches, a ‘v-model’ (Blanchard and Fabrycky, 2008) consisting of the matching of hierarchically decomposed production requirements with a bottom-up solution list through continuous synthesis and evaluation is adopted. The major difference noted in the approach reported here is the equal top-down decomposition of both production requirements and factory recipes as shown in Figure 1. At every stage of the decomposition, results derived from the integrated layers of recipes are synthesised and evaluated and particularly compared with expected indicators of the production requirements.

Resource selection ontologies for factory design

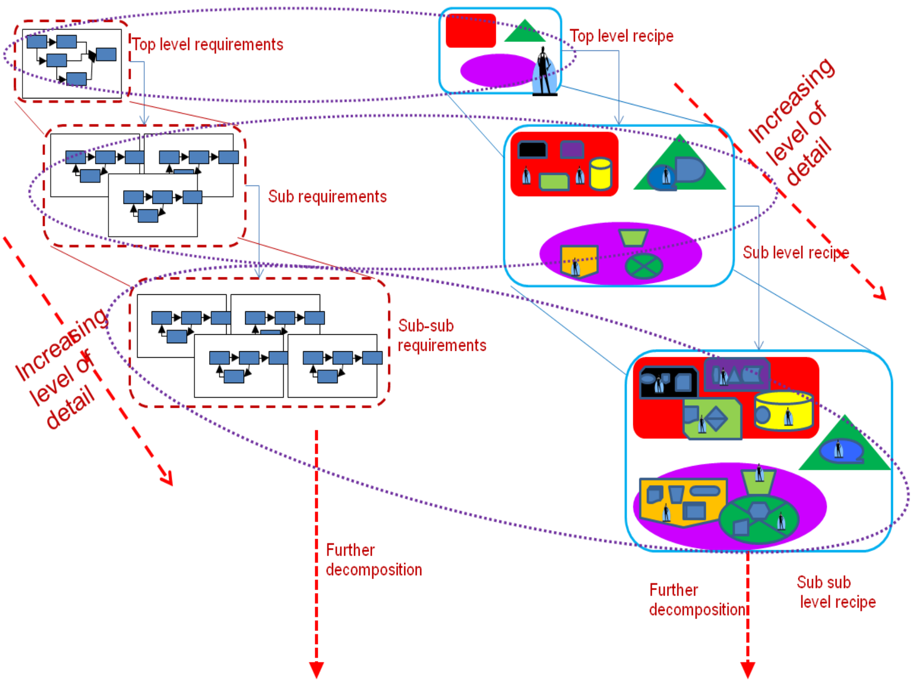


Figure 1: Conceptual view of the hierarchical decomposition of production requirements and layout recipes

The recipe-based factory design approach dwells on models and methods required to enable the convergence of meaning across the life cycle of virtual factory development. This is achieved through a common high level semantic language which acts as a communication backbone between product, process and resource sets of data. This backbone is supported by models for the characterisation of equipment resources, recipes for factory designs and a library of best practice examples. The application of these integrated datasets will enable quicker configuration of new or modified factories. The selected factory recipes are connected to a virtual factory environment which generates the full model of the proposed factories for detailed assessment using various expert tools.

The factory recipe approach starts with a classification mechanism which has been largely published by the authors and their colleagues (CHRISTEN-ROSE et al., 2012). This is shown in Figure 2 as ‘cladistics’ data. The cladistics data provides practical classifications of production systems with the objective to systematically organise them. A dedicated tool for the specification and selection of layout types have been developed and published in (Nemeth et al., 2012). The logic is that, after the selection of the factory layout type, data required for full generation of factories and their simulations are collected. This led to the development of a Requirement Engineering tool which seeks to describe product structures and process types. The Requirement Engineering framework is basically a web-based graphical user interface (web-GUI) which is integrated to the semantic engine to support reasoning. Two main results are achieved from the Requirement

Engineering tool. Data required for full simulation of the factory is captured and transferred via an enterprise service bus (ESB) to factory simulators. The second part of the results is data describing the product and process requirements.

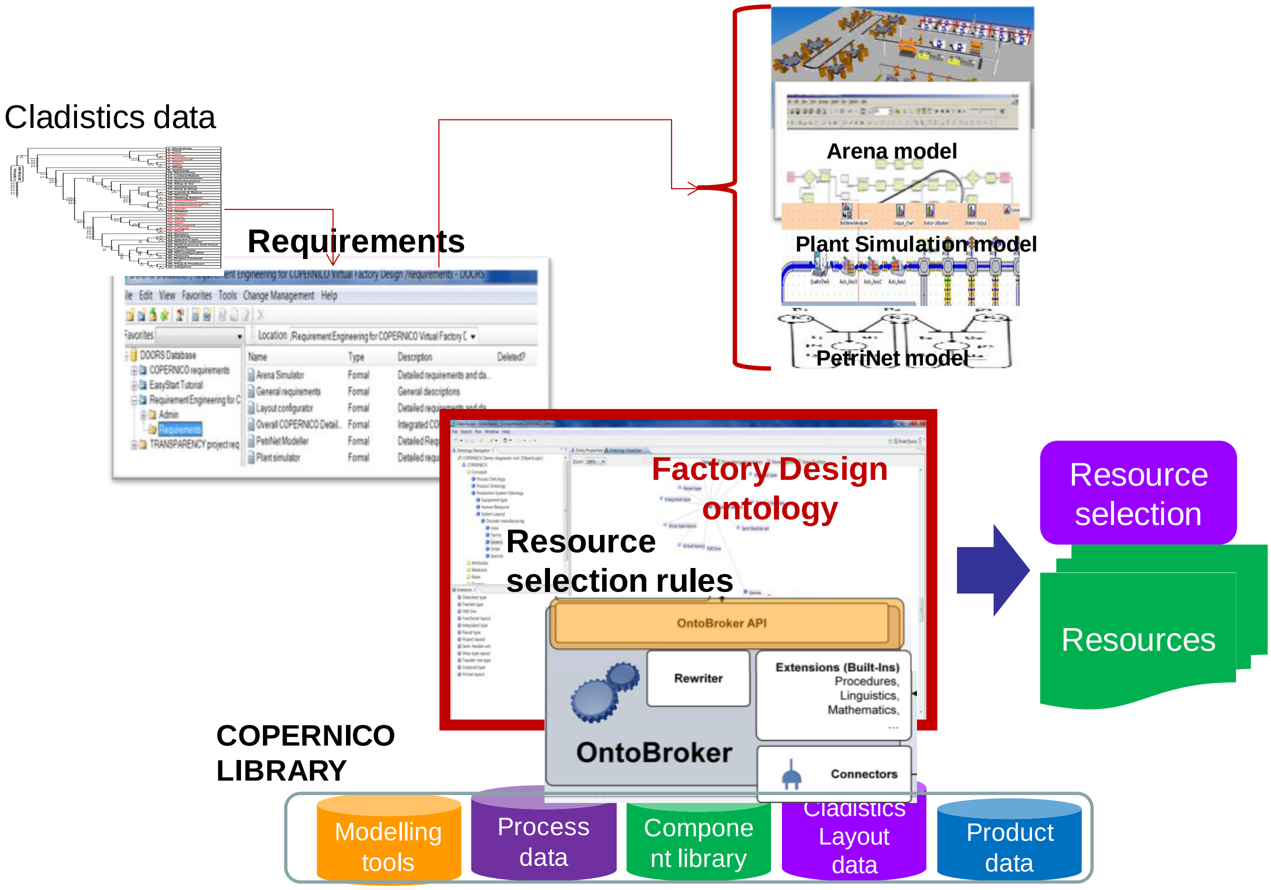


Figure 2: Recipe-based factory design model

The schema of the data captured by the Requirement Engineering tool is mapped onto carefully developed semantic data models. These models are built with OntoStudio ontology creator and hosted on the OntoBroker reasoner (see Figure 3). The ontology is used to represent structured data, define rules on the data, and finally query it. To realise the ontology, the semantic reasoner, OntoBroker, is used to load the ontology and also interface with external data sources. They also provide query interfaces and execute rules. The overall architecture shown in Figure 3 describes the various tools that the ontologies needed to interface including the factory recipe library.

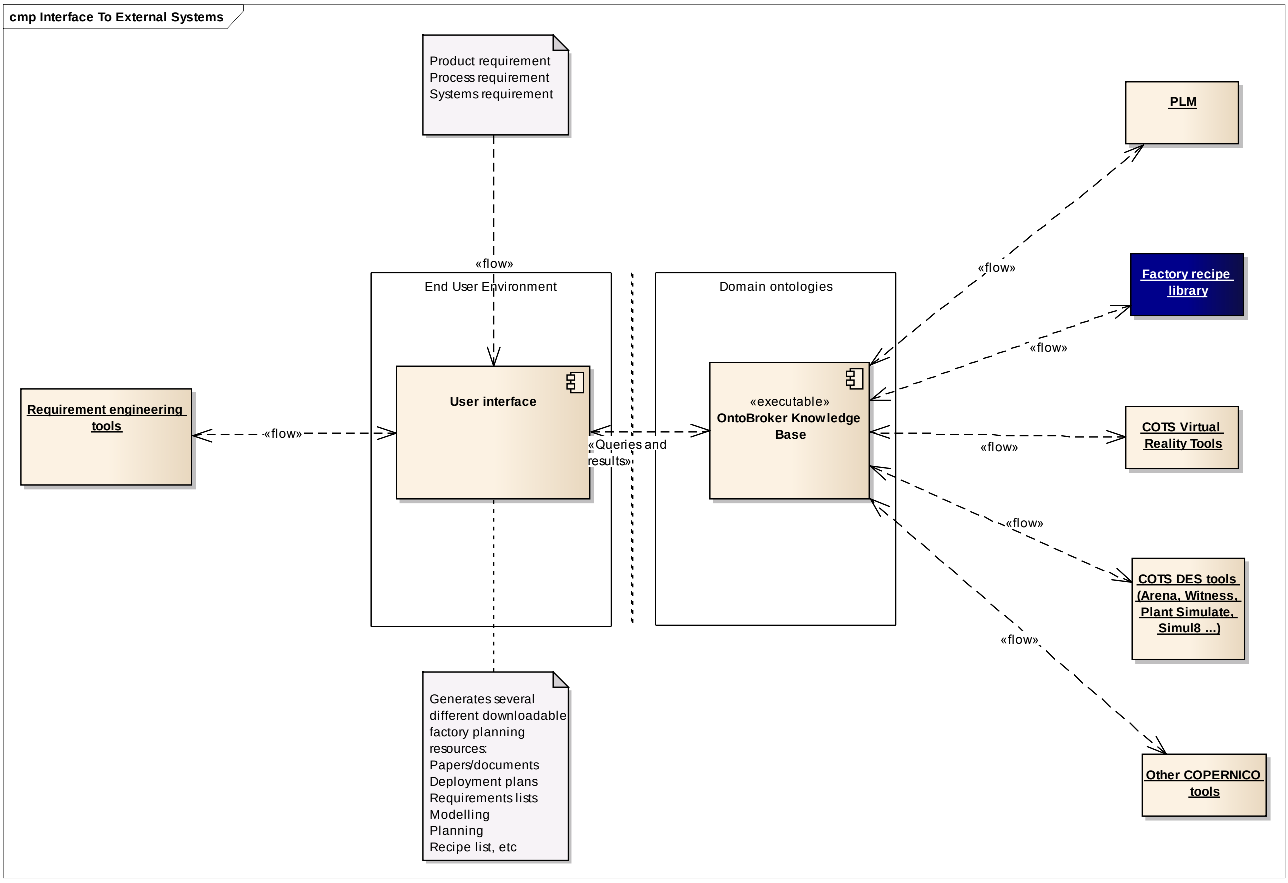


Figure 3: Architecture for recipe-based factory design tool

The internal representation language used is called ObjectLogic. The structure of OntoBroker can be seen in Figure 4. At the top of the figure the applications connect to OntoBroker. OntoBroker provides several interfaces to clients such as SOAP, native TCP, or Java API. At the bottom the external data sources are collected. OntoBroker maps the data of external systems such as SQL databases or web services to ontology concepts. This way it can perform reasoning on external data. The core reasoner OntoBroker can be extended with many modules and connectors that integrate external data sources, and other kinds of OSGi bundles.

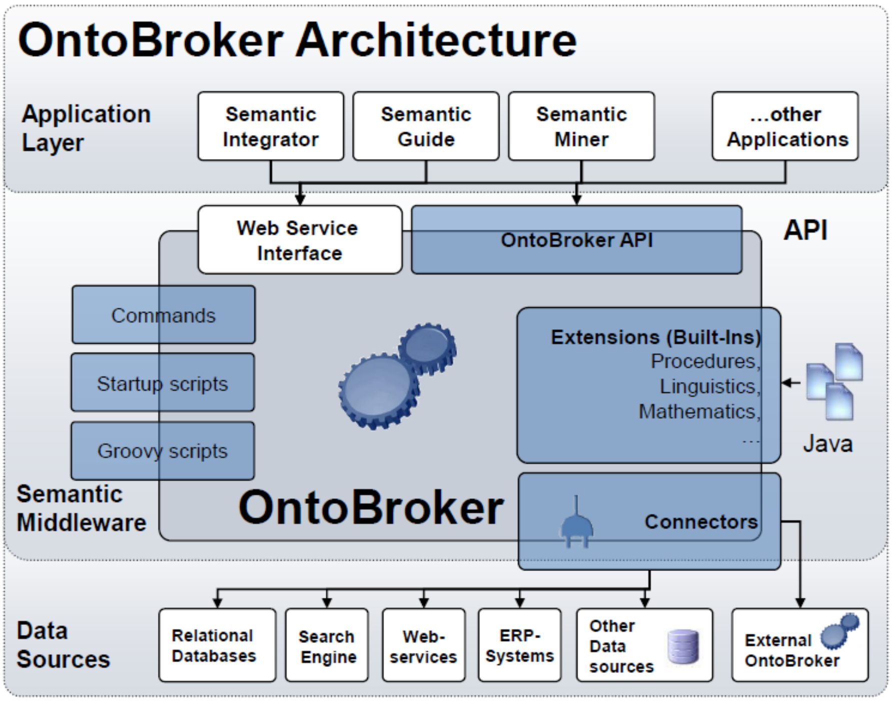


Figure 4: Architecture for OntoBroker (Ontoprise, 2011)

The semantic model contains ontologies for describing products, processes and resources. The resource concepts are built around ‘capabilities’ and through the support of relevant selection rules these resources can be chosen to meet the product-process requirements automatically. The scientific innovation achieved through the deployment of this technique therefore is that based on the specification of product and process requirements, resources of capabilities and competencies meeting the product-process requirements can be selected automatically.

4.0 Illustrative resource selection ontologies in support of recipe-based factory design

The semantic model for recipe-based factory design consists of product, process and production system ontologies as shown in Figure 5. The factory resources are described with the production system ontology. The production system ontologies are interconnected with other concepts in the domain of product and process ontologies. The assumption is that a carefully captured production system requirement can conveniently be assigned to relevant factory recipes so that based on well defined queries, solutions can be generated. In the extended view of the COPERNICO project, these queries will be prompted through a graphical user interface which will also receive the results derived from the semantic model.

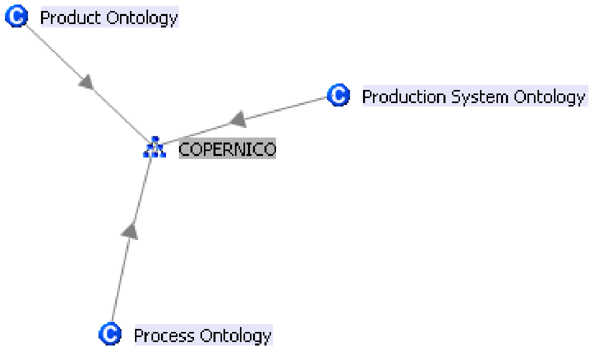


Figure 5: Top level COPERNICO ontology

The production system ontology consists of concepts for ‘systems layout’, ‘equipment and human resources’ (see Figure 6). The system layout ontology concept describes the various possible layout types whilst the equipment and human resource concepts consist of the potential equipment and human resource skill types, capable of fulfilling the requirements of the systems layout. The capabilities of the concepts related to the production system ontology are described in their ‘attributes’. The connections between different concepts are expressed in ‘relations’.

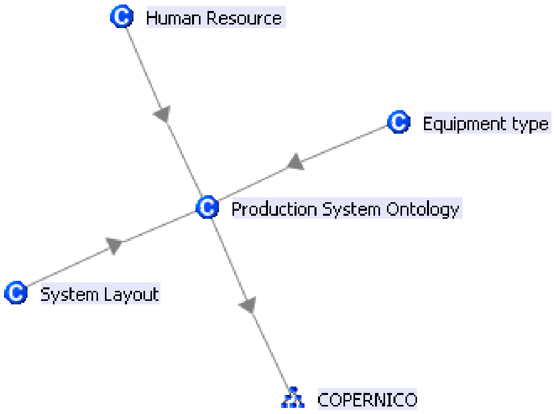


Figure 6: Production system ontology (top level)

The topology of manufacturing equipment was defined to consist of Production units; Assembly units; Material handling units; Finishing systems; Preparation systems; Storage systems; Packaging systems; Computers, IT and support systems. They were modelled as shown in Figure 7.

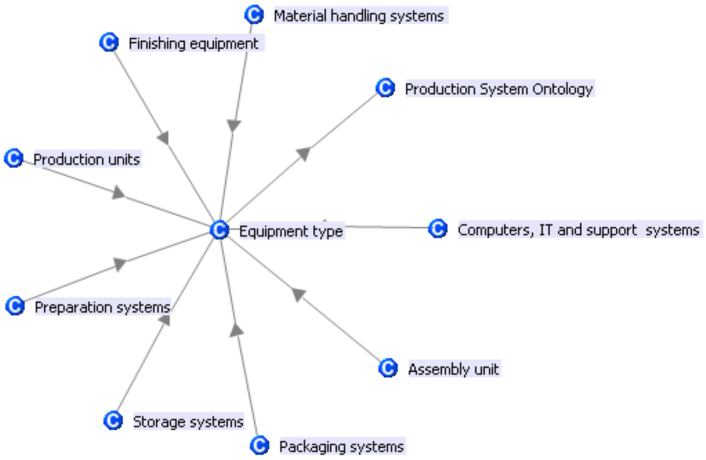


Figure 7: Equipment topology

The core semantic resource elements modelled consisted of ontologies describing some manufacturing equipment such as conveyors, robots, bending, drilling, milling, turning, press machines. These ontologies are expandable to include many other resource sets. An ontology for a resource contains ‘concepts’ of some characteristics. For example the PressMachines concept (see Figure 8) has several properties and attributes such as MachineHeight, MachineLength, MachineName, Power, PressForce, OperationType, PressHeadNumber. Some of these properties are for making connection between the PressMachines concept and for interfacing with external databases (named with an addition syllable “Data”, it means this data is from Database). Hence these ontologies can serve two purposes: 1. providing results through direct reasoning from the logics and instances built directly into the OntoBroker or 2. integrating with external databases and providing reasoning through the OntoBroker.

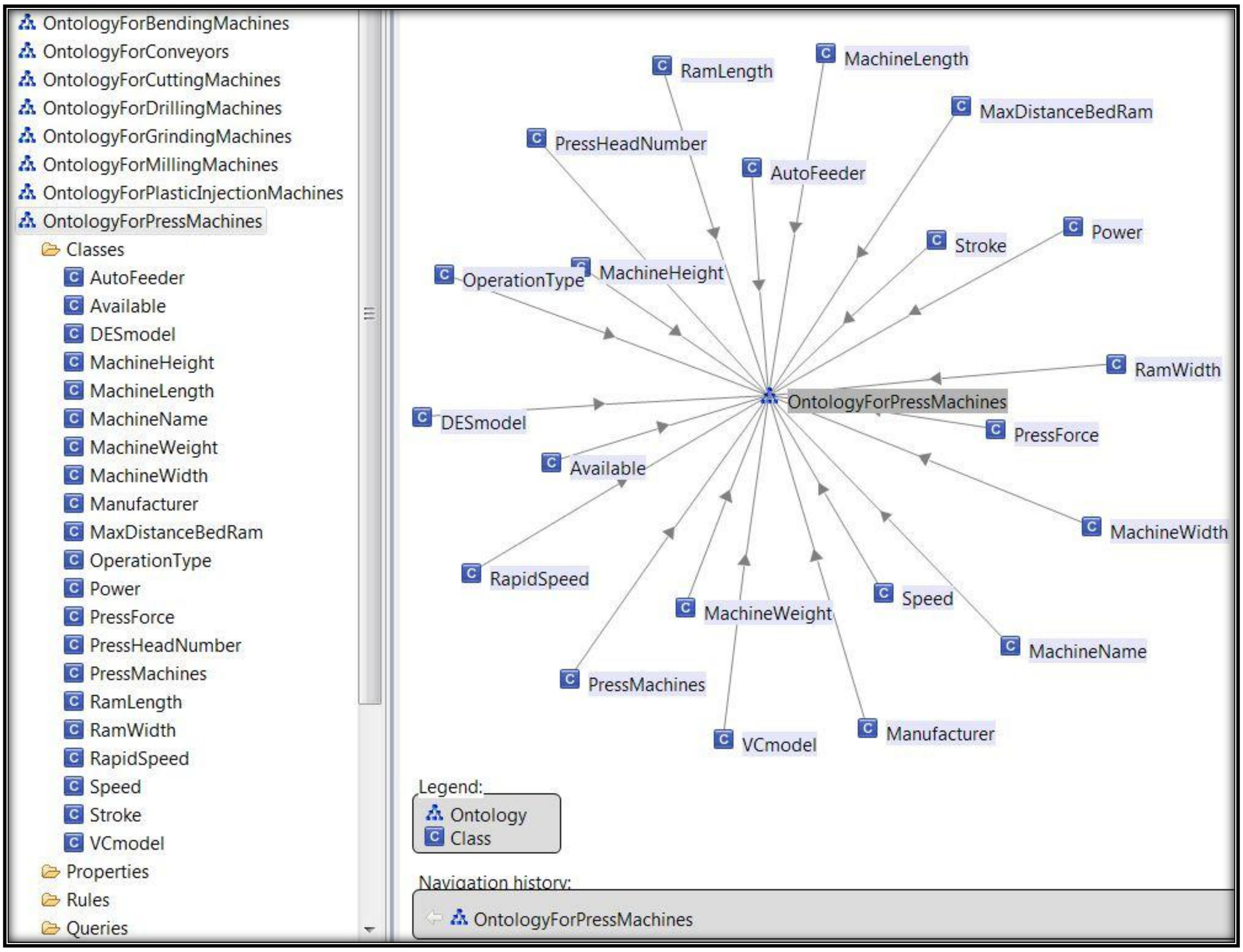
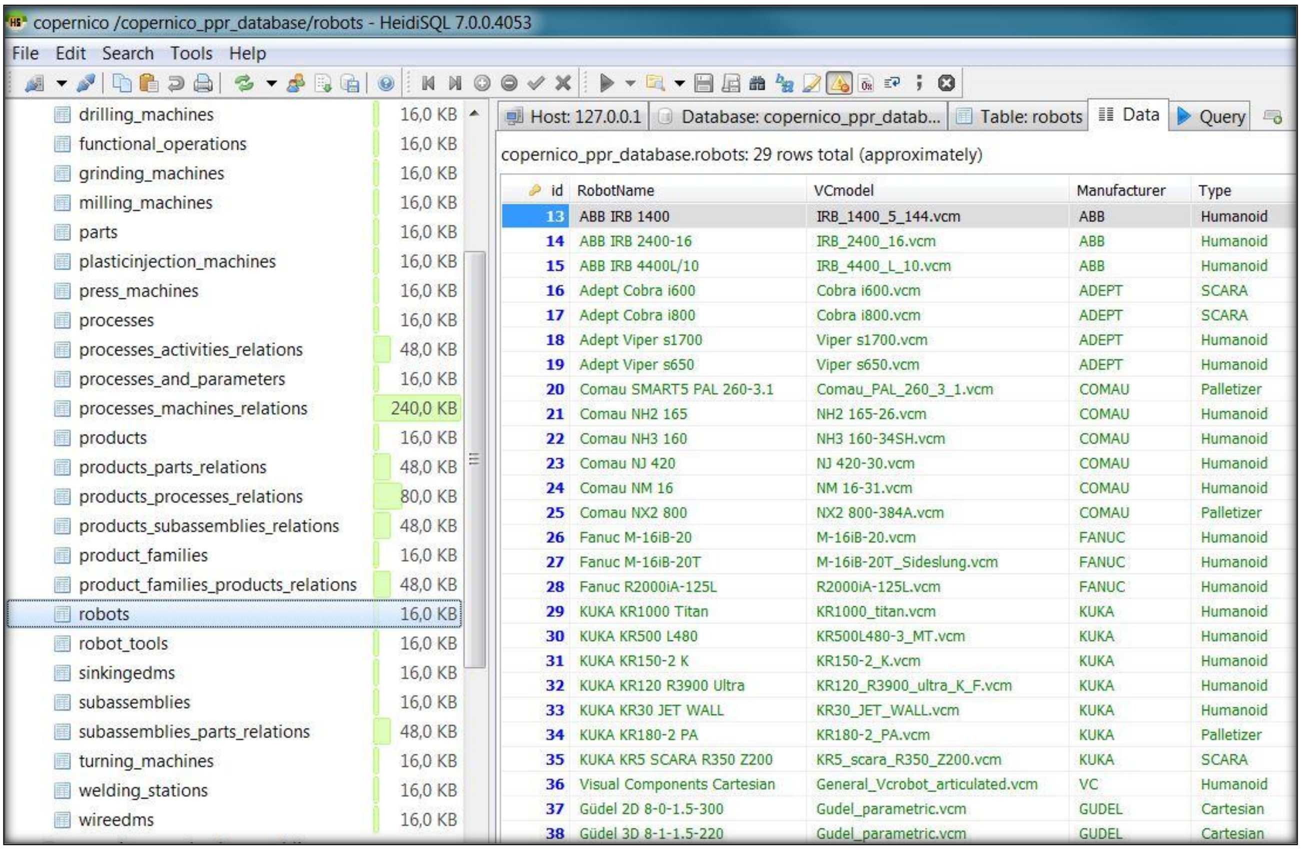


Figure 8: An ontology example for PressMachine

A library was populated and it contains several manufacturing system components such as robots, machine tools (turning, milling, drilling, press –machines etc.), manual workstations, conveyors, human operators, etc. Several geometric and non-geometric data of components – such as name, power, speed, load, range, weight etc. are stored in these databases. For example a snapshot of the HeidiSQL imported “robots” data is shown in Figure 9.



drilling_machines	16,0 KB
functional_operations	16,0 KB
grinding_machines	16,0 KB
milling_machines	16,0 KB
parts	16,0 KB
plasticinjection_machines	16,0 KB
press_machines	16,0 KB
processes	16,0 KB
processes_activities_relations	48,0 KB
processes_and_parameters	16,0 KB
processes_machines_relations	240,0 KB
products	16,0 KB
products_parts_relations	48,0 KB
products_processes_relations	80,0 KB
products_subassemblies_relations	48,0 KB
product_families	16,0 KB
product_families_products_relations	48,0 KB
robots	16,0 KB
robot_tools	16,0 KB
sinkingedms	16,0 KB
subassemblies	16,0 KB
subassemblies_parts_relations	48,0 KB
turning_machines	16,0 KB
welding_stations	16,0 KB
wireedms	16,0 KB

copernico_ppr_database.robots: 29 rows total (approximately)

id	RobotName	VCmodel	Manufacturer	Type
13	ABB IRB 1400	IRB_1400_5_144.vcm	ABB	Humanoid
14	ABB IRB 2400-16	IRB_2400_16.vcm	ABB	Humanoid
15	ABB IRB 4400L/10	IRB_4400_L_10.vcm	ABB	Humanoid
16	Adept Cobra i600	Cobra i600.vcm	ADEPT	SCARA
17	Adept Cobra i800	Cobra i800.vcm	ADEPT	SCARA
18	Adept Viper s1700	Viper s1700.vcm	ADEPT	Humanoid
19	Adept Viper s650	Viper s650.vcm	ADEPT	Humanoid
20	Comau SMART5 PAL 260-3.1	Comau_PAL_260_3_1.vcm	COMAU	Palletizer
21	Comau NH2 165	NH2 165-26.vcm	COMAU	Humanoid
22	Comau NH3 160	NH3 160-34SH.vcm	COMAU	Humanoid
23	Comau NJ 420	NJ 420-30.vcm	COMAU	Humanoid
24	Comau NM 16	NM 16-31.vcm	COMAU	Humanoid
25	Comau NX2 800	NX2 800-384A.vcm	COMAU	Palletizer
26	Fanuc M-16iB-20	M-16iB-20.vcm	FANUC	Humanoid
27	Fanuc M-16iB-20T	M-16iB-20T_Sideslung.vcm	FANUC	Humanoid
28	Fanuc R2000iA-125L	R2000iA-125L.vcm	FANUC	Humanoid
29	KUKA KR1000 Titan	KR1000_titan.vcm	KUKA	Humanoid
30	KUKA KR500 L480	KR500L480-3_MT.vcm	KUKA	Humanoid
31	KUKA KR150-2 K	KR150-2_K.vcm	KUKA	Humanoid
32	KUKA KR120 R3900 Ultra	KR120_R3900_ultra_K_F.vcm	KUKA	Humanoid
33	KUKA KR30 JET WALL	KR30_JET_WALL.vcm	KUKA	Humanoid
34	KUKA KR180-2 PA	KR180-2_PA.vcm	KUKA	Palletizer
35	KUKA KR5 SCARA R350 Z200	KR5_scara_R350_Z200.vcm	KUKA	SCARA
36	Visual Components Cartesian	General_Vcrobot_articulated.vcm	VC	Humanoid
37	Güdel 2D 8-0-1.5-300	Gudel_parametric.vcm	GUDEL	Cartesian
38	Güdel 3D 8-1-1.5-220	Gudel_parametric.vcm	GUDEL	Cartesian

Figure 9: Robots table in SQL Database

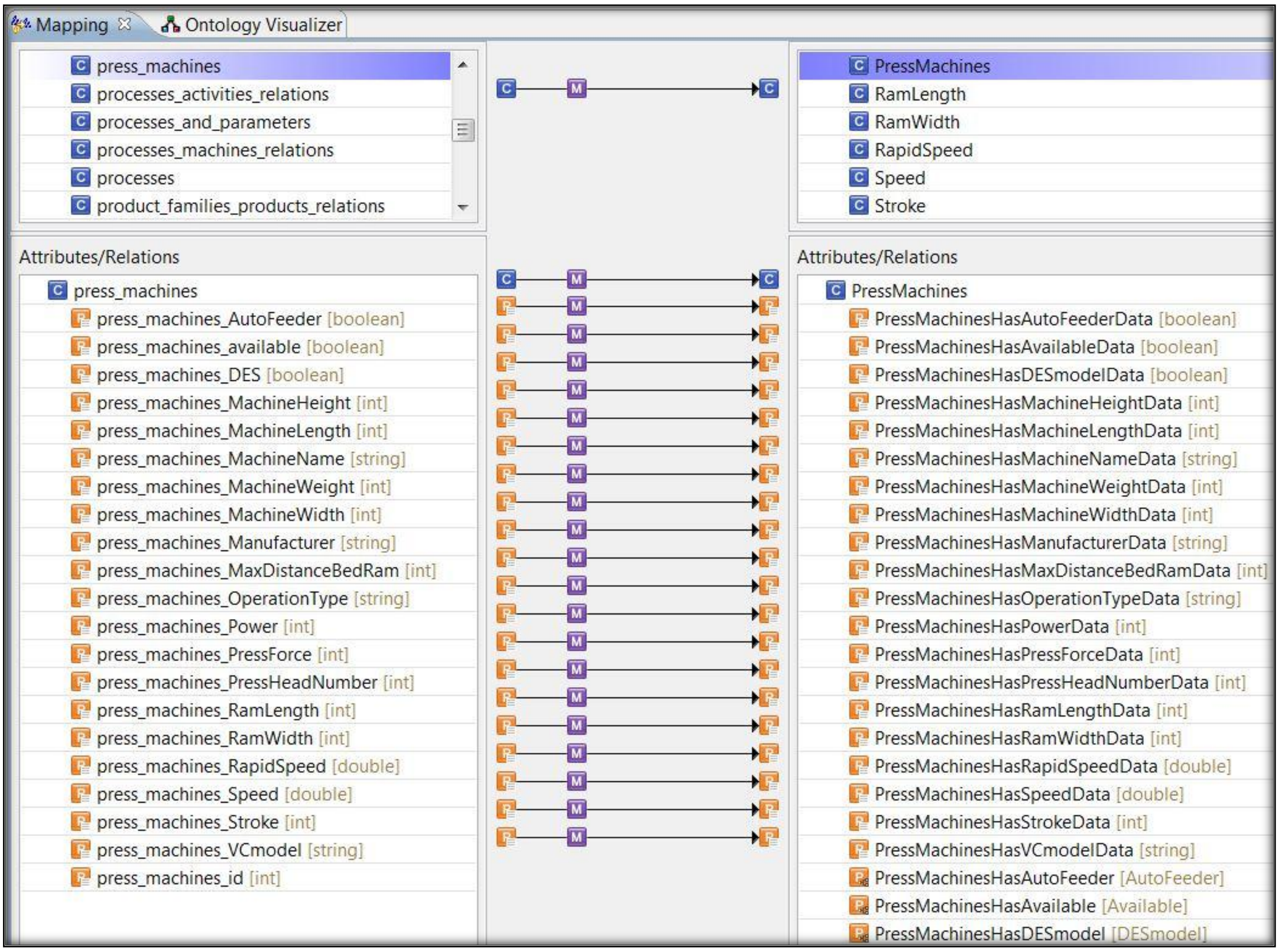
In the case example related to the development of resource selection ontologies for company ABC, an SME located in Sheffield, UK, a database of already existing manufacturing resources was considered. Integrating the domain ontology in the OntoBroker with the MySQL database required that the domain ontology be modified to suit the mapping of the MySQL schema. Usually, the imported MySQL schema appears as a form of ontology as shown in Figure 9. Integration of OntoBroker and MySQL database required that the domain ontology be modified to suit the mapping of the MySQL schema. The imported MySQL schema appears as a form of ontology as shown in Figure 10. This ontology contains all the tables of the database as concepts and the properties of these concepts are the columns of each table in the Database. The connection between this imported ontology and the database is defined by rules. The connection with the domain ontologies had to be defined by mapping properties of database ontology to the corresponding properties of domain ontologies in order to use data from database while querying ontologies. It means when the queries search any data then these information will come directly from the database what could be modified at any time.

Ontology Navigator

- DatabaseExtension [ObjectLogic]
  - copernicoProduct
  - Database
    - Classes
      - activities
      - bending_machines
      - conveyors
      - cutting_machines
      - DBMapping
      - drilling_machines
      - functional_operations
      - grinding_machines
      - milling_machines
      - parts
      - plasticinjection_machines
      - press_machines
      - processes
      - processes_activities_relations
      - processes_and_parameters
      - processes_machines_relations
      - product_families
      - product_families_products_relations
      - products
      - products_parts_relations
      - products_processes_relations
      - products_subassemblies_relations
      - robot_tools
      - robots
      - sinkingedms
      - subassemblies
      - subassemblies_parts_relations
      - turning_machines
      - welding_stations
      - wireedms

Figure 10: The imported database as an ontology

An example showing how the mapping was achieved for PressMachine ontology is shown in Figure 11. The left side of the mapping view on the picture shows the database ontology as the 'source' and the right side shows the domain ontologies of equipment and their properties as the 'target'.



press_machines	PressMachines
processes_activities_relations	RamLength
processes_and_parameters	RamWidth
processes_machines_relations	RapidSpeed
processes	Speed
product_families_products_relations	Stroke

Attributes/Relations	Attributes/Relations
press_machines	PressMachines
press_machines_AutoFeeder [boolean]	PressMachinesHasAutoFeederData [boolean]
press_machines_available [boolean]	PressMachinesHasAvailableData [boolean]
press_machines_DES [boolean]	PressMachinesHasDESmodelData [boolean]
press_machines_MachineHeight [int]	PressMachinesHasMachineHeightData [int]
press_machines_MachineLength [int]	PressMachinesHasMachineLengthData [int]
press_machines_MachineName [string]	PressMachinesHasMachineNameData [string]
press_machines_MachineWeight [int]	PressMachinesHasMachineWeightData [int]
press_machines_MachineWidth [int]	PressMachinesHasMachineWidthData [int]
press_machines_Manufacturer [string]	PressMachinesHasManufacturerData [string]
press_machines_MaxDistanceBedRam [int]	PressMachinesHasMaxDistanceBedRamData [int]
press_machines_OperationType [string]	PressMachinesHasOperationTypeData [string]
press_machines_Power [int]	PressMachinesHasPowerData [int]
press_machines_PressForce [int]	PressMachinesHasPressForceData [int]
press_machines_PressHeadNumber [int]	PressMachinesHasPressHeadNumberData [int]
press_machines_RamLength [int]	PressMachinesHasRamLengthData [int]
press_machines_RamWidth [int]	PressMachinesHasRamWidthData [int]
press_machines_RapidSpeed [double]	PressMachinesHasRapidSpeedData [double]
press_machines_Speed [double]	PressMachinesHasSpeedData [double]
press_machines_Stroke [int]	PressMachinesHasStrokeData [int]
press_machines_VCmodel [string]	PressMachinesHasVCmodelData [string]
press_machines_id [int]	PressMachinesHasAutoFeeder [AutoFeeder]
	PressMachinesHasAvailable [Available]
	PressMachinesHasDESmodel [DESmodel]

Figure 11: Mappings of the press machines ontology

5.0 Resource capabilities and queries

In the semantic model, the capabilities of equipment are detailed in their ‘attributes’. Attributes basically describe the characteristics of the specified concepts. Through the ‘relations’ aspect of the ontology, equipment with specified attributes can be ‘linked’ to specific production requirements and based on semantic rules appropriate selections can be made. As shown in Figure 12, a snapshot of part of the attributes for various equipment is shown. In addition to the attributes, the relations layer is also shown. As can be seen in Figure 12, various capabilities meeting different production requirements are defined. Different equipment types are also modelled and linked with their capabilities. Through the relationship entities, various equipment sets can be assigned to specific product-process requirements.

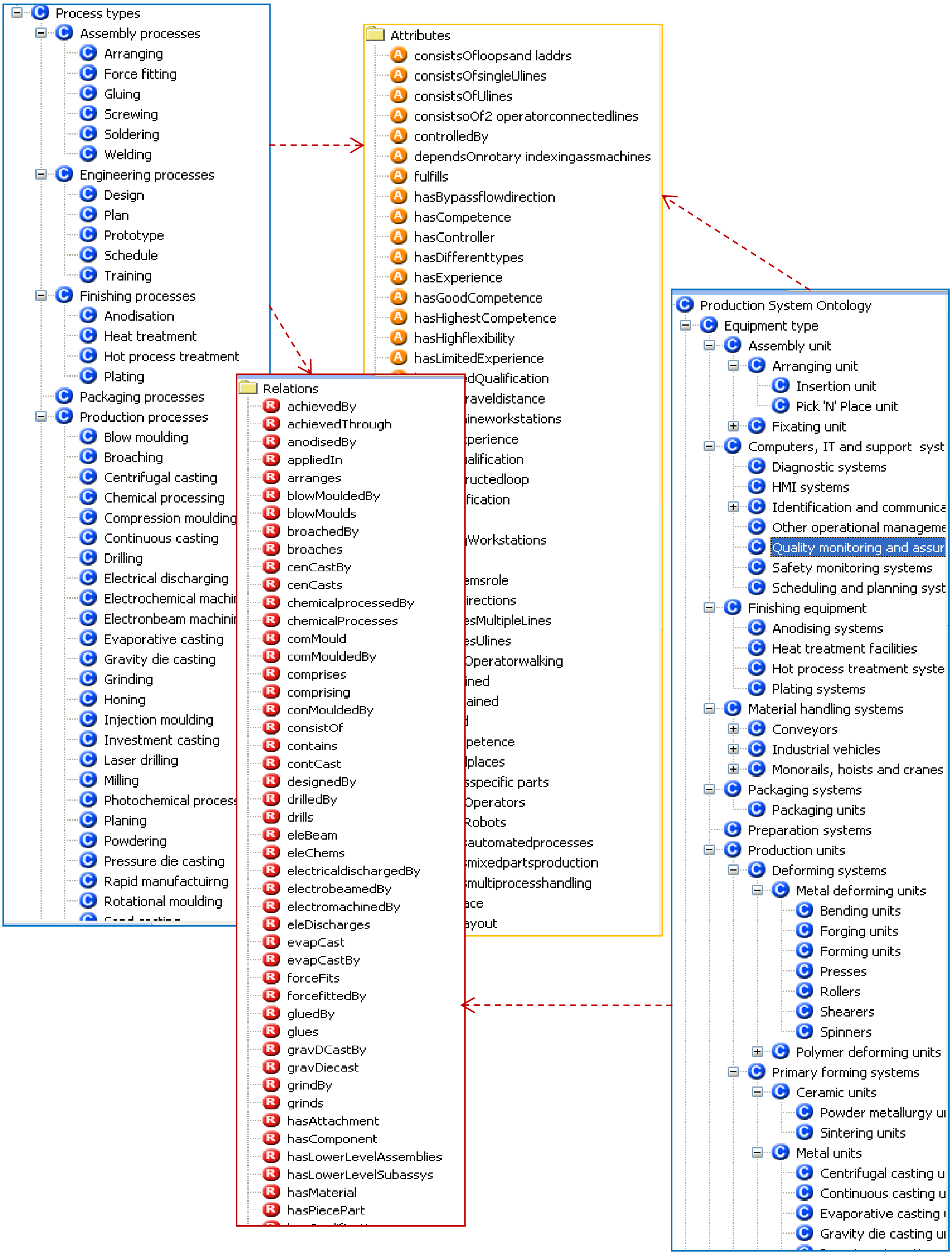
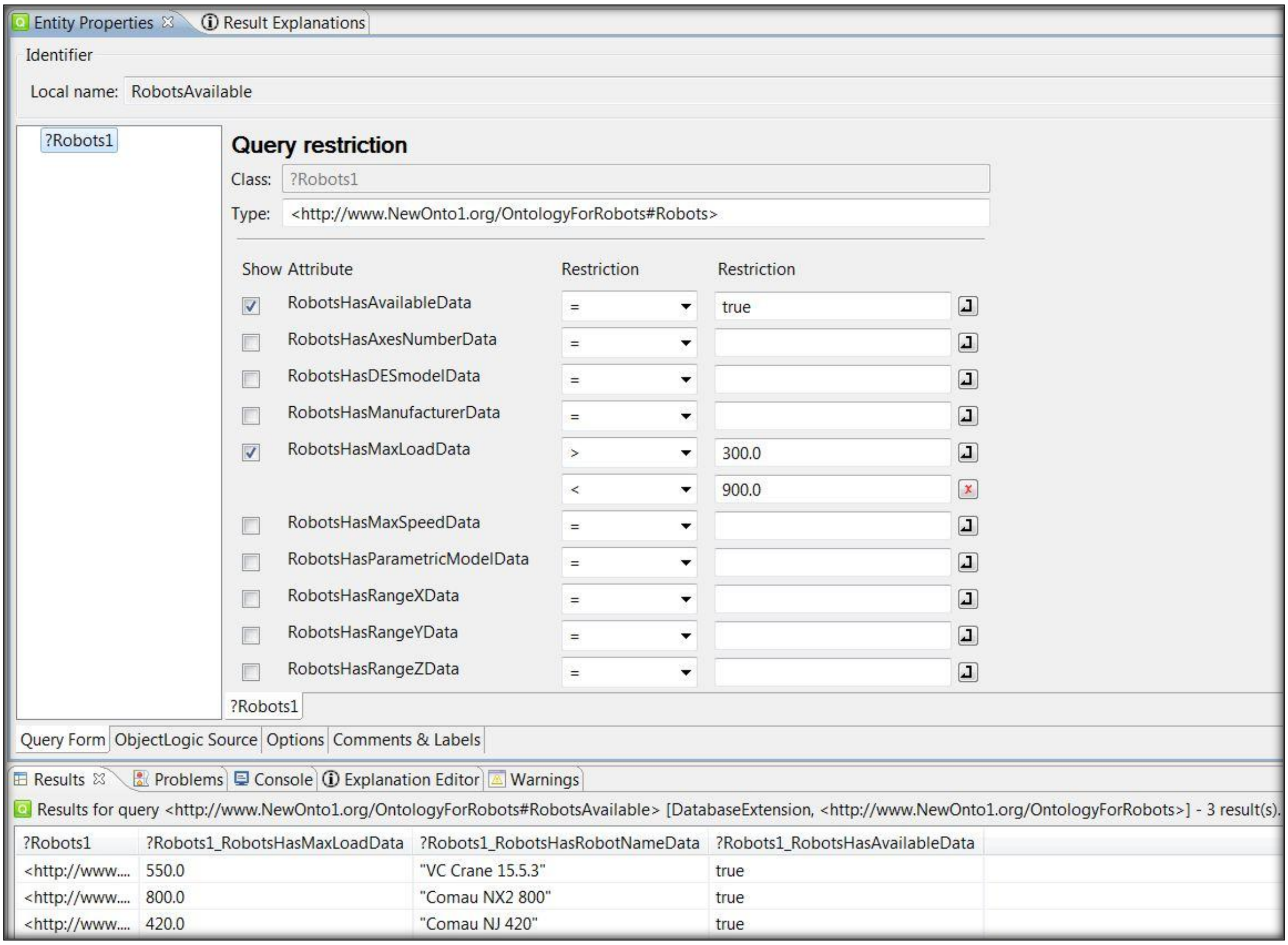


Figure 12: Integrating systems attributes with process descriptions

Some queries were defined with example results shown in Figures 13 and 14. Any number of query restrictions can be defined in arbitrary combinations. The results can be seen on the bottom of the screen shots with each result having a unique identifier which is for the unambiguous identification of data in the SQL database. For example, the OntoBroker can be queried for robots with maximum load capacity of 550kg, 800kg and 420kg and available for use. These queries in the final tool, yet to be reported, will be received through a web-based graphical user interface. The result is as shown in the bottom part of Figure 13.



Local name: RobotsAvailable

Query restriction

Class: ?Robots1

Type: <http://www.NewOnto1.org/OntologyForRobots#Robots>

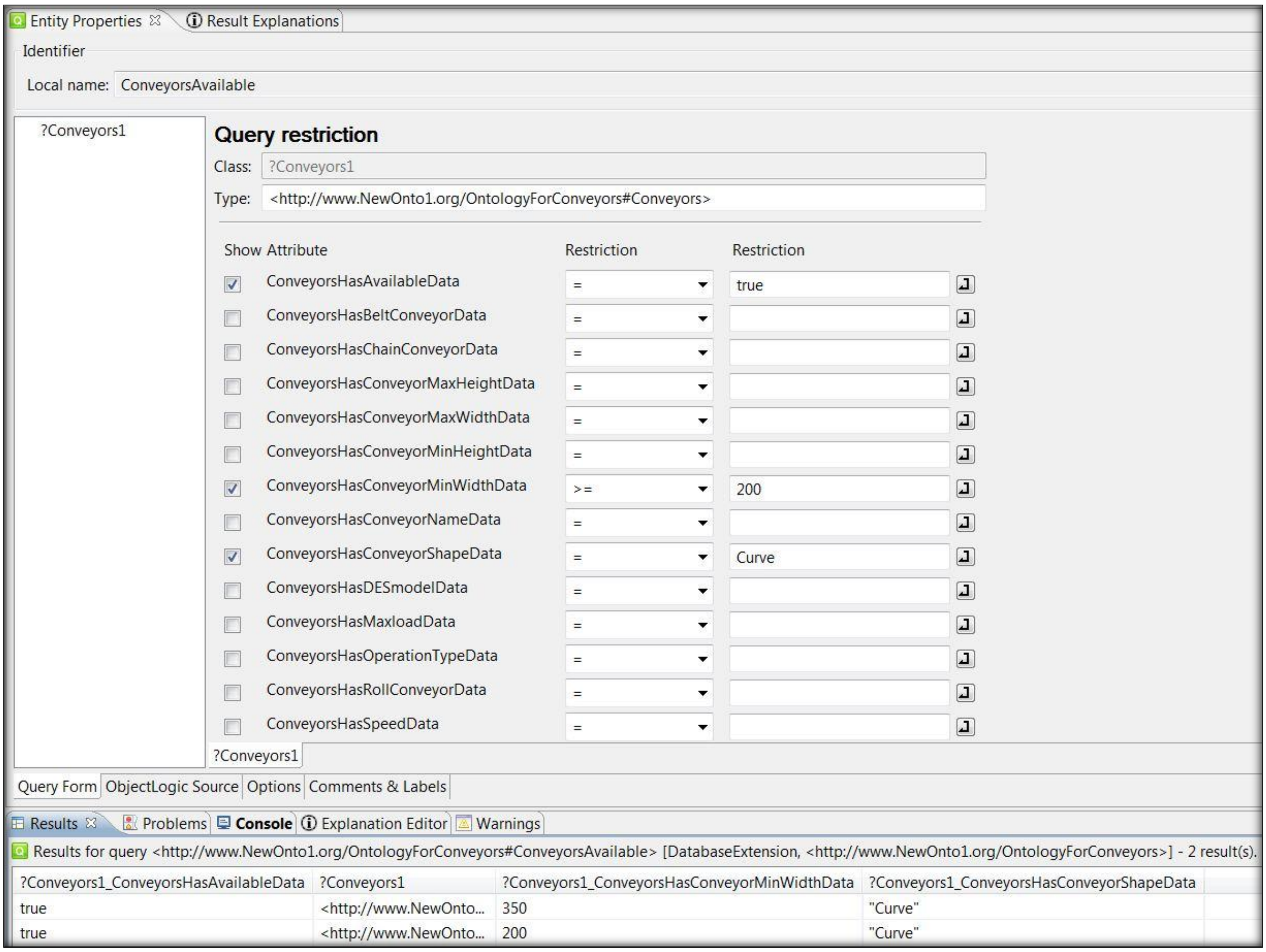
Show	Attribute	Restriction	Restriction
☑	RobotsHasAvailableData	=	true
☐	RobotsHasAxesNumberData	=	
☐	RobotsHasDESmodelData	=	
☐	RobotsHasManufacturerData	=	
☑	RobotsHasMaxLoadData	>	300.0
		<	900.0
☐	RobotsHasMaxSpeedData	=	
☐	RobotsHasParametricModelData	=	
☐	RobotsHasRangeXData	=	
☐	RobotsHasRangeYData	=	
☐	RobotsHasRangeZData	=	

Results for query <http://www.NewOnto1.org/OntologyForRobots#RobotsAvailable> [DatabaseExtension, <http://www.NewOnto1.org/OntologyForRobots>] - 3 result(s).

?Robots1	?Robots1_RobotsHasMaxLoadData	?Robots1_RobotsHasRobotNameData	?Robots1_RobotsHasAvailableData
<http://www....	550.0	"VC Crane 15.5.3"	true
<http://www....	800.0	"Comau NX2 800"	true
<http://www....	420.0	"Comau NJ 420"	true

Figure 13: Test query and results for robots

Based on a process requirement, a transport activity with minimum width ‘350mm and 200mm’ and ‘available’ shows the two curved-shape conveyor types (see Figure 14).



Identifier

Local name: ConveyorsAvailable

?Conveyors1

Query restriction

Class: ?Conveyors1

Type: <http://www.NewOnto1.org/OntologyForConveyors#Conveyors>

Show	Attribute	Restriction	Restriction
☑	ConveyorsHasAvailableData	=	true
☐	ConveyorsHasBeltConveyorData	=	
☐	ConveyorsHasChainConveyorData	=	
☐	ConveyorsHasConveyorMaxHeightData	=	
☐	ConveyorsHasConveyorMaxWidthData	=	
☐	ConveyorsHasConveyorMinHeightData	=	
☑	ConveyorsHasConveyorMinWidthData	>=	200
☐	ConveyorsHasConveyorNameData	=	
☑	ConveyorsHasConveyorShapeData	=	Curve
☐	ConveyorsHasDESmodelData	=	
☐	ConveyorsHasMaxloadData	=	
☐	ConveyorsHasOperationTypeData	=	
☐	ConveyorsHasRollConveyorData	=	
☐	ConveyorsHasSpeedData	=	

?Conveyors1

Results for query <http://www.NewOnto1.org/OntologyForConveyors#ConveyorsAvailable> [DatabaseExtension, <http://www.NewOnto1.org/OntologyForConveyors>] - 2 result(s).

?Conveyors1_ConveyorsHasAvailableData	?Conveyors1	?Conveyors1_ConveyorsHasConveyorMinWidthData	?Conveyors1_ConveyorsHasConveyorShapeData
true	<http://www.NewOnto...	350	"Curve"
true	<http://www.NewOnto...	200	"Curve"

Figure 14: Test query and results for conveyors

6.0 Observations and conclusions

The previous sections of the paper have described the concepts behind the recipe-based approach to factory design. Within this concept semantic models are embedded for selecting resources meeting product and process requirements. The reasons for selecting OntoStudio and OntoBroker as the modelling environment and platform respectively have been reported in one of the author's previous publications (Agyapong-Kodua et al., 2013). In this publication, the authors explained that OntoStudio provides adequate modelling formalisms in support of the ObjectLogic language which is flexible in its expression of concepts, attributes and relations. It is particularly useful because of its backbone reasoner and repository, OntoBroker.

Therefore, this paper focussed on demonstrating how ontology-based resource models can be integrated with existing databases of factory resources so that based on their semantically described capabilities, queries requiring specific resources to meet product-process requirements will provide results based on enhanced reasoning through the OntoBroker. Through this approach, designers are enabled with sets of resources to choose from. In the models presented, 3D models of the resources are linked to the resource list so that they can be applied in simulation environments. This shows therefore that structural models and their encapsulated data can be re-used via the use of suitable 'in context' semantic models of types outlined in section 4. It follows also that resource systems can be semantically modelled so that their capabilities can be matched with product and process requirements. The full semantic description of product-process requirements can be found in (Agyapong-Kodua et al., 2013).

The methodology has strength in integrating several data sources and based on appropriate mapping logic, to assign resources matching product-process requirements. As a result, it allows the synergistic use of various kinds of mental, structural and dynamic systems models which facilitate complexity handling and lead to better and faster dynamic analysis of factory models. In view of this, when modelling in context, existing factory data can be semantically matched onto the resource ontologies to provide rapid support to resource selection.

In some other complementary papers (Agyapong-Kodua et al., 2013, Zendoia et al., 2013) , the authors describe the use of Requirement Engineering tools to capture initial product and process data. These datasets are saved in a central database which is integrated with the OntoBroker semantic reasoner to support decision making. These extensions were made primarily to provide support for rapid and effective capture, visual representation and validation of resource systems, within any given factory design setting. The purpose for doing so was to create a semantic resource model which can be fleshed out over time and integrated with other databases.

The authors and their colleagues are currently working on the development of graphical user interfaces (GUI), which will now interrogate the semantic model and provide user friendly results at multiple levels.

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References

AGYAPONG-KODUA, K. 2009. *Multi-product cost and value stream modelling in support of Business Process Analysis.* PhD, Loughborough University.

AGYAPONG-KODUA, K., AJAEFOBI, J. O. & WESTON, R. H. 2009. Modelling dynamic value streams in support of process design and evaluation. *Int. J of Computer Integrated Manufacturing,* 22**,** 411-427.

AGYAPONG-KODUA, K., AJAEFOBI, J. O., WESTON, R. H. & RATCHEV, S. 2012. Development of a multi-product cost and value stream modelling methodology. *International Journal of Production Research,* 50**,** 6431-6456.

AGYAPONG-KODUA, K., LOHSE, N., DARLINGTON, R. & RATCHEV, S. 2013. Review of semantic modelling technologies in support of virtual factory design. *International Journal of Production Research,* 51**,** 4388-4404.

AGYAPONG-KODUA, K. & WESTON, R. H. 2011. Systems approach to modelling cost and value dynamics in manufacturing enterprises. *International Journal of Production Research,* 49**,** 2143-2167.

AJAEFOBI, J. & WESTON, R. 2005. Modelling Human Systems in Support of Process Engineering. *In:* ZÜLCH, G., JAGDEV, H. & STOCK, P. (eds.) *Integrating Human Aspects in Production Management.* Springer US.

AJAEFOBI, J., WESTON, R., WAHID, B. & RAHIMIFARD, A. 2010. Integrated approach to modelling human systems as reuseable components of manufacturing workplaces. *International Journal of Computer Integrated Manufacturing,* 23**,** 195-215.

AJAEFOBI, J. O. 2004. Human Systems Modelling in support of Enhanced Process Realisation. *PhD Thesis, Loughborough University, UK.*

AMICE 1993. *CIMOSA: open system architecture for CIM,* Berlin, Springer- Verlag.

ARMOUR, G. C. & BUFFA, E. S. 1963. A heuristic algorithm and simulation approach to relative allocation of facilities. *Management Science,* 9**,** 294-300.

ASHWORTH, C. M. 1988. Structured systems analysis and design method (SSADM). *Information Software Technology,* 30**,** 153-163.

BALAKRISHNAN, J., CHENG, C. H., CONWAY, D. G. & LAU, C. M. 2003. A hybrid genetic algorithm for the dynamic plant layout problem. *International Journal of Production Economics,* 86**,** 107-120.

BAYKASOGLU, A., DERELI, T. & SABUNCU, I. 2006. An ant colony algorithm for solving budget constrained and unconstrained dynamic facility layout problems. *Omega,* 34**,** 385-396.

BERNUS, P. & NEMES, L. 1996. *Enterprise integration-engineering tools for designing enterprises,* Australia, Chapman & Hall.

BICHENO, J. 2000. *The Lean Toolbox,* Buckingham, England, PICSIE Books.

BLANCHARD, B. S. & FABRYCKY, W. J. 2008. *Systems Engineering and Analysis,* USA, Prentice Hall; 5th edition

BOOTHROYD, G. & DEWHURST, P. 1986. *Product design for assembly,* Wakefield, Rhode Island, Boothroyd Dewhurst Inc.

BYER, N. & WESTON, R. H. 2003. Matching teams to business processes. *Enterprise Inter- and Intra-Organizational Integration: Building International Consensus,* 108**,** 183-194.

CEN/ISO 19440. Enterprise Integration- Constructs for Modelling *EN ISO 19440:2007,* Work item: 00310074.

CHATHA, K. A. & WESTON, R. 2005. Combined Enterprise & Simulation Modelling in support of Process Engineering. *Int. J of Computer Integrated Manufacturing,* 18**,** 652-670.

CHEN, C.-K. & TSAI, C.-H. 2008. Developing a process re-engineering-oriented organizational change exploratory simulation system (PROCESS). *International Journal of Production Research,,* 46**,** 4463-4482.

CHIANG, W. C. & KOUVELIS, P. 1996. An improved tabu search heuristic for solving facility layout design problems. *International Journal of Production Research*, 34**,** 2565-2585.

CHRISTEN-ROSE, A., BALDWIN, J., AGYAPONG-KODUA, K. & RIDGWAY, K. 2012. Methodologies for Practical Applications of Unified Linnaean and Cladistic Classifications of Production Systems. *In proceedings of 5th International Conference on Operations and Supply Chain Management.* Rotterdam.

CHUNG, Y. K. 1999. A neuro-based expert system for facility layout construction. *Journal of Intelligent Manufacturing,* 10**,** 359-385.

CHWIF, L., PEREIRA BARRETTO, M. R. & MOSCATO, L. A. 1998. A solution to the facility layout problem using simulated annealing. *Computers in Industry,* 36**,** 125-132.

COPERNICO 2010. Cooperation Environment for Rapid Design, Prototyping and New Integration Concepts for the Factory of the Future. *CP-IP 229025-2 COPERNICO,* NMP-2008-3.4-1 Rapid design and virtual prototyping of factories.

CUI, Z. H. & WESTON, R. 2010. Modelling the effect of product variations on the design of Economy of Scope Manufacturing Systems. *International Journal of Computer Integrated Manufacturing,* 23**,** 61-86.

DAVENPORT, T. H. 1993. *Process Innovation: Reengineering work through information technology,* Boston, Mass, Harvard Business School Press.

DEAN, M., CONNOLLY, D., HARMELEN, F. V., HENDLER, J., HORROCKS, I., MCGUINNESS, D. L., PATEL-SCHNEIDER, P. L. & STEIN, L. A. 2002. OWL Web Ontology Language. *1.0 Reference, W3C Working Draft,* Available from <http://www.w3.org/TR/owl-ref/>.

DING, C. H. & WESTON, R. 2007. Role based modelling approach to designing multi-product systems. *Iciea 2007: 2nd Ieee Conference on Industrial Electronics and Applications, Vols 1-4, Proceedings***,** 1706-1711.

DOUMEINGTS, G., VALLESPIR, B. & CHEN, D. 1998. *GRAI Grid Decisional Modelling, In Handbook of Information Systems, P. Bernus, K. Mertins and G. Schmidt* Springer-Verlag, Berlin. pp. 313-337.

DREZNER, Z. 1987. A heuristic procedure for the layout of a large number of facilities. *International Journal of Management Science,* 33**,** 907-915.

DUGGAN, K. 2003. *Creating mixed model value streams,* USA, Productivity press.

DUNKER, T., RADONSB, G. & WESTKAMPERA, E. 2005. Combining evolutionary computation and dynamic programming for solving a dynamic facility layout problem. *European Journal of Operational Research,* 165**,** 55-69.

FALLSIDE, D. C. & WALMSLEY, P. 2004. XML Schema Part 0: Primer, Second Edition. *W3C recommendation,* http://www.w3.org/TR/xmlschema-0/,W3CXSD1.0.

FERNÁNDEZ LÓPEZ, M. Overview Of Methodologies For Building Ontologies. Proceedings of the IJCAI-99 workshop on Ontologies and Problem-Solving Methods (KRR5), 1999 Stockholm, Sweden.

FP5-GROWTH 2000. Modular Plant Architecture. *GIRD-CT-00298,* Key Action Innovative Product, Processes and Organisation.

FP5-IRMA 2010. A configurable virtual reality system for Multi-purpose Industrial Manufacturing Applications. *GIRD-CT-2000-00236,* Key action Innovative Products, Processes and Organisation.

FP6-DIFAC 2006. Digital factory for human oriented Production System.

GRUBIC, T. & FAN, I.-S. 2010. Supply chain ontology: Review, analysis and synthesis. *Computers in Industry,* 61**,** 776-786.

GRÜNINGER, M., SHAPIRO, S., FOX, M. S. & WEPPNER, H. 2010. Combining RFID with ontologies to create smart objects. *International Journal of Production Research,* 48**,** 2633-2654.

GUNASEKARAN, A. & IRANI, Z. 2010. Modelling and analysis of outsourcing decisions in global supply chains. *International Journal of Production Research,* 48**,** 301-304.

GUNASEKARAN, A. & KOBU, B. 2002. Modelling and analysis of business process reengineering. *International Journal of Production Research,* 40**,** 2521-2546.

HAMANN, T. & VERNADAT, F. 1992. The intra cell layout problem in automated manufacturing system. *8th international Conference on CAD/CAM, robotics and factory of the future (CARs & FOF).* Metz, France, August 17-19.

HAMMER, M. & CHAMPY, J. 1993. *Reengineering the corporation: A manifesto for business revolution,* New York, HarperBusiness.

HASSAN, M. M. D. 1994. Machine layout problem in modern manufacturing facilities. *International Journal of Production Research,* 32**,** 2559-2584.

HERAGU, S. S. & KUSIAK, A. 1988. Machine layout problem in flexible manufacturing systems. *Operations Research Letters,* 36**,** 258-268.

HINES, P., HOLWEG, M. & RICH, N. 2004. Learning to evolve: A review of contemporary lean thinking. *International Journal of Operations & Production Management,* 24**,** 994-1011.

HINES, P. & NICK, R. 1997. The seven value stream mapping tools. *International Journal of Operations and Production Management,* 17**,** 46-64.

HORROCKS, I. & HARMELEN, F. 2001. Reference Description of the DAML+ OIL: Ontology Markup Language. *Technical report,* Available from <http://www.daml.org/2001/03/reference.html>.

IQBAR, M. & HASHMI, M. S. J. 2001. Design and analysis of a virtual factory layout. *Journal of Materials Processing Technology,* 118**,** 403-410.

KHALIL, S. N. & WESTON, R. H. 2010. Modelling Human Resource Systems in Support of Efficient Production. *Balanced Automation Systems for Future Manufacturing Networks,* 322**,** 72-79.

KHALIL, T. M. 1973. Facilities relative allocation technique (FRAT). *International Journal of Production Research,* 11**,** 183-194.

KIM, J. G. & KIM, Y. D. 2000. Layout planning for facilities with fixed shapes and input and output points. *International Journal of Production Research,* 38**,** 4635-4653.

KOBE, G. 1990. DFMA: design for manufacture and assembly. *Automotive Industries,* March**,** 34-38.

KOSANKE, K. 1996. Process oriented presentation of modelling methodologies. *Proceedings of the IFIP TC5 Working conference on models and methodologies for Enterprise Integration***,** 45-55.

KROES, P. 2002. Design Methodology and the nature of technical artefacts. *Design Studies,* 23**,** 287-302.

KUO, T.-C., HUANG, S. H. & ZHANG, H.-C. 2001. Design for manufacture and design for 'X'; concepts, applications and perspectives. *Journal of Computers and Industrial Engineering,* 41**,** 241-260.

LEE, G. 2005. *Strategos guide to Value Stream and Process Map,* Strategos International, USA, Engineering and Management Press USA.

LEE, R. & MOORE, J. M. 1967. CORELAP-computerized relationship layout planning. *The Journal of Industrial Engineering,* 18**,** 195-200.

LOHSE, N., SCHÄFER, C. & RATCHEV, S. 2006. Towards an Integrated Assembly Process Decomposition and Modular Equipment Configuration: A Knowledge Enhanced Iterative Approach. *IFIP International Federation for Information Processing,* ,, 198**,** 215-225.

MARCA, D. A. & MCGOWAN, C. L. 1988. *SADT: Structured Analysis and Design Technique,* London, Prentice Hall.

MCGUINNESS, D. L., FIKES, F., RICE, J. & S, W. 2000. The Chimaera Ontology Environment. *In 17th National Conference on Artificial Intelligence (AAAI'00).* Austin, USA.

MCKENDALL, A. R. & SHANG, J. 2006. Hybrid ant systems for the dynamic facility layout problem. *Computers & Operations Research,* 33**,** 790-803.

MCKENDALL, A. R., SHANG, J. & KUPPUSAMY, S. 2006. Simulated annealing heuristics for the dynamic facility layout problem. *Computers& Operations Research,* 33**,** 2431-2444.

MIR, M. & IMAM, M. H. 2001. A hybrid optimization approach for layout design of unequal-area facilities. *Computers & Industrial Engineering,* 39**,** 49-63.

NEMETH, I., PUSPOKI, J., HARASZKO, C. & BALDWIN, J. S. 2012. Rapid layout design of manufacturing systems. *In:* ELISABETH ILIE-ZUDOR, Z. K., LÁSZLÓ MONOSTORI (ed.) *14th International Conference on Modern Information Technology in the Innovation Processes of Industrial Enterprises. MITIP.* Budapest, Hungary.: Hungarian Academy of Sciences, Computer and Automation Research Institute.

NIST 1993. INTEGRATION DEFINITION FOR FUNCTION MODELING (IDEF0). *Federal Information Processing Standards Publications (FIPS PUBS), National Institute of Standards and Technology (NIST),.*

ONTOPRISE 2011. OntoBroker Architecture. *Karlsruhe University, Germany*.

PAHL, G., BEITZ, W., FELDHUSEN, J. & GROTE, K. H. 2007. *Engineering Design, A systematic Approach,* London, Springer-Verlag.

PEDRAZZOLI, P., SACCO, M., JÖNSSON, A. & BOER, C. R. 2007. Virtual Factory Framework. Key enabler for future manufacturing. *In:* P. F. CUNHA & MAROPOULOS, P. G. (eds.) *Digital Enterprise Technology*. Bath, UK: Springer, US.

PIERREVAL, H., CAUX, C., PARIS, J. L. & VIGUIER, F. 2003. Evolutionary approaches to the design and organization of manufacturing systems. *Computers & Industrial Engineering,* 44**,** 339-364.

RAHIMIFARD, A. & WESTON, R. 2007. The enhanced use of enterprise and simulation modelling techniques to support factory changeability. *International journal of computer integrated manufacturing,* 20**,** 307-328.

RIBIÈRE, M. & CHARLTON, P. 2000. Ontology Overview. *Networking and Applications Lab.* Paris: Motorola Labs.

RICHARDSON, G. P. 1999. Reflections for the future of system dynamics. *Journal of Operational Research Society,* 50**,** 440-449.

SCARR, A. J. 1986. Product design for automated manufacture and assembly. *Annals of CIRP,* 35**,** 1.

SCHOLZ-REITER, B., FREITAG, M. & SCHNIEDER, A. 2004. Modelling and control of production systems based on nonlinear dynamics theory. *CIRPS Annals-Manufacturing Technology,* 51**,** 375-378.

SCHREIBER, G., AKKERMANS, H. & ANJEWIERDEN, A. 1999. *Knowledge engineering and management. The CommonKADS Methodology,* Massachussets, MIT press.

SEEHOF, J. M. & EVANS, W. O. 1967. Automated layout design program. *The Journal of Industrial Engineering,* 18**,** 690-695.

SHAYAN, E. & CHITTILAPPILLY, A. 2004. Genetic algorithm for facilities layout problems based on slicing tree structure. *International Journal of Production Research,* 42**,** 4055-4067.

SHETH, V. S. 1995. *Facilities and Materials Handling-Methods and requirement,* New York, Marcel Dekker.

SIEMENS 2000. http://www.plm.automation.siemens.com/en_gb/products/tecnomatix/plant_design/factorycad/index.shtml.

SOLIMANPUR, M., VRAT, P. & SHANKAR, R. 2005. An ant algorithm for the single row layout problem in flexible manufacturing systems. *Computers & Operations Research Letters,* 32**,** 583-598.

STERMAN, J. 2000. *Business Dynamics: Systems thinking and modeling for a complex world,* McGraw Hill.

STOLL, H. W. 1986. Design for Manufacture: An Overview. *Applied Mechanics Review,* 39**,** 1356-64.

TODOROVA, K. & STEFANOV, K. 2009. Selection and use of domain ontologies in Learning Networks for Lifelong Competence Development Sofia, Bulgaria: Department of

Information Technologies, Faculty of Mathematics and Informatics, University of Sofia “St. Kliment Ohridski.

TOMPKINS, J. A. & REED, J. R. 1976. An applied model for the facilities design problem. *International Journal of Production Research,* 14**,** 583-595.

TONG, J., VAN LUTTERVELT, C., WEDMAN, F. & BIKKER, H. 2003. Computer-guided system for design of factories. *International Journal of Computer Integrated Manufacturing,* 16**,** 571-585.

VERNADAT, F. & BERIO, G. 1999. New developments in enterprise modelling using CIMOSA. *Computers in Industry,* 40**,** 99-114.

VERNADAT, F. B. 2002. UEML: towards a unified enterprise modelling language. *Int. J. of Production Research,* 40**,** 4309-4321.

VFF 2009. VFF, Holistic, extensible, scalable and standard Virtual Factory Framework, www.vff-project.eu/, (FP7-NMP-2008-3.4-1, 228595).

VUJOSEVIC, R., RASKAR, R., YETUKURI, V., JOTHISHANKAR, M. C. & JUANG, S.-H. 1995. Simulation, animation and analysis of design disassembly for maintainability analysis. *International Journal of Production Research,* 33**,** 2999-3022.

WANG, M. J., HU, M. H. & KU, M. H. 2005. A solution to the unequal area facilities layout problem by genetic algorithm. *Computers in Industry,* 56**,** 207-220.

WESTON, R., ZHEN, M., RAHIMIFARD, A., AJAEFOBI, J., DING, C., GUERRERO, A., WAHID, B. & MASOOD, T. 2006. Simulation model interoperability in support of complex organisation design and change. *Modelling and Simulation 2006***,** 28-33.

WESTON, R. H., RAHIMIFARD, A., AJAEFOBI, J. O. & CUI, Z. 2009. On modelling reusable components of change-capable manufacturing systems. *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture,* 223**,** 313-336.

WIENDAHL, H. P., HARMS, T. & FIEBIG, C. 2002. Virtual factory design-a new tool for a cooperative planning approach. *Proceedings of the First CIRP (UK) Seminar on Digital Enterprise Technology.* Durham, UK: University Press of Durham.

WILLIAMS, T. J. 2002. The Purdue Enterprise Reference Architecture. *Instrument Society of America. Research Triangle Park, North Carolina, USA.*

WOLSTENHOLME, E. F. 1999. Qualitative verses quantitative modelling: the evolving balance. *Journal of Operational Research Society,* 50**,** 422-428.

WOMACK, J. P. & JONES, D. T. 2003. *Lean thinking - Banish Waste and Create Wealth in Your Corporation,* New York, Free press.

WU, Y. & APPLETON, E. 2002. The optimisation of block layout and aisle structure by a genetic algorithm. *Computers & Industrial Engineering,* 41**,** 371-387.

ZENDOIA, J., ZAPP, M., AGYAPONG-KODUA, K., LOHSE, N. & SINGH, M. 2013. Fundamentals of a co-design methodology for improving the performance of machine tools based on semantic representation. *International Journal of Computer Integrated Manufacturing,* 26**,** 751-761.