New Models of Agile Manufacturing Assisted by Semantic

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Abstract

This paper proposes a process management system that enables new dynamic manufacturing models to be implemented. This system facilitates the automation of process modelling, thus reducing the workload for process engineers. To this end, it focuses on the incorporation of knowledge in the definition of the processes and services involved. The document presents a general scenario in which industrial machinery is offered as services (IMaaS), integrated under a Service-oriented Architecture (SOA); this is followed by a definition of an ontology that enables the incorporation of knowledge into the proposed scenario; finally the implementation of a prototype, along with a test scenario, is presented, enabling the viability of the proposal to be demonstrated.

1. Introduction

The capacity that the Internet has provided to customers to select the consumer articles that best suit their needs at any given time and at the best prices is causing manufacturing organisations to move from traditional production paradigms centered on mass production to models that facilitate mass customization [1]. This new scenario demands that organisations implement new, more dynamic and more flexible management models that easily enable them to adapt to environmental changes brought about by market demand [2].

In order to respond to the needs of new models, the BPM (Business Process Management) paradigm has become the focus of more appropriate business process management [3] because it contemplates continuous change as one of its main characteristics in addition to the dynamic adaptation of the business processes and IT infrastructures that sustain them.

Within the framework of manufacturing organisations it is difficult to completely implement BPMSs due to the conceptual and technological gap between the Enterprise level and productions levels, caused by the rigidity of the elements located in the lower levels of production [3]. Offering a vision of industrial machinery as a service (IMaaS) [4], integrated in accordance with a service oriented architecture (SOA) paradigm, has led to a successful proposal for solving this problem by considering industrial machinery manufacturing processes as just another element of the business process management system.

The removal of this gap opens up a wide range of possibilities in the management of processes in manufacturing organisations. However, this range of possibilities is causing the traditional bottleneck between Enterpise level and productions levels to now be transferred to the process modelling and management domain.

In order to reduce this workload, knowledge is to be incorporated in the definition of the processes and services involved by means of the use of ontologies. This obtains a tool that enables the composition and modelling of the business processes to be automated in accordance with the strategic objectives of the organisation and, in this way, facilitate the work of the process engineer.

In order to develop the proposal, the following section presents a brief review of the state-of-the-art of related aspects. This is followed by a description of the general proposal for a scenario in which industrial machinery is offered as a service (IMaaS), integrated in accordance with a service-oriented architecture. This is followed by the proposal of an ontology that enables the incorporation of knowledge into the proposed scenario. In section 5, the implementation of a prototype of this system is provided in conjunction with a test scenario, based on an industrial manufacturing model, which has enabled the viability of the proposal to be validated and demonstrated. Finally the main research conclusions are presented.

2. Background

The need to integrate manufacturing processes in the global map of the business model has led to a wide variety of proposals. These have developed from

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traditional integration models that make use of ad-hoc adapters (Modbus, Profibus, AS-I, FIPIO, DeviceNET, Interbus and Industrial Ethernet) to systems based on more successful IT solutions such as networking devices introduced under the concept of Schneider's Transparent Factory [5], communication under the SOAP protocol as proposed by ABB [6], systems based on Web Services [7] and a number of proposals arising from European projects [8] based on the use of Web Services and WS-*. IMaaS was developed alongside these proposals [9][4] with a focus on presenting industrial machinery as part of a Business Process Management System (BPMS) that indicates its functionality as services in accordance with the SOA paradigm. IMaaS defines a process that conceptually and technologically normalises industrial machinery. Conceptual Normalisation establishes a model that removes conceptual restrictions between manufacturing process and business processes.

The Technological Normalisation of industrial machinery establishes the architecture (IMaaS architecture) that removes former technological restrictions [4].

In order to cover requirements such as self organisation, automation and reactive and proactive behavior, it is necessary for there to be communication between the organisation, the applications and the machinery. To enable this communication to exist it is essential to formally classify the information referring to a domain, for which ontologies are presented as useful tools. Two major ontology development areas can be distinguished with regard to manufacturing companies: the conceptualisation of manufacturing domains and the application of semantics to the management of business processes.

The conceptualisation of the domain is a fundamental part of the use of ontologies as it lists the concepts involved and identifies the relationships between them in order to generate taxonomies that list all the identified concepts to form the ontology. Examples of these studies include [10], where the use of ontologies is proposed with the ADACOR architecture, [11] which proposes MASON (MAnufacturing Semantics ONtology), a more specific manufacturing domain ontology based on the description of the domain as a sum of resources, operations and entities, proposed by [12]. Continuing with this theme, in [13] ontology is used as an element to represent knowledge by means of instances of the resources available for the machinery and to achieve, therefore, machinery that is capable of automatically reconfiguring itself in accordance with the objective.

Once the elements have been identified, use can be made of semantics for the management of business processes. There is a series of proposals that are based on semantically representing the services that the machines can offer. In [14], the use of Semantic Web Services for the automation of production systems is put forward. It is based on the hypothesis that if the manufacturing components can be described using semantics interpretable by machines, then the other intelligent components can reason and deduce the knowledge sufficient to reciprocally act. In [15] the use of Semantic Web Services such as Middleware is proposed for the reconfiguration of manufacturing systems. Thanks to the semantic description of the services and to a series of rules that model certain events, the automatic selection of services based on a series of events and objectives is enabled.

However, manufacturing cannot be considered to be an isolated process within the company, rather it must be understood to be just another process within the company's business processes. In this field there is also a wide range of proposals. In [16], an architecture based on the semantic description of services and on a BPEL (Business Process Execution Language) engine is proposed as the means for executing said services. However, there is strong debate with regard to which perspective is the most appropriate for the dynamic composition of services and as yet a consensus does not seem to have been reached. In [17] a comparison is made between BPEL and OWL-S and the conclusion is that OWL-S is more appropriate for dynamic environments and BPEL is the ideal choice for controlled workflows. In [18] the replacement of BPEL4WS (Business Process Execution Language for Web Services) technology by Semantic Web Services is proposed. Accordingly, a tool to translate BPEL to OWL-S is proposed. In [19] a set of limitations on BPM methodologies is identified and the proposal to overcome them is a combination of BPM and SWS leading to what the authors have called Semantic Business Process Management.

From the analysis of the above proposals it can be discerned that BPM systems are presented as an ideal solution for dynamic management processes and that IMaaS enables their implementation in manufacturing companies where the technological and conceptual gap between the production levels and the rest of the processes is more pronounced. The fact that production processes are now considered within the global map of the company's processes has led to an increase in management possibilities and the need to incorporate requirements such as self-management, self-organisation, proactivity and reactivity. Accordingly, intelligence in the form of semantics is now proposed for inclusion in BPM systems, although the problem is still being discussed.

3. General proposal

New manufacturing models only make sense if they can be developed in realistic scenarios that include the needs of the business and of the technologies used to sustain them. For this reason, in this paper we have proposed a management system based on the SOA architecture in which industrial machinery behaves as a service provider (IMaaS), and business policies, objectives and strategies are managed by means of BPMS, which acts within this SOA scenario as an IMaaS service consumer. It is these services, modelled as processes, that are automated by the proposed dynamic manufacturing system.

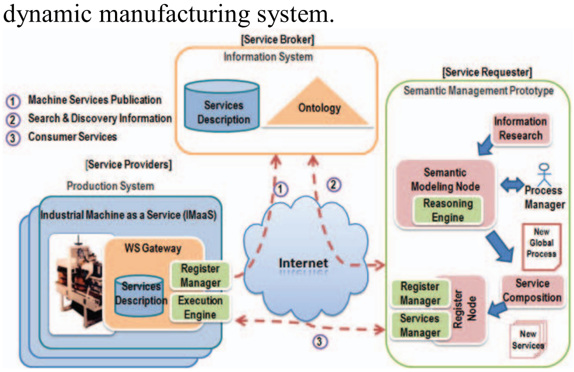

Figure 1. Functional diagram of the proposed system.

The scenario that has been designed to support the dynamic production system is composed of three elements: the production system, the information system and the semantic process management system. The scenario is organised in accordance with the SOA paradigm where the production system takes on the role of service provider; the information system encompasses the service intermediary and the ontology that contains the conceptualisation of the company's business elements; and the semantic process management system represents the role of process modeller and service consumer.

The production system is composed of IMaaS industrial machinery [9] and is responsible for carrying out the modelled processes by means of the services that it offers. These services are registered in the information system as can be seen in the Publication block in Fig. 2 so they can be discovered by the rest of the elements of the company.

The semantic process management system is responsible for managing the new production processes, creating, based on the indications of the process engineer, a complete process that can be undertaken by the production plant, which enables the process engineer to model in accordance with the established policies and desired objectives and with the specific production elements operation mode. The Semantic Modelling Node will be responsible for generating the new production processes based on the semantic information extracted from the instances defined in the proposed ontology. This enables the process engineer to be released from much of his workload. Once the new modelled process is available, it is automatically translated to an execution language, discovering the services offered by the machinery that implements the required subprocesses and sending the new process to the industrial machinery for execution. In the Semantic Management block in Fig.2 the sequence of activities for semantic process modelling is shown.

In a traditional BPMS process modelling is a tedious activity that often requires the collaboration of several process managers. It is assumed that each one of the process managers has sufficient knowledge of the domain and is fully responsible for the modelling and, therefore, for the suitability of the manufacturing process. Moreover, once the new process has been modelled it is necessary to specify the services that are necessary in order to be able to compose the new service, as can be seen in the BPMS block in Fig. 2.

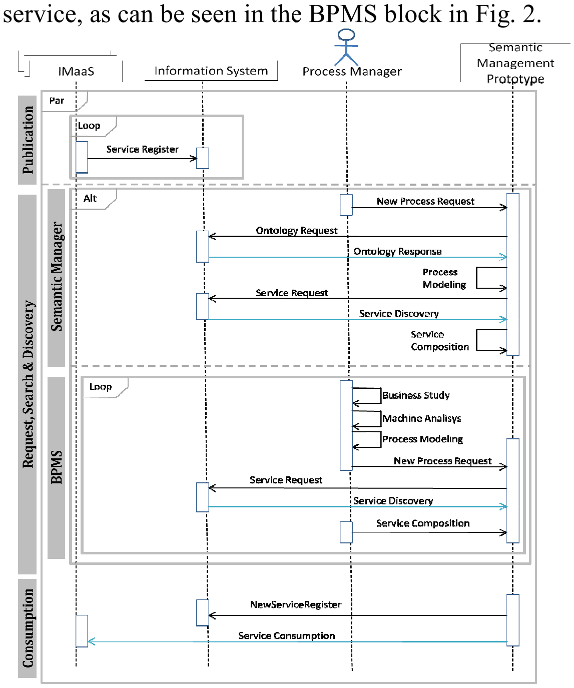

Figure 2. Sequence diagram: creation of a new process.

Once composed, the new process is registered so that it can be used again in the future.

The information system is responsible for recording all available processes and updating information about the industrial domain in such a way that any change that may affect the functioning of the business will be taken into account when new processes are generated by the semantic process management system.

Thanks to semantic management, information can be extracted from the ontology in order to model the processes, which enables greater automation when composing processes. The system also automates the selection of the services that are carried out. As can be seen in the Request, Search and Discovery block in Fig. 2, the semantic management system enables a reduction of the required interaction between the business management system and the process manager with respect to a traditional BPMS.

4. Proposed ontology

The ontology constitutes the reasoning base for the semantic modelling node (fig. 1.) and integrates both the concepts of the business process and the definition of raw materials, machinery, products, etc. The need for all the terms to be defined emanates from the aim to integrate the manufacturing process into the business processes of the company.

This proposal is focused on producing a semantic description of the physical structure of manufacturing organisations, the description of the possible processing services and their relationship with the different machines and with other processing services.

These generic definitions can be used to define the instances referring to a particular domain, reflecting the relationships and restrictions between the different instances. This definition will lead, in subsequent phases, to automation in the composition of new processes. First, a brief study of the domain is made in order to subsequently carry out the conceptualisation and implementation of the ontology.

4.1. Study of the domain

The study of the domain has been carried out taking into account the classification of processes described in [10]. It identifies three groups of production processes: coordination and control, transport and storage, processing and assembly. In turn, each one is divided into more specific processes, which we have not detailed for reasons of space. Second, an analysis of the main machines used in manufacturing organisations has been made and the relationships between the different processes have been established: for example, transport processes can only be undertaken by conveyor belts, turn tables, rail carriages, etc. and milling machines cannot be used for assembly processes.

Furthermore, in a manufacturing plant the machines do not act independently of each other, rather it is the combination of the activities undertaken by each machine that leads to the finished manufactured product. Accordingly, the way in which the machines co-operate must be defined. In this case, it is mainly due to geographical proximity, transporting materials to adjacent machines or processing them with machines situated on a specific belt.

4.2. Conceptualisation

In this section, the vocabulary and axioms referring to the domain (called TBox in descriptive logic) are defined and conceptualisation is carried out in accordance with the three aspects mentioned above: physical components and the relationship between them; activities, processes and the relationships between them; and the relationships between processes and physical elements.

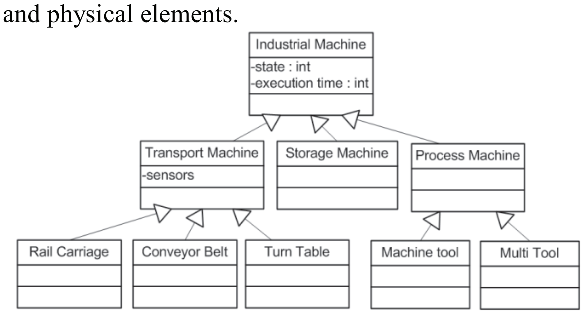

Figure 3. View of the most generic classes of machinery.

The conceptualisation of the physical elements implies the definition of numerous classes. It should be stated that industrial machinery has been defined as the main class, identifying transport machinery, processing machinery and storage machinery as its subclasses. Each subclass, in turn, is composed of others that represent more specific machinery.

For these classes there is a series of logical relationships in accordance with their physical relationships. Some of the relationships are described below in accordance with the position of the machines with respect to other machines. These relationships have special relevance in the reasoning shown in section 5. For example, any *Transport Machine* (tr) can be physically connected to another *Transport Machine* (tr2) on one of its sides of the X axis. These relationships are inherited by any of the subclasses of the *Transport Machine* concept shown in Fig. 3. such as *Rail Carriage* (RC), *Conveyor Belt* (CB) and *Turn Table* (TT).

$$(\forall tr1,tr2) hasAxisX+(tr1,tr2);$$
$$(\forall tr1,tr2) hasAxisX-(tr1,tr2);$$

In accordance with the geographical relationships between the different physical elements, a series of rules can be extrapolated to establish which machines are physically connected to each other (*hasDirectConnection*) and which machines can be reached through other machines (*hasConnection*). For example, if a *Transport Machine* (tr1) has a physical connection with another *Transport Machine* (tr2) at either end (*hasAxisX*+/-) then it is directly connected.

$$(\forall tr1,tr2) hasAxisX+(tr1,tr2) \lor hasAxisX-(tr1,tr2) \rightarrow hasDirectConectionOnAxisX(tr1,tr2);$$

If a *Transport Machine* (tr1) is physically connected to another (tr2) and this in turn is directly connected to a third *Transport Machine* (tr3), then there is at least one connection between the first machine (tr1) and the third machine (tr3), so they are both connected.

$$(\forall tr1,tr2) hasDirectConection(tr1,tr2) \land hasDirectConection(tr2,tr3) \rightarrow hasConection(tr1,tr3);$$

4.2.1. Activities, processes and their relationships. In this section, manufacturing domain processes and activities have also been identified, establishing as the main class the generic concept Process with its subclasses defined as transport, processing and storage. Each one of these classes is divided, in turn, into other subclasses that represent more specific concepts such as in the case of processes: drilling, milling, move to end, move to sensor, etc.

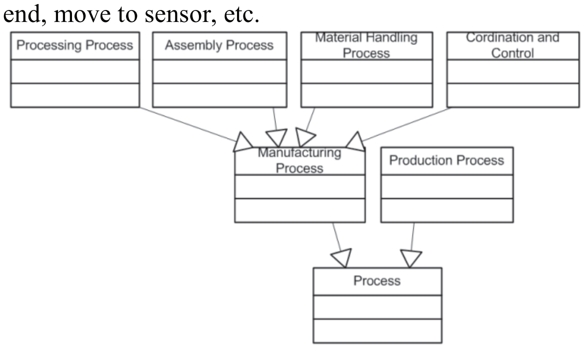

Figure 4. View of the most generic classes of the process classification.

The main relationships identified between processes are composition and association. The production process can be composed of several subprocesses or the execution need of a process can be linked to the execution of another process, as is shown below. For example, a manufacturing process (mp) can be a subprocess of a production process (pp).

$$(\forall mp,pp) SubProcesOf(mp,pp);$$

4.2.2. Hardware and relationship between them. In this section, the relationships between the production processes and the industrial machinery that can carry out the processes are established in the ontology. The machinery offers these processes as services, in accordance with the IMaaS architecture, so a process may be implemented by more than one machine. Moreover, a classification of the services in accordance with the type of machine that offers them has been defined and a series of relationships has been established for the classes that conceptualise the processes and for those that conceptualise the types of machinery.

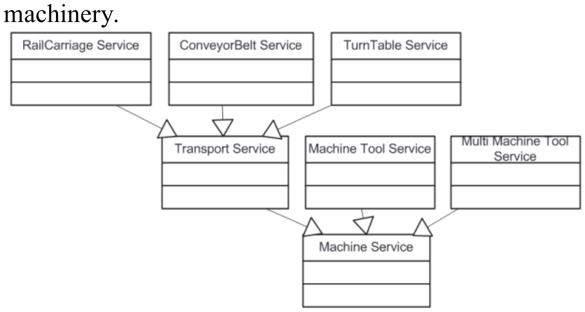

Figure 5. View of the most generic classes of the service classification.

Finally, it has been specified which service implements each process and which machinery offers each service. Some relationships between machines and the processes they implement are shown below along with the relationships between the offered services and the machines that offer them. For example, a *transport service* fig. 5 (ts) implements a *material handling process* fig. 4. (mhp), or a *machine tool service* (mts) implements a *manufacturing process*.

$$(\forall ts,mhp) Implements(ts,mhp);$$
$$(\forall mt,mp) Implements(ms,mp)$$

4.3 Reasoning Base

Thanks to the ontology, a reasoning series can be established to enable the automatic selection of the services required to be able to carry out the processes modelled by the process engineer in accordance with the manufacturing objectives. In this way the knowledge required to automatically compose, based on the objectives, a process that can be carried out by specific industrial plant can be extracted.

By making a simple layout of how this knowledge can be generated we can appreciate the importance of identifying the correct relationships between classes.

Accordingly, the semantic modelling node must be initially aware of where material is going to be processed and what processes are going to be carried out. In accordance with these processes, the services that implement processes are identified in addition to the industrial machinery that offers them. Once the machines that are capable of carrying out the process are identified, the machines through which the material must pass in order to be processed are calculated. Depending on each machine, the associated service will be automatically selected in order to implement it and continue on to the adjacent machine until the raw material reaches the machine corresponding to processing. In this way we can identify between which processes there is a dependent relationship, in such a way that the selection of one of them implies that both are selected for the composition of the new process.

5. Test and validation scenario

In order to validate this proposal a global test scenario has been defined. It is based on Fig. 1, in which the validation process has been applied to a scale model that simulates an industrial manufacturing process.

5.1. Global test scenario

The scenario that has been defined for the experimentation is composed of three elements: the production system, the information system and the semantic management prototype. It is a scenario based on the SOA paradigm and implemented with Web Services, in which the production system plays the role of service provider, the information system is the service intermediary and the semantic management prototype is the service consumer.

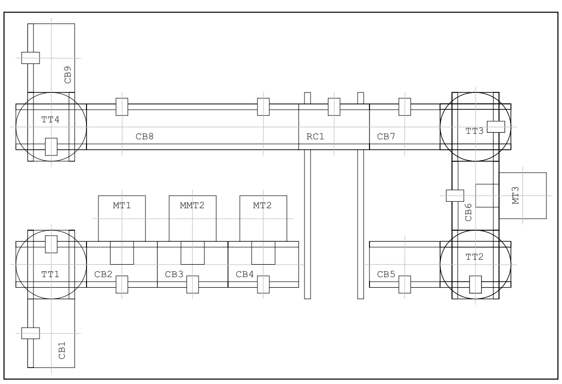

Figure 6. Drawing of the manufacturing model.

As we have mentioned in previous sections, the identified problem consists of the difficulties inherent in modelling multiple and complex manufacturing processes. In our proposal (Fig. 1), the semantic management prototype is responsible for this function.

The main objective of this prototype, in addition to the consumption of services, is to mitigate the problems in question. Thanks to the rules of inference and to a semantic reasoning engine, the system is capable of automatically ordering and locating the services necessary to undertake new processes.

The Semantic Management prototype has been implemented with the Jena library to manage the ontology and Bossam as the reasoning engine for obtaining the inferences. The definition of the new process is translated to a BPEL sheet that contains the description and sequencing of the operations to be carried out by the industrial machinery.

Table 1. Services offered by the industrial machinery.

Name	Arguments	Description
Conveyor Belt (CB)		
MoveToSensor	Direction:INT{1,-1} Sensor:INT{0-N} Stop:BOOL	Move the piece to until indicated sensor.
MoveToEnd	Direction:INT{1,-1}	Move the piece to the end of the belt.
Turntable:Conveyor Belt (TT)		
TurnMove	Direction:INT{1,-1}	Turn the table and expedite the piece
Rail Carriage:Conveyor Belt (RC)		
Transport	Direction:INT{1,-1} InputDirection:INT OutputDirection:INT	Get a piece, transport and expedite it.
Machine Tool (MT)		
Process	Time:INT	Move the tool out and down, process the piece .
Machine Multi Tool:Machine Tool (MMT)		
ProcessWith Tool	Tool:INT{0-2} Time:INT	Process the piece with the indicated tool.

The second element of the scenario is the manufacturing system, or service provider. This system is composed of a scale model of an industrial factory and its design can be seen in Fig. 6 and Fig. 7 shows a photo of the same. This production system, which was designed by the information technology and computing department of the University of Alicante, has been implemented by the company STAUDINGER GMHB, and is composed of the following industrial machines: a flexible production line formed by a milling machine, a drilling machine and pneumatic drill, a manufacturing cell with a milling machine and several conveyor belts.Communication with each element of the model is carried out by means of an RS-485 interface using the DCOM industrial protocol. The service provider is implemented in the Lantronix brand generic incorporated device called XPORT, whose characteristics are suitable for the preparation of the platform, such as its very small size and good computational capacity.

Table 1 shows the definition of the process map of the industrial machines that compose the scale model. In the description of these services, for reasons of space, a nomenclature based on the process inheritance between the different components has been followed, in such a way that newComponent:BaseComponent means that the elementdefinedinNewComponent.

The information system encompasses all the elements and resources used by the rest of the systems within the organisation in order to carry out the business or company activities. These elements include the UDDI record, implemented with the jUDDI server that stores the WSDL and BPEL documents that describe the functionalities and business processes of the organisation and the ontology with the information referring to the conceptualisation of the specific scenario, published directly on the APACHE TOMCAT server.

5.2. Ontology implementation and instantiation

The implementation of the ontology has been carried out by means of the OWL DL language. This language has been chosen in order to represent the ontologies because it is the language that enables the greatest level of expression while maintaining the principles of completeness and computational decidability. In conjunction with this language, the SWRL rules language has been used to model certain relationships of the domain concepts.

The instances have been defined in accordance with the elements available in the industrial scale model (Fig. 6) and the services they offer, modeling nine Conveyor Belts, four Turn Tables, one Rail Carriage, three Machine Tools, and one Multi-Tool machine. In order to implement the ontology and the definition of the initial instances, the Protégé tool has been used, resulting in the OWL document that has been published as part of the information system of the proposal.

5.3. Experimentation

In order to validate the proposed model, a series of tests has been carried out to demonstrate the use of the model for the composition of manufacturing processes in accordance with the reasoning of the information available in the ontology.

Accordingly, the system was informed of a series of processes to be undertaken and the initial location of the raw material. Based on this, the system was able to correctly identify the machines necessary for processing the material in accordance with the request and the shortest routes were calculated (in this case the paths crossing the least number of machines) and, finally, the services associated with the machines were selected in order to move the goods to the machine that would process them.

The same test was carried out with one of the transport machines disconnected. The system was able at all times to select the most suitable machinery in order to transfer the material to the machine that had to process it.

A machine that carried out one of the selected processes was also disconnected. Also in this case, the semantic management prototype was able to find another machine that was capable of carrying out this process and recalculated the path required to reach this machine, correctly selecting the services available.

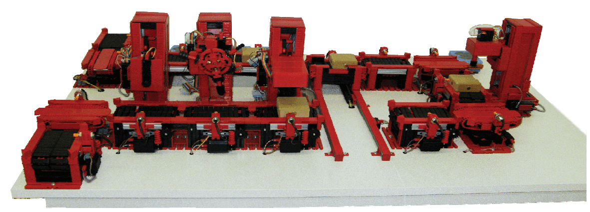

Figure 7. Industrial model for testing.

6. Conclusions

This paper has proposed a manufacturing process management system based on the use of ontologies. Its main objective is to mitigate the process modeling workload of process engineers, automatically inferring, in accordance with the semantic relationships of the components of the industrial domain, the processes and activities required to compose a new process.

In order to test the validity of the proposal, we have proposed and implemented a general scenario based on the SOA architecture in which industrial machinery behaves as a service provider and business policies, objectives and strategies are managed by a BPMS that acts as an IMaaS service consumer. The modelling of these processes, implemented as services, is automatically managed by the inference motor incorporated into the proposed dynamic manufacturing system.

Currently, work is under way to modify the proposed semantic management system in order to contemplate the composition of processes by means of BPMN annotation. We are also developing a system that will enable the automatic generation of semantic descriptions of the services offered in OWL-S. This will enable us to achieve a higher level of automation in the composition of new processes.

7. Acknowledgements

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