Internet Enabled Modelling of Extended Manufacturing Enterprises Using the Process Based Techniques

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Abstract

The paper presents the preliminary results of an ongoing research project on Internet enabled process-based modelling of extended manufacturing enterprises. It is proposed to apply the Open System Architecture for CIM (CIMOSA) modelling framework alongside with object-oriented Petri Net models of enterprise processes and object-oriented techniques for extended enterprises modelling. The main features of the proposed approach are described and some components discussed. Elementary examples of object-oriented Petri Net implementation and real-time visualisation are presented.

Key words: Enterprise modelling, CIMOSA, Petri nets, extended enterprise, enterprise process.

1. Introduction

In the modern global competitive environment manufacturing enterprises need active co-operation with a large network of suppliers and customers to form extended enterprises. Being a subject of fast changes such co-operation has to be supported by dynamic models that will allow parts of different enterprises to be integrated through Internet/Intranet/Extranet to provide the complete life cycle for the products [1]. The availability of such models can significantly increase understanding of the operation of an extended enterprise and thus improve its co-ordination and management. The distributed Internet-based dynamic models should represent the complicated structure of the extended enterprise to certain level of depth and be able to respond to frequent changes of operational status, employing a permanent feedback from the 'real' system.

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In the recent years much attention was paid to the problems of process control of distributed manufacturing systems and supply chain management using the event driven and agent-based approaches [2,3]. In the presented work we are investigating the application of process-based modelling techniques in order to provide modellers with possibility to 'observe' the extended enterprise organisational, resources, informational and real-time process models via Internet and analyse extended enterprise processes quantitatively. Furthermore, the research is also to try to filter out the complexity of the models and provide business users with intuitive visualiable information.

Since late 1970s a number of process-based techniques were introduced within the Computer Integrated Manufacturing paradigms. Recently a short overview is available in [4] and a more detailed description in [5]. The CIMOSA modelling paradigm is based on event-driven process based modelling approach [6]. Unlike other approaches it allows users to model different parts of the enterprise and to integrate them later and views the whole enterprise as a federation of communicating agents (functional entities)

[7]. This approach also uses the central concept of the process as a way of chaining activities and adopts a hierarchical view of organisational structure, providing two generic construction elements: organisation unit and organisation cell, which were updated recently to represent the modern organisation structures, such as an extended enterprise [6].

In the recent paper on manufacturing business integration using CIMOSA and Petri Nets formalisms [8] a formal systems engineering workbench is presented. It combines CIMOSA, generalised stochastic time Petri Nets, predicate-action Petri Nets and object-oriented design. This modelling method associates business processes and object oriented design in order to produce complete business model.

Following a number of previous applications of CIMOSA for enterprise modelling [8,9], it is proposed to investigate using the approach as a reference architecture for Internet-enabled extended enterprise modelling. Furthermore, the enterprise process models are implemented using the Object Petri Net approach, and the organisational, informational and resource aspects modelled and implemented using object-oriented techniques combining with an object-oriented database.

2. Object-oriented Petri Net Modelling of Enterprise Processes

Petri Net (PN) is a mathematical formalism specially suited to analyse and model dynamic discrete event systems. Due to its strong analytical properties and simple graphical representation, PN seems to be well fitted for detailed and precise modelling of business processes of a manufacturing enterprise.

The analytical properties of PN are well documented by a large number of published algorithms and methods on reachability and invariant analysis [10]. After its invention

in early 60s different types of PN were introduced, starting from the simple Place/Transition PN to High Level, Stochastic, Coloured and Object PN. Different types of PN were widely used for modelling in various fields including communication networks, automatic control, manufacturing systems, hardware design, etc.

In the paper [8] predicate-action and stochastic PNs are used for business process modelling following the CIMOSA approach. The predicate-action PN is an extension of Place/Transition PN which associates the firing of transitions with external events and thus can be used to define the internal sequences of activities and external interactions with system components. The Generalised Stochastic Time PNs are used for analysis and simulation in order to obtain performance parameters of the business processes.

In our approach it is proposed to use two layers of PN models: Place/Transition and Object PN. Both layers represent the same extended enterprise process. The use of Place/Transition PN with their strong analytical capabilities seems to be essential as the tests (reachability tree and invariant analysis) can be applied during the design process and also run in 'background' later to warn the user any possible behaviour problems in the system after minor changes. The application of Place/Transition PN might significantly eliminate 'simple' user mistakes and possibly warning about 'dangerous' system behaviours if occurred.

The use of Place/Transition PN for manufacturing system modelling is described in a number of papers and books [11]. To be able to apply Place/Transition PN for extended enterprise processes modelling it is needed to supply them with the adequate interpretation. In our case we used the approaches proposed in [12].

In order to be able to represent the complicated enterprise processes adequately and enable proper simulations, the classical Place/Transition PNs are typically extended by

‘colour’, ‘time’ and ‘hierarchy’. For the purpose of Internet based extended enterprise processes modelling these kinds of PN extension seem to be still not sufficient, as the models are supposed to enable user to ‘observe’ the particular properties of resource and product objects, the functionality and behaviour of the enterprise processes, the external interactions of enterprise activities with system components, etc.

In the recent work [13] the integration of PN and object-oriented concepts are described. In our case the Time Hierarchical PN are ‘enriched’ with resources, events and products objects and the description fields of extended enterprise activities can be accessed directly from the PN model. In the proposed approach the PN will represent the extended enterprise processes, the tokens represent product objects or availability of resources, places represent resource objects or states. The transitions can be ‘linked’ with concrete activity and its events or methods of the concrete objects can be executed and their attributes can be read and changed.

The next level of PN extent uses Internet simulation and visualisation software being ‘linked’ to PN model components. Internet-enabled numerical simulation and visualisation can significantly improve the ‘quality’ of the model for the users and enable precise and possibly real time simulations (with data obtained from concrete equipment and simulation runs under actual manufacturing conditions). The real-time Internet-based visualisation provides the user with the real time image of certain activity or physical operation at a remote part of the extended enterprise via video streaming technology.

3. Object-Oriented Technique and the Prototype System Architecture

Object-oriented modelling methodology proved its efficiency in many fields. This

approach was also suggested for enterprise systems modelling following the CIMOSA approach [9].

The PN are well suited for processes modelling. The attempts have been made by authors to apply PN technique for modelling the organisational and resources aspects of extended enterprise. Such approach appeared to have several disadvantages. The resulting nets seem to be too complicated, lack ‘transparency’ and therefore were difficult to understand. The application of PN as ‘front end’ will also demand a highly skilled user who is supposed to be familiar with PN modelling approach.

In the proposed research the object-oriented approach is supposed to cover the actual implementation of organisational, informational and resource aspects of the extended manufacturing enterprise. The model of the enterprise will be built as a set of communicating objects: organisational, processes, resources, events and products following the CIMOSA modelling approach. The process objects will include Object PN process models, as it was mentioned earlier, to represent the dynamic nature of manufacturing enterprise.

The investigation should be done to create relevant generic classes for the extended enterprise models and ‘link’ them with the corresponding PN process models components via Internet. The outlines of the application of object-oriented technique following the CIMOSA Modelling Framework are given in [14]. In the proposed approach the object-oriented paradigm is considered more as a tool for software development and ‘support’ of CIMOSA modelling than as a modelling method. The application of object-oriented technique should also make it possible to provide the user with simple graphical formalism and enable modularity, code reuse and database integration into Internet-based modelling environment.

The simplified structure of the prototype modelling environment is presented on the figure 1. It consists of organisational and process models, the database, numerical simulation and real time visualisation features. All the parts of the model will be 'communicating' with each other and can be accessed by user via Internet/Intranet/Extranet.

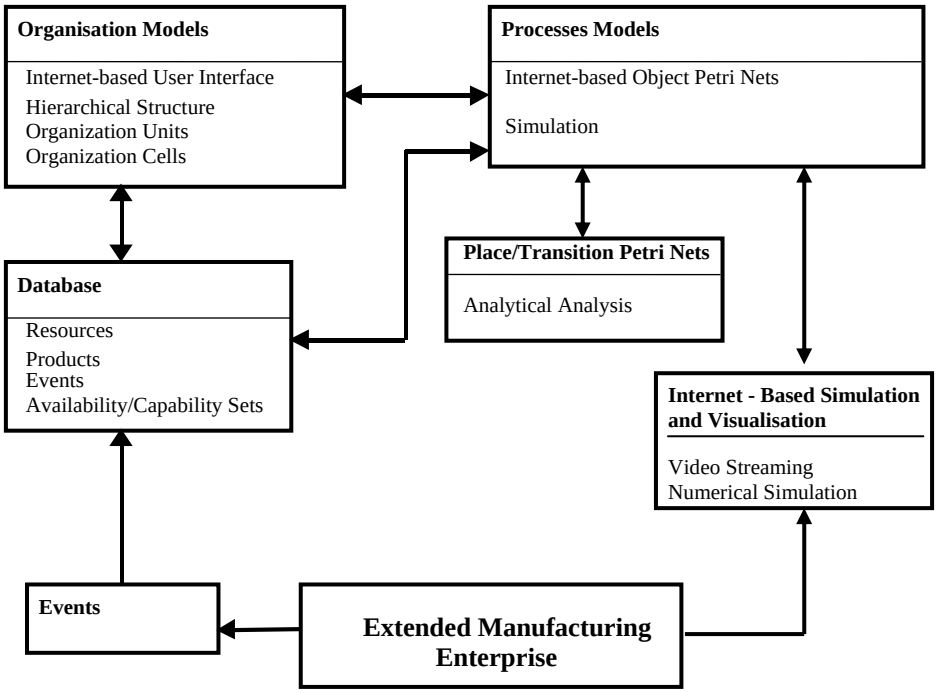

Figure 1. Internet - based modelling environment.

The proposed modelling approach satisfies the main principles of enterprise modelling as they are listed in [5]:

- Separation of concern

Model of extended manufacturing enterprise to be separated into domains, each block considered as a separate part with the PN domain process and sub-processes models attached to it.

- Functional decomposition

The functional decomposition is maintained via application of Hierarchical PN and

hierarchical organisation structure. To maintain the important properties of the PN model (such as liveness, boundedness etc.) the PN sub-nets have to be 'inserted' via transition refinement method described in [12].

- Model genericity

Generic classes will be defined for all parts of the model. The extended distributed manufacturing enterprise can be specified (in object-oriented modelling approach sense) as: $S = \langle O_S, P_S, R_S, E_S, V_S \rangle$, where O_S is a finite set of organisation classes, P_S is a finite set of processes classes, R_S is a finite set of resources classes, E_S is a finite set if events classes and V_S is a finite set of product classes.

- Model visualisation and process-based approach

The friendly-user interface will provide all necessary links between the organisational units, resources and processes objects. The core model engine is based on PN and is process-based. Main processes to be modelled from their start to end by 'chaining' the sub-nets from different organisational unit objects.

4. Example of a Petri Net Model for a Manufacturing Cell

In this section we will briefly describe the ObjectPetri Model program developed for enterprise processes modelling and an elementary example of Object Petri Net model of a simple manufacturing cell. The software is currently being developed as Java application and is a prototype of the Object Petri Net process models part of the Internet-based system. For the development of the presented software we were partly using the code from PetriTool by Rink Brink, Rochester Institute of Technology (www.csh.rit.edu/~rick/thesis/thesis.html).

Let us consider a simple manufacturing cell as illustrated in the figure 2. The cell

consists of three machines and a robot. The cell is supposed to process two types of parts: part A and part B. When parts arrive to buffer they are moved by the Robot to Machine 1, after Machine 1 finishes processing the part A is moved to Machine 2 and part B to Machine 3. For simplicity let us assume that only one product can be processed in a cell at the time. The Petri Net model of the presented cell created in ObjectPetri Model is shown in figure 3.

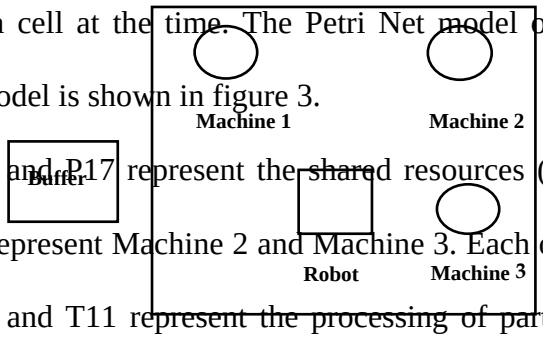

Figure 2. A simple manufacturing cell.

Places P14 and P17 represent the shared resources (Robot and Machine 1), places P18 and P19 represent Machine 2 and Machine 3. Each of the 'linear' nets starting with transitions T5 and T11 represent the processing of parts A and part B. The buffer is presented by the place P23. The reachability tree analysis algorithm implemented in PetriTool can be run in the ObjectPetri Model to check the properties of the net.

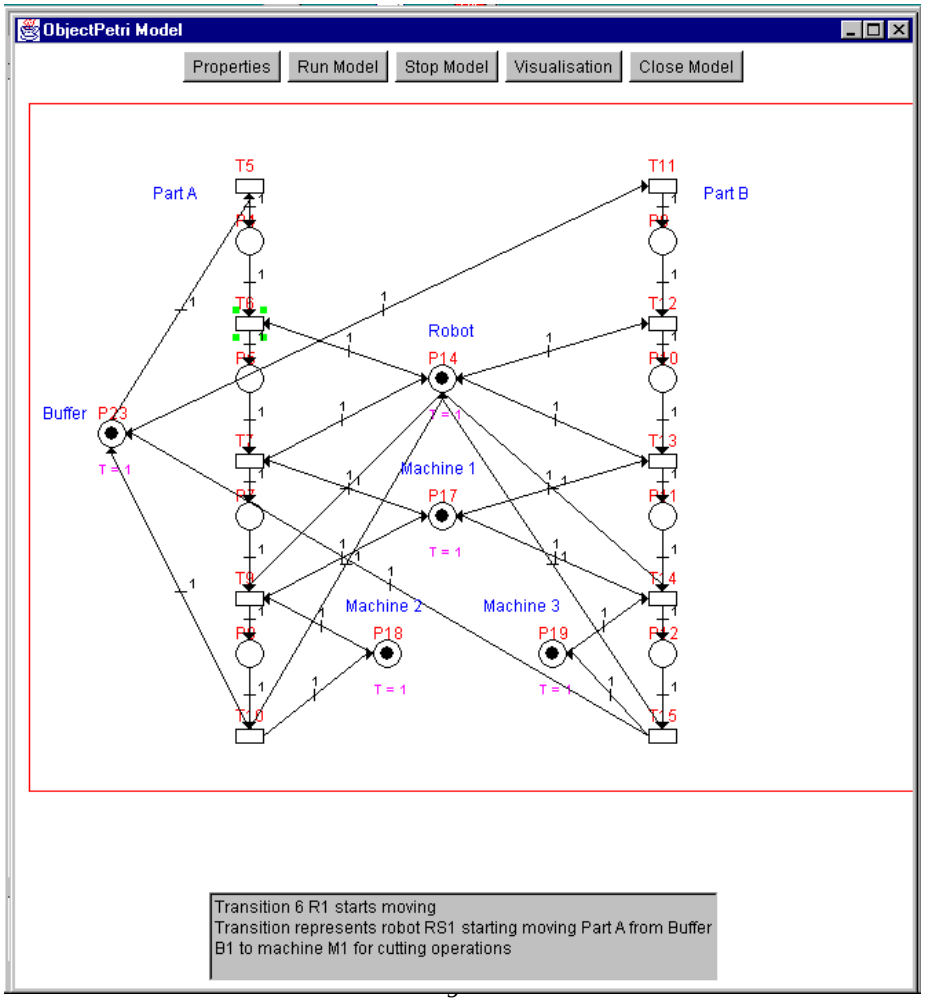

Figure 3. Petri Nets model of manufacturing cell.

Each place, transition and token of the model is an object of the corresponding type. The short description of the object can be observed in the text window by clicking a component as shown in figure 3. By pressing the *Run Model* button the user runs the model. The text window then loads the description text of the currently 'firing' transition to describe the real time state of the system. Currently the PN model is simulated 'autonomously', i.e. the firing times of the transitions are previously assigned to them. In the Internet-enabled modelling environment the transition firing times are supposed to be governed by the events, generated by the database or actual enterprise processes via Internet. In this way each Petri Net model is supposed to work 'in tact'

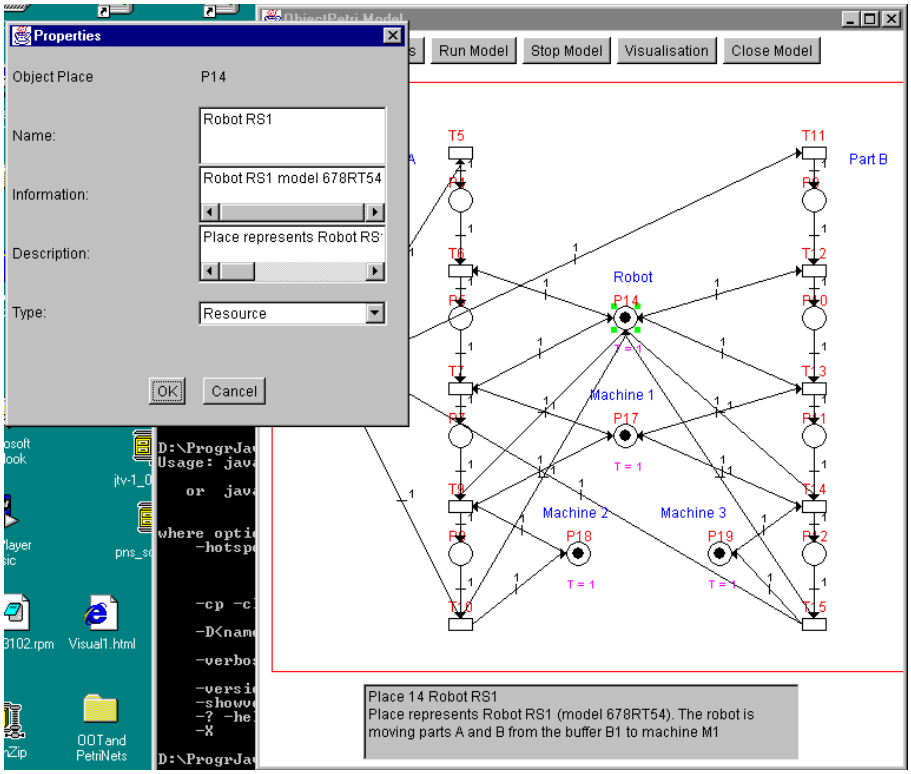

Figure 4. Model components properties.

with the process it describes.

The *Properties* button, if pressed, opens a dialog window with the field values of the corresponding component database record, as shown in figure 4. The full structure of

the database records and generic classes will be implemented later. They will cover the availability and capability sets, costs, quantities, documents, products description files etc. Currently the available fields are short text description and type.

The real-time visualisation feature is currently implemented using the RTSP RealServer at the Faculty of Information and Engineering Systems of the Leeds Metropolitan University (http://dstar.ies.lmu.ac.uk/~alex/real.html) and the RealPlayer. As shown in figure 5, the *Visualisation* button of ObjectPetri Model opens a browser window with embedded real-time media. In this example we used a .rpm metafile to embed the media into the webpage using the browser plugins.

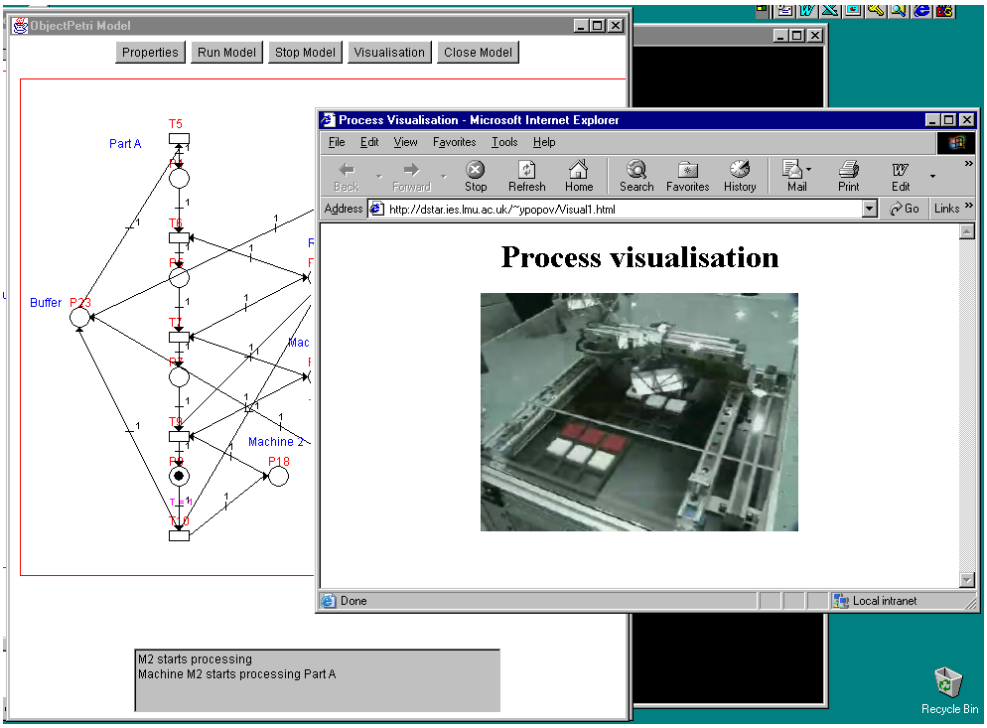

Figure 5. Real time visualization of the process.

5. An Application Scenario

Figure 6 shows the modelling approach being applied to a modern manufacturing enterprise scenario. A modern manufacturing company should be heavily relied on using Internet/Intranet for supporting its business operations in terms of data flow and

work flow management, and the collaborative design and manufacturing activities. The modelling and simulation system developed based on the approach can cope with the dynamic changes across various levels of the enterprise and visualize the data and work flow on the networks transparently. The production networks and interconnections within the enterprise are emulated by the multi-layer Petri Nets. Therefore, the approach and associated system can be used as a tool for managing the complex manufacturing processes across the enterprise networks quantitatively and qualitatively in real time and thus enable to achieve production transparency, efficiency, agility and responsiveness. The preliminary trial results illustrate the approach and system are very promising.

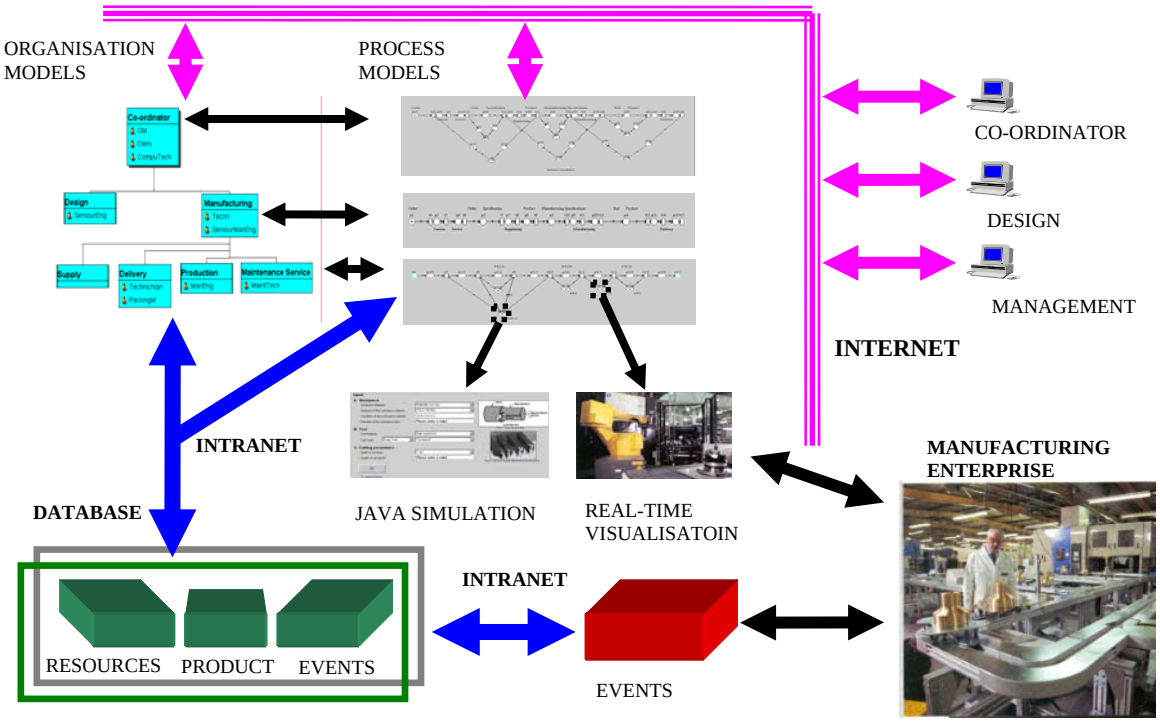

Figure 6. An application scenario at the manufacturing company

6. Conclusions

This paper presents some novel ideas and the associated results on application of

process based and object oriented techniques for Internet-enabled extended manufacturing enterprise modelling.

The paper describes the implementation of two-layer Petri Net process models using the Object and Place/Transition Petri Nets. The application of Petri Net modelling approach is illustrated by the ObjectPetri Model Java application. The real-time visualisation capability is realised using the RTSP RealServer and the RealPlayer.

The authors are attempting to further investigate the CIMOSA Modelling Framework application for extended enterprise modelling and so to implement the Internet based extended enterprise modelling environment as a distributed Java application.

Acknowledgements

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