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Distributed planning and control systems for the virtual enterprise: organizational requirements and development life-cycle

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This paper describes the requirements analysis and system specification of an Order Promise module to be used as part of a broader Decision Support System for production and operations planning of a Virtual Enterprise. This work is part of a broader project with a particular focus on the microelectronics industry which is a good example of Virtual Enterprise, and where a quick response to the customers needs and to unpredictable changes in production conditions is considered a major factor for success. First, the analysis and specification are presented within a development framework that involves the study of organizational issues of semiconductor enterprises. The use of ontological engineering for supporting the communication and shared understanding of the system concepts is explained and a virtual enterprise ontology is outlined. Following the clarification of the concept of virtual enterprise, the generic techno-organizational requirements for the information system are derived. Finally, a specification of the global planning module and a more detailed one regarding the order promise module is presented.

Keywords: Virtual enterprises, distributed planning and control, decision support systems, information systems development

1. Introduction

In today's world, manufacturing companies tend to be organized as a network of different units namely plants, logistic centers and storage facilities. In order to produce cost effective products within the time scales requested by the customers, many manufacturing enterprises are therefore becoming global businesses covering multiple manufacturing sites consisting of different shop floors, subcontractors and suppliers. The concept of Virtual Enterprise (VE) emerged in this context, and can be generally defined as a set of enterprises which behave like a single company through strong co-operation towards mutual goals. In these companies, planning and control activities can be very complex, and have to take place both within the enterprise and across the whole supply network in order to achieve high levels of performance. Moreover, the logistics associated to manufacturing products in several different plants and subcontracted companies become an important and critical practical issue.

The semiconductor (SC) industry clearly has the features of a virtual enterprise, in particular concerning distributed sites and different ownership situations of the plants. The manufacturing processes involve, in general, a set of sites (that may be located in different regions and countries), subcontracting and outsourcing, and create therefore quite complex logistic problems that have to be explicitly taken into account in the planning processes (Leachman, 1993). Furthermore, due to the increasing demanding requests of customers, in a highly competitive environment, the need for very flexible planning systems and for reliable control mechanisms becomes very important. Quick response to the customers needs and to unpredictable changes in production conditions is also a need.

Nevertheless, the information systems currently available, do not satisfy the distributed planning and control needs, as they lack support for co-ordinated production within a network and for enterprise wide business processes. Moreover, these information systems are based on some premises that are no longer valid (particularly MRP based systems), and the need of supply chain management implies fundamental changes in the design of information systems for planning and control (Vollmann *et al.*, 1997).

The work[1] reported in this paper describes part of an information system development coping with the planning and control tasks in a virtual enterprise environment. The system aims at improving manufacturing performance in a virtual enterprise by integrating the heterogeneous manufacturing systems and by bridging the gap between the higher planning levels and the lower distributed shop floor control levels. The system will address three major requirements that are currently missing: generation of production plans that are feasible and optimized with respect to the VE, capacity checking based on independent and autonomous capacity models, and reactive actions taking into account possible effects on other local units. The general objectives of the system are to support manufacturing solutions and services with high potential for improvement of the enterprise performance, leading to: shorter customer order lead times, improved delivery precision, reduced inventory and stocks, improved resource utilization, quick response to customer enquiries, cost reduction in the logistic processes. In particular, these targets will be partially attained by implementing means for improved customer due date calculation, and by a multi-site planning tool to co-ordinate local activities across the virtual enterprise network.

In this paper we give relevance to the development issues of an ''order promise'' system module and in a lesser extent to the ''global planning'' module. We present the analysis and specification of these modules within a development framework that involves the analysis of some SC enterprises organizational issues and the use of ontological engineering for supporting the communication and shared understanding of the system concepts.

In Section 2 some organizational issues of the SC virtual enterprises are analyzed. We describe the manufacturing processes as well as the planning specificities of this industry. After clarifying the concept of virtual enterprise, the organizational change through business processes reengineering is shortly analyzed and generic techno-organizational requirements for the information system are derived. Section 3 describes our approach to the requirements identification and system specification beginning with the planning and control system goals and generic features. An ontology of the virtual enterprise is presented and its application in the system development described. In Section 4 a specification of the global planning module and a more detailed one regarding the order promise module is presented, together with some comments on the algorithms. Finally, in Section 5 we discuss the results of this work and consider further developments.

2. Organizational issues in SC virtual enterprises

As mentioned above, SC companies have experienced global markets for a long time and have been establishing corporations based on networks of firms, or what can be called virtual enterprises. In this section, a global analysis of the organizational change trends in SC companies is made, resulting in the statement of some concerns related with Business Process Reengineering (BPR), namely labor division, participation, qualification and agility. From this analysis we draw the preliminary planning and control system requirements and specification with organizational concerns.

2.1. *The semiconductor industry*

The semiconductor manufacturing process flow may be divided into two main stages, usually known as Front-End and Back-End (see Fig. 1). The Front-End includes the manufacturing of integrated circuit structures on silicon wafers (wafer fab) and the wafer electrical probe testing (probe). The Back-End includes two major steps: assembly and final test. In the Front-End, silicon wafers are processed, and the output of the first step of this stage is wafers with a number of identical patterns of a basic integrated

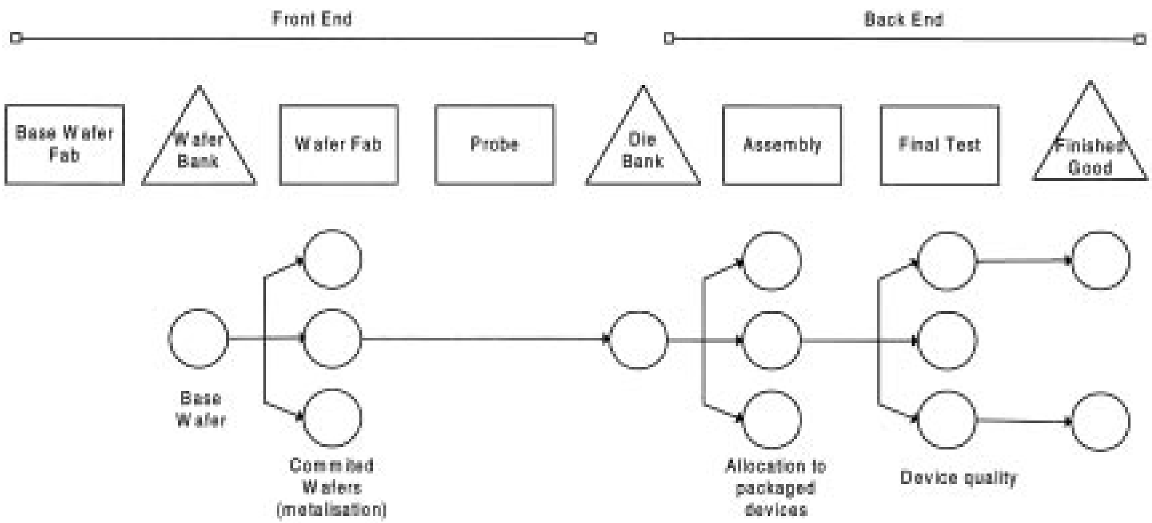

Fig. 1. Semiconductor manufacturing process.

circuit, called dies. The next step (wafer fab) deals with the metallization of wafers that are related to the specific customer requirements (Atherton, 1995).

There is a stocking point in those steps called the wafer bank, or mirror bank. The last step of Front-End deals with the electrical testing of the metallized wafers. The probed wafers are then kept in another stocking point called the die bank. At the Back-End, in the assembly step, the wafers are sliced into individual chips and assembled into sealed plastic or ceramic packages to become package devices. Finally, testing and labeling of the packaged devices is performed, before shipment to the customer. Products in the semiconductor industry have a divergent type of structure. In general, a single base wafer is the source product for several types of wafers, a single die type is the source product for several types of packaged devices, and a single packaged device is the source product for several finished goods types (Leachman, 1996).

2.2. *The planning process*

The planning process should closely reflect the interface between the production system and the market. In the case of the semiconductor industry, and for the Back-End stage, the production is triggered by firm orders, and then the die bank, like a de-coupling point, determines the minimum customer order lead-time. Nowadays, this decoupling point tends to move towards earlier stages of the manufacturing process (see Fig. 2). The planning activities upstream the decoupling point (Front-End stage) are based mainly in forecasts, although some customer orders may have been already confirmed.

In the context of this work, we are basically interested in the global planning of incoming requests. However, to get a reliable response for each order request and to optimize the order flow throughout all the entities involved, takes a considerable amount of effort. This may be not acceptable when there is a need to ensure a fast order processing and a feasible capacity checking.

The approach followed to overcome this problem was to break the planning process into two main levels. A global level that is concerned with overall co-ordination of the various nodes of the network and the logistic issues, and a local level that carries out the detailed plan for each node. These two levels form the *rough planner system* and they are called whenever an order request exists.

A subsequent action is performed by updating the capacity model of each node, by the action of a *fine planner system* functioning as global optimizer for the VE, and running whenever it is convenient.

2.3. *The concept of virtual enterprise*

Before approaching system development issues for the planning and control in SC enterprises, we review

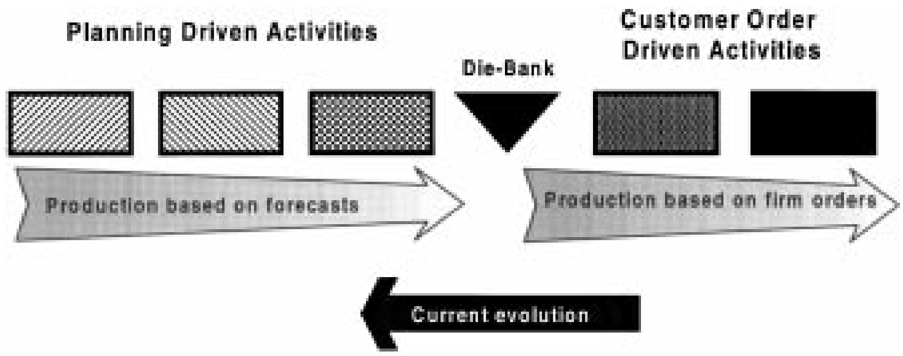

Fig. 2. Planning decoupling point.

the concept of virtual enterprise. In the literature, we can find several approaches to these issues, but they are not completely satisfactory in solving the ambiguity and imprecision associated to the terms used in the domain. First of all, it is interesting to review some terms related to the VE. (APICS, 1995):

> Virtual Corporation—[...], the capabilities and systems of the firm are merged with those of the suppliers, resulting in a new type of corporation where the boundaries between the suppliers systems and those of the firm seem to disappear. (...).
>
> Virtual Factory—[...]. It is a transformation process that involves merging the capabilities and capacities of the firm with those of its suppliers. (...).

Based on the GERAM (Generic Enterprise and Reference Architecture and Methodology) entities, Ferreira (1995) presents a framework that allows the consideration of the *extended enterprise*. This is achieved by labelling products, the manufacturing enterprise, the engineering design enterprise, and the strategic enterprise, as new entities of the reference architecture. In this context, the concept of *extended enterprise* encompasses not only the integration of processes from different manufacturing enterprises, but also their integration with the engineering enterprise and the strategic management enterprise. As one would expect, it may happen that the previously mentioned entities are in fact different enterprises, thus reinforcing the need for integration within the extended enterprise.

In Browne *et al.* (1995) the concept of *extended enterprise* is also explored. The *extended enterprise* is viewed as ''an expression of the market driven requirements to embrace external resources in the enterprise without owing them''. The emphasis is put in the integration of manufacturing and distribution planning and control systems. A similar concept is that of *supply chain*. For EIL (1995) the *supply chain* of a manufacturing enterprise is a world-wide network of suppliers, factories, warehouses, distribution centers through which raw materials are acquired, transformed and delivered to customers.

Another related interesting concept is that of *network organization* in which *separate firms*, each retaining its own authority in major budgeting and pricing matters, operate as integral parts of a larger organization co-ordinated by a *core firm*. In this context, the different firms, spread along a value-added chain (e.g., suppliers, manufacturers, and distributors), tend to function in a way that stresses complementary, ongoing relationships, and reciprocity (Ching *et al.*, 1993).

From the company's point of view, it is possible to identify two major types of networks, reflecting the intended type of co-operation:

- Client/supplier networks, where the companies are involved according to a variable degree of commercial dependency; in ideal terms, this commercial dependency would subsume a logistic dependency (planning, control, and distribution).
- Technical networks, where the companies co-operate by putting together their complementary competencies in e.g., product design or distribution, as a means for improving competitiveness.

These two major types are not completely disjoint, as technical networks can also imply a commercial and logistic dependency.

In the context of this project we came to the following operational definition:

> The Virtual Enterprise is a subset of units and processes within the supply chain which behave like a single company through strong co-operation towards mutual goals.

First, it is clear that we are talking of a physically distributed network of units possibly owned by different companies. Second, it should also be clear that we focus on the manufacturing aspects of the company, or on aspects that are strongly related to manufacturing.

Finally we should emphasize that the virtual enterprise concept is very suitable for the semiconductor manufacturing enterprises, as it is clear that these are highly distributed in their activities and are often part of a vertically integrated supply chain.

2.4. *Generic organizational requirements for a PPC system in a virtual enterprise*

As a general trend in the SC industry, companies are experiencing a major shift from a manufacturing driven organization to a business driven one, with more than one business competing for manufacturing capacity. This change involves the total enterprise, and relies heavily on improved logistics, planning and control functions. This major shift from manufacturing centric views to business centric views and activities is one of the motivations for global restructuring and reorganization. Figures 3 and 4 depict an overview of the current and future models for the business processes.

Taking the future generic business process as a scenario, a production planning and control system for virtual enterprises (PPC-VE) could play an important role besides intrinsic planning and control improvement.

This role would consist in the implementation of innovative organizational and co-operation schemes

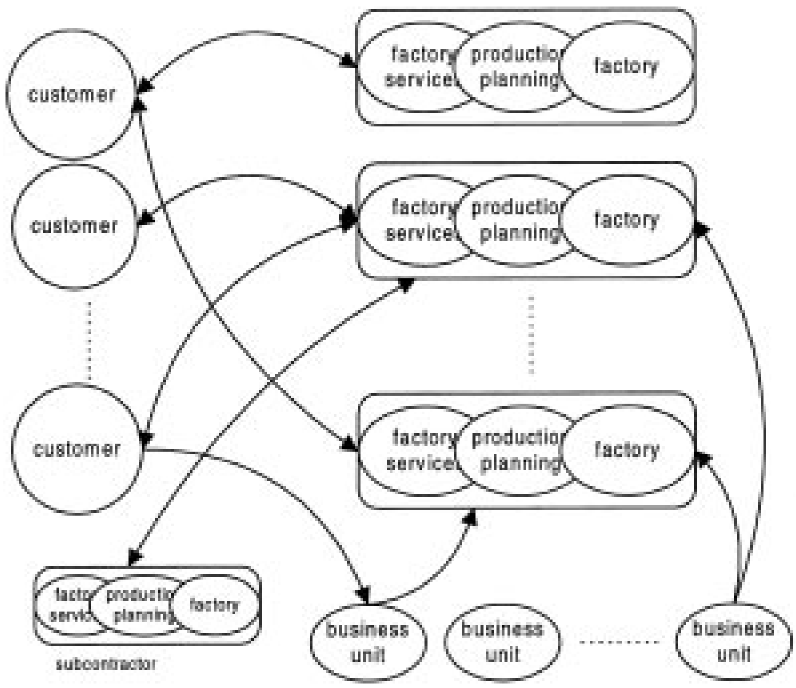

Fig. 3. Current generic business process.

in the Virtual Enterprise setting, supporting agility. Next, we present some techno-organizational requirements that should be observed in the system specification, to follow this direction.

2.4.1. *Configurability with respect to labor division*

The system should not impose any particular work organization on the company functions involved, planning and control, marketing and sales and manufacturing. Nevertheless, there are technical and economic constraints as well as best practices that must be taken into account.

On one hand, there are some organizational assumptions that must be considered for the reduction of technical and architectural complexity. This involves considering decentralized vs centralized planning and control or group support (e.g., marketing and planning teams) vs support to individual tasks. On the other hand, PPC-VE should take into account socio-organizational best practices in incorporating functional and architectural principles that promote, or at least do not hinder in any sense, the adoption of team-work, skills enhancement, empowerment and delegation of decision making to the lower levels in the hierarchy.

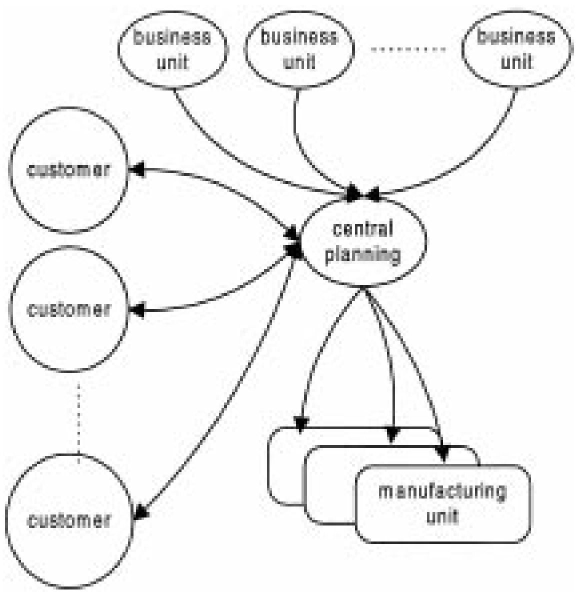

Fig. 4. Future generic business process.

2.4.2. *Co-operation within the virtual enterprise environment*

Inter-site collaboration

One important issue is the inter-site co-operation, and in particular when it is enabled by tools from the PPC-VE set. Two dimensions of this issue are highlighted:

- the relationship between central planning and the manufacturing units,
- the relationship between manufacturing units.

The first dimension directly influences the design of PPC-VE concerning release and acceptance of plans, as well as co-operation concerning replanning in the case of early warnings. In other words, it influences the global planning/local planning interaction, and the communication tools for implementing that interaction.

The second dimension has to do with the design of hybrid protocols (involving some automation and human intervention) enabling consensus in decision making in the case of local reactions to outdated and/or unfeasible plans. This has direct influence in the so called inter-local reactivity.

Support to team work and virtual team work

As stated by companies, the link between Planning to Sales & Marketing is the driver for ensuring high quality fast customer response. The design of PPC-VE's order promising and global planning modules must take into account this critical interaction aspect. This is already to some degree covered by existing systems,[2] but with a logic of a traditional departmental organization. The increasingly important link between planning and sales/marketing can become so critical that it justifies the implementation of teams integrating these functions. Thus, it is envisaged that IT tools go beyond connecting functions to explicitly integrate them. Hence, PPC-VE modules should be designed with this in mind.

Going even beyond local team work, one can propose the idea of teams composed by people in different sites—Virtual Teams. This can arise in two scenarios:

- in a global planning centralizing strategy, virtual team work would be related mainly with inter-site local planning co-ordination—local plans adjustment and repair;

- in a strategy in which more planning autonomy is given to local sites, virtual team work would include, along with the previous issue, the sales and marketing functions.

These scenarios, although speculative, must be taken seriously and should influence somehow the related PPC-VE modules in terms of information and functions distribution as well as users interaction.

2.4.3. *Support to agility in virtual enterprises*

PPC-VE supports agility in a company, specifically with respect to the promising/planning/controlling aspects. This issue has two main implications concerning system design:

The right balance between specific features and configurability: The system should be organized as a ''tool'' set, meaning that modules should be small, easy to replace by new ones; each module should have a precise functionality, so that it can be easily adjusted by any BPR, or adaptation need; so, although each tool should be a separate entity, the set must provide an overall solution for the planning problems.

The support to distributed decision making: As autonomy is a key issue in achieving a high degree of agility (concerning planning and control), this distribution has important implications on the operational side and again on human and social aspects i.e., on the overall effectiveness, local reactivity and inter-local negotiation for problem solving (e.g., plan repair) are not only technical features, they have very important organizational implications, the software must not impose a pre-defined task assignment, although being configurable in a range defined by both the industry organizational trends and socio-organizational best/practices.

3. The development of a planning and control system for the SC virtual enterprises

In a virtual enterprise environment planning and control activities can become very complex, and have to take place both within the enterprise and across the whole supply network in order to achieve high levels of performance. Nowadays, these planning and control tasks are not well supported by state-of-the-art solutions. Moreover, the logistics associated to manufacturing products in several different plants and subcontracted companies become an important practical issue.

The information system described here—a production planning and control system for virtual enterprises—aims not only at improving the planning and control in the SC virtual enterprises through novel problem solving techniques, but also at playing an important role in the implementation of innovative organizational and co-operation schemes, supporting an agile perspective. In this section we will focus on the requirements identification and systems specification issues.

3.1. *System goals*

Collaborating manufacturing in virtual enterprises leads to specific requirements concerning information systems. We can namely stress the high degree of distribution, the high heterogeneous environment (legacy systems), the need for mechanisms within a production network for co-ordination and co-operation and the need for suitable security measures.

These requirements lead to two main goals for the planning system: the improvement of manufacturing performance across the whole manufacturing chain in a virtual enterprise environment and the achievement of a reliable and on time distributed order management for incoming requests. In addition, system openness, scalability and capability to integrate with other enterprise IT systems, will be given the utmost priority in order to guarantee future flexibility for changes. Major advances will be required over state-of-the-art and will lead to new concepts and tools for distributed planning and scheduling.

3.2. *Mediation in the systems development through the use of ontologies*

This system is being developed within a large R&D trans-national project, comprising partners with different academic and industrial cultures. Concerning the industrial partners, the different companies have organizations and languages that can be substantially different. Even if the general objectives and goals of the system under development were set in a precise manner, this was not the case of its scope. The very nature of the project, involving the idea of virtual enterprise, led to difficulties in defining the entities covered by the concept and the roles to be played by those entities. From the point of view of the project management there are obvious difficulties. The project teams work largely by themselves, with reduced interaction with each other. Periodical technical meetings are held with the purpose of aligning objectives and synchronizing the various tasks. These co-ordination aspects are in practice an additional problem in terms of an efficient and smooth course of the project.

In this context, the system development initially ran into difficulties given the profusion of concepts and terms, and the confrontation of different perspectives. Our experience showed what others had already reported, in a different context, that terminological confusion breeds conceptual confusion and vice-versa (Bradshaw *et al.*, 1992). This is mostly true in phases of conceptual brainstorming and confrontation of perspectives which characterize the early phases of the system development process. One way to improve this process is to agree *a priori* with a conceptual and terminological core, setting the ground for the subsequent discussion. Such a core would assume a mediation role between the development actors. This led us to the use of ontologies in implementing the referred mediation scheme.[3]

Ontologies are an active research area in the field of Artificial Intelligence supporting a modeling view of knowledge engineering as opposed to a transfer view (Guarino, 1995). In this perspective, knowledge engineering is viewed not as the capture and storage of something extracted from an expert's mind but as the result of a constructive modeling process of an objective reality. Different definitions of ontology can be found in the literature. A concise definition that is becoming widely accepted is the one proposed by Gruber (1993): ''an explicit specification of a conceptualisation''. A good synthesis of what an ontology is appears in Uschold and Gruninger (1996), quoting a source in the SRKB mailing list. ''Ontologies are agreements about shared conceptualisations. Shared conceptualisations include conceptual frameworks for modeling domain knowledge, content specific protocols for communication among inter-operating agents and agreements about the representation of particular domain theories. In the knowledge sharing context, ontologies are specified in the form of definitions of representational vocabulary'' (Gruber, 1994).

3.2.1. *Purpose of an ontology in the systems development life cycle*

Ontologies have been applied so far in a range of works with several purposes. Knowledge sharing and reuse are the base line directly or indirectly referred in each of them. Sharing arises when a common conceptualisation of a given domain is essential to the undertaking and co-ordination of activities within that domain. Sharing implies some sort of communication between different people, people and implemented computational systems, different implemented computational systems (Uschold, 1995). Reuse can be viewed as the step forward towards a generalized sharing, through formalization mechanisms. Our purpose in building an ontology for this project is to improve the communication between partners concerning the requirements identification, specification and design phases of the planning and control system. In this way we expect to achieve a faster agreement on the system's conceptual model and a more consistent use of terms and concepts throughout the software development. Eventually, when a more mature state of this ontology is reached, we intend to code it and make it available for reuse, contributing for the clarification of the Virtual Enterprise concept. As a side effect, we also expect to contribute to the research of a less explored role of an ontology, the one of communication medium between people.

Table 1. Networked/extendend organizations

VIRTUAL ENTERPRISE: is a set of inter-related VE UNITS that are totally or partially committed to some common *PURPOSE* (the relation between VE UNITS can be one of *OWNERSHIP* or a looser one of belonging to a common supplier chain).

VE UNIT: An *ORGANIZATIONAL UNIT* belonging to the set that composes a VIRTUAL ENTERPRISE. A VE UNIT may be a manutacturing/processing plant, a subcontractor, a transport provider, a supplier or a warehouse (the term *OU* is here used in its broader sense i.e., as an UNIT providing the a complete set of products or services, e.g. a plant, a manufacturing unit, a warehouse, etc).

Table 2. Plans management

PLAN: *an ACTIVITY SPECIFICATION with an INTENDED PURPOSE.*
PLANNING: *an ACTIVITY whose INTENDED PURPOSE is to produce a PLAN.*
PRODUCTION PLAN: is a *PLAN* whose *INTENDED PURPOSE* is to specify when and where PRODUCTION ACTIVITIES will be performed. A PRODUCTION PLAN produces an assignment of *ACTIVITIES* to VE UNITS and *TIME INTERVALS*.
ROUGH PRODUCTION PLAN: is a PRODUCTION PLAN based on aggregate information and setting *TIME INTERVALS* for production in the VE UNITS considered to be feasible candidates.
FINE PRODUCTION PLAN: is a PRODUCTION PLAN based on more detailed information, and setting *CALENDAR DATE's* for production in specific VE UNITS.
GLOBAL PLANNING: an *ACTIVITY* whose *INTENDED PURPOSE* is to produce PRODUCTION PLANs.
LOCAL PLANNING: an *ACTIVITY* whose *INTENDED PURPOSE* is to produce *PRODUCTION PLANs* for a single VE UNIT.
CAPACITY: is an *ATTRIBUTE* of a *RESOURCE* representing what is available for allocation to *ACTIVITIES* over time. The CAPACITY of a *RESOURCE* constrains the number of *ACTIVITIES* that it can simultaneously support.
RESOURCE: is an *ENTITY* with some amount of CAPACITY that is allocable to *ACTIVITIES* over time.

Table 3. Orders management

ORDER: it is a CUSTOMER request for PRODUCT, issued to a SUPPLIER. An ORDER contains one or more ORDER ITEMS (an ORDER contains general information such as the CUSTOMER identifier, number of items, shipping address, etc).
ORDER ITEM: an item within an ORDER. This includes reference to the PRODUCT SPECIFICATION, the quantity of PRODUCT to produce and the CUSTOMER's requested DELIVERY DATE.
CUSTOMER ORDER: is an ORDER in which the CUSTOMER is an EXTERNAL CUSTOMER (a CUSTOMER ORDER can be in one of the following states under negotiation, confirmed, planned, being executed, completed).
PRODUCTION ORDER: is an ORDER in which the CUSTOMER is an INTERNAL CUSTOMER (a PRODUCTION ORDER can be in one of the following states under planning, planned, being executed, on schedule, late, stopped cancelled and completed).
PRODUCT REQUEST: is a statement defining a CUSTOMER's needs, in terms of PRODUCT types, quantities and DUE DATES.
CUSTOMER: the requirer of a PRODUCT. He expresses is requirements in terms of ORDERS A CUSTOMER can be an INTERNAL CUSTOMER or an EXTERNAL CUSTOMER depending on its commitment to the VIRTUAL ENTERPRISE.
SUPPLIER: a provider of goods or services.
PRODUCT: is the result of a manufacturing *ACTIVITIES* chain. A manufacturing enterprise *PURPOSE* is to make PRODUCTS.
ENQUIRY: is an *ACTIVITY* that an EXTERNAL CUSTOMER *EXECUTES* with the *PURPOSE* of obtaining information about PRODUCTS, prices and DELIVERY DATES. This process eventually leads to placing a COSTUMER ORDER.
QUOTATION: is a statement of price, description of PRODUCTS, DUE DATES, and other terms of sale, oftered by a supplier to a prospective CUSTOMER.
DUE DATE: is the *CALENDAR DATE* when PRODUCTS are available for delivery.
DELIVERY DATE: is the *CALENDAR DATE* when PRODUCTS are delivered to the *CUSTOMER*.
ORDER PROMISING: an *ACTIVITY* whose *PURPOSE* is to produce a QUOTATION in response to an EXTERNAL CUSTOMER REQUEST.
AVAILABLE-TO-PROMISE: is a quantity of PRODUCT available to allocate in a given *TIME POINT* to satisty a CUSTOMER REQUEST. This quantity is calculated on the basis of the company's inventory and actual and planned production.

3.2.2. *Issues in the ontology development*

In the construction of the Virtual Enterprise ontology (VEo) we followed whenever possible the methodology for developing ontologies outlined by Uschold and King (1995). This methodology includes the following steps: identify purpose, build the ontology (capture, code, integrate existing ontologies), evaluation and documentation. According to our goals, we concentrated in the purpose identification and building steps, particularly the capture phase. The later is probably a crucial step in the process, and consists in identifying the key concepts and relationships in the domain, producing precise text definitions, identifying terms, and teaching an agreement on these issues. Another important aspect in the capture phase is the inclusion/integration of other ontologies. In our case, the Enterprise Ontology (Uschold *et al*., 1996) was particularly helpful and was thoroughly used in the VE Ontology construction. The Plan Ontology (Tate, 1995), although in a draft state, was also used.

3.3. *An extract of the virtual enterprise ontology*

For illustration purposes, we present now an extract of the VE ontology, focusing on some core definitions relevant for the purpose of developing a planning and control system. It should be noted that this ontology is still under construction, and dynamically evolving. At this stage, a certain degree of non-formalism is kept. As a first step towards defining this ontology, we have started by an attempt to list all possible entities involved in what might be the VE. As a basis, we have taken concepts from a related, more precise idea, that of a Supply Chain. Then we have tried to match those concepts and terms with those in already existing more general ontologies, such as the Enterprise Ontology (EO). The VE Ontology is committed to the Meta-Ontology defined in the EO. We adopted the following notation: words in upper case are terms defined in the VE Ontology; words in upper case and italics were included from other ontologies (their formal definition is not presented, as their usual interpretation is enough for the purposes of this explanation).

3.4. *The VE ontology as a mediator in the system development life cycle*

As referred above, one less explored role of an ontology is the one of communication medium between different people working together for a given purpose. This is the case of a (software) system development process where teams composed by end users and system developers have to collaborate throughout the development life cycle. In this research work our goal is to extend the communication role towards the mediation of the ''world views'' of the development actors. In doing so, we intend to improve the engineering of an intrinsically complex software system, particularly in the requirements identification, system specification and system design phases, overcoming some of the difficulties described before.

Figure 5 shows the general approach to the use of ontologies in the system development process. During the development life cycle, world views of end-users and developers constraint the purpose, scope and goals of the development object, as well as the discourse to describe and reason about the domain/system. Though the purpose, scope and goals of the system must be minimally agreed early in the project, conceptual differences and language misunderstandings and redundancies are important obstacles in a smooth evolving of the process.

The degree of influence that each world view can have in the development life cycle phases is qualitatively represented in the figure by the two areas separated by the thick grey line. End-users world-view has more influence in the requirements identification and specification phases whilst developers world view is more influential in the system design phase. System development phases and milestones are shown overlapping each other to symbolize both the fuzziness of the borders between phases and a desirable system development approach based on evolutionary prototyping. The role of the ontology as mediator is materialized in the concepts and terminology used in the system development milestones—statement of requirements, specification models and system architecture, which are expressed according to the terminology and structure defined by that ontology.

4. Global planning and order promise specification

In this section we present the specification of the PPC-VE system, focusing on the Order Promise functionality. The system analysis and specification was undertook following the method described in the last section and the generic techno-organizational requirements devised in Section 2.

4.1. *Global planning specification*

To exemplify the use of the VE ontology we begin by transcribing the statement of requirements (at a very broad level) for the Global Planning set of activities, using the terminology defined in the ontology.

> Global Planning and Control must include a set of activities designated by *order promise* that should respond to a CUSTOMER ENQUIRY by commitment to a DUE DATE, PRODUCT QUANTITY, PRODUCT QUALITY and PRODUCT PRICE i.e., a CUSTOMER QUOTATION. These promises are used to build up a rough PRODUCTION PLAN. A ROUGH PRODUCTION PLAN is a PLAN containing suggested TIME INTERVALS for production in the UNITS which are considered to be feasible candidates at an aggregate level. The ROUGH PRODUCTION PLAN is revised every time a CUSTOMER ENQUIRY is received or when an exception occurs requiring repairing the ROUGH PRODUCTION PLAN (see details on exceptions below).
>
> The ROUGH PRODUCTION PLAN is used by a *global* PLANNING set of activities in the generation of a FINE PRODUCTION PLAN for each UNIT in the VIRTUAL ENTERPRISE. A FINE PRODUCTION PLAN is a PRODUCTION PLAN with a high degree of feasibility with respect to throughput, slack, conformance to the original PLAN and cost. The PURPOSE of the *global* PLANNING set of activities is to generate FINE PRODUCTION PLANS.
>
> In order to adjust the ROUGH PRODUCTION PLANS and CUSTOMER QUOTATIONS in face of unexpected constraints, a set of reactive ACTIVITIES are needed. This set of activities is designated by *exceptions handling*. Examples of exceptions may be unrealised forecasts and unexpected UNIT CAPACITY change, . . .

The statement of requirements is the starting point for a semi-formal specification of the planning and control system. To illustrate this, the well-known

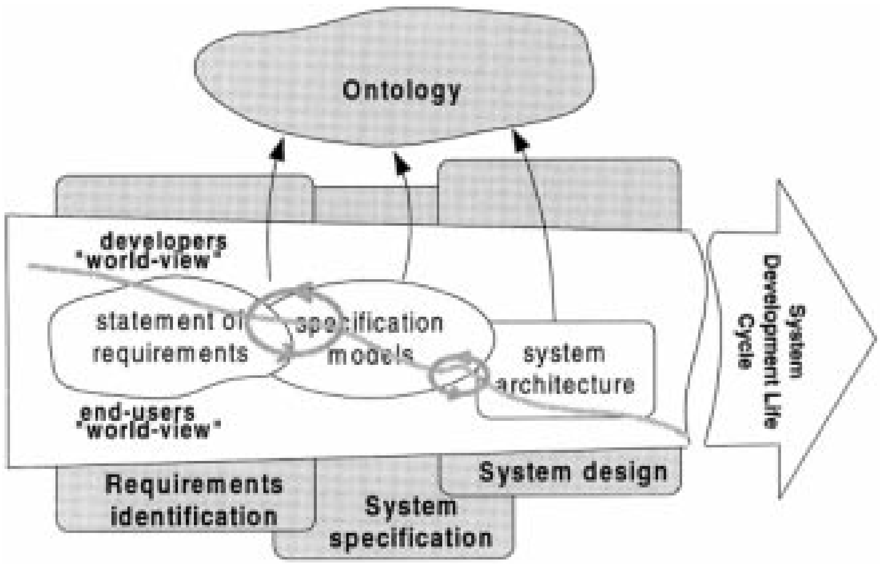

Fig. 5. Use of the VE Ontology in the Planning and Control system development.

OMT (Object Modeling Technology) methodology (Rumbaugh *et al*., 1991) was followed and its functional model used to translate the statement of requirements into the systems specification functional part. An extract of the model is shown in Fig. 6. The use of the VE Ontology assures a conceptual and terminological coherence and consistence. A more detailed specification of the global planning functionality is depicted in Figs. 7 and 8, that also show the relationships with the local planning issues.

4.2. *Order Promise specification*

Order Promising stands for all activities related to the acceptance of an incoming customer order against a feasible date (Higgins, 1996). Accordingly, its general goals can be stated as: to answer to an incoming inquiry in a very short term, to confirm another feasible due date if the customer request cannot be fulfilled, and to establish accurate and highly reliable commitments with the customers.

According to the Virtual Enterprise Ontology, *order promising* is an activity whose purpose is to produce a quotation in response to a customer request. *Quotation* is a statement of price, description of products, due dates, and other terms of sale, offered by a supplier to a prospective customer.

The interaction with the customer is carried out by the order promise system. As inquiries are received from customers, the system calculates the best order item delivery dates that can be offered, and then reserves this supply, if desired by the customer. Usually, when a customer order comes in the sales department of the enterprise, the order promise system checks the availability of the requested product through ''available-to-promise'' (ATP). If the customer order can not be assigned to the ATP, the Rough Planning functionality is triggered in order to allocate the order in the new resulting plan. This allocation is performed by checking feasibility through some kind of ''what-if'' analysis. As a result of this analysis, there may be a need for changes in the plan, involving one or more units of the VE. Then, the system returns all possible answers, with planned delivery dates and costs. In the case the order is committed to the system, capacity or inventory is reserved (up-date of ATP), so that future promises will be accurate.

The order promise module should provide reliable promise dates that respect all constraints of the several

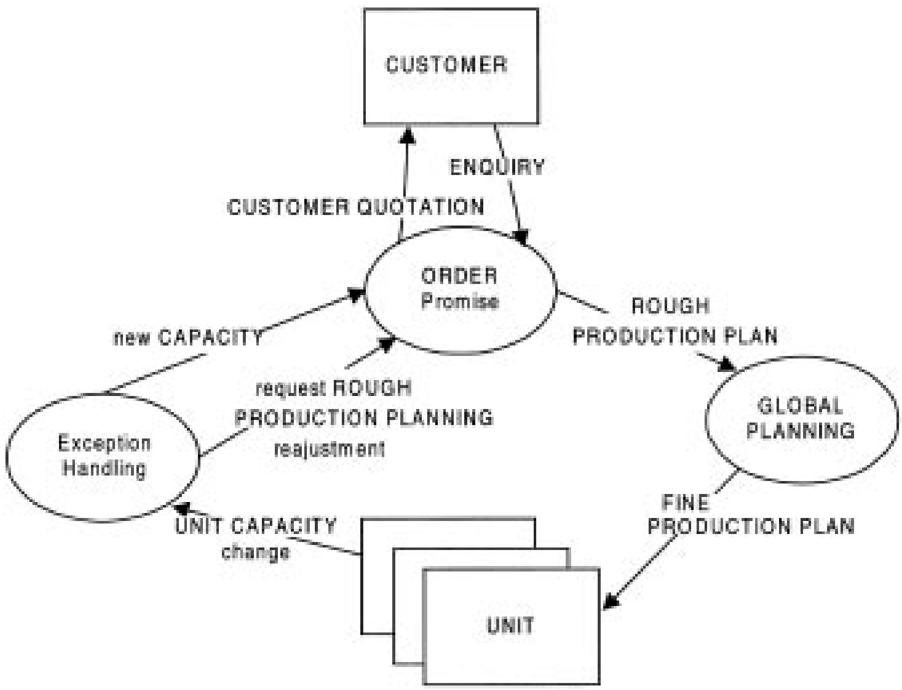

Fig. 6. General Global Planning and Control functional specification model.

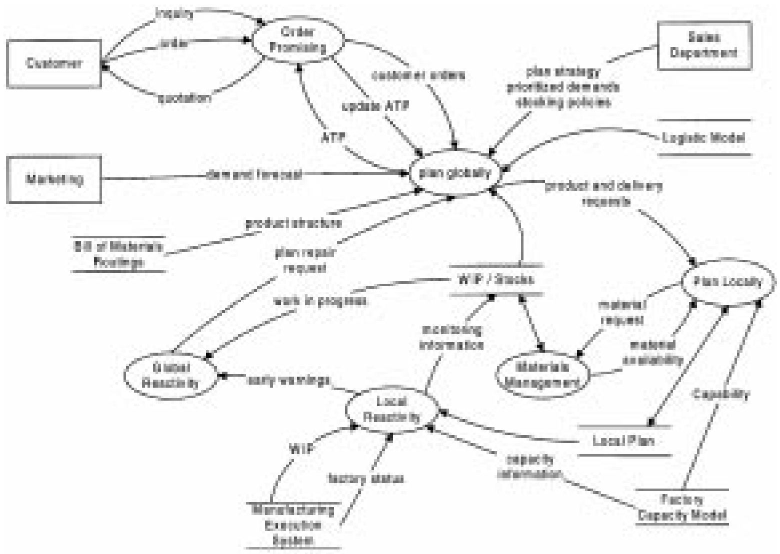

Fig. 7. Functional model of the PPC-VE global planning feature.

units through the enterprise. These constraints include the current demand, the production capacity, the materials availability, transportation alternatives, lead times and available inventory. Besides the customer inquiries, the inputs for the Order Promise module are the ATP data, the current Production Plan (output from the planning system), the available rough capacities and the demand (including backlog, forecasts, stock replenishments and engineering orders). The outputs are the quotations in response to customer requests, and a rough plan where each order has a production time window (including order-

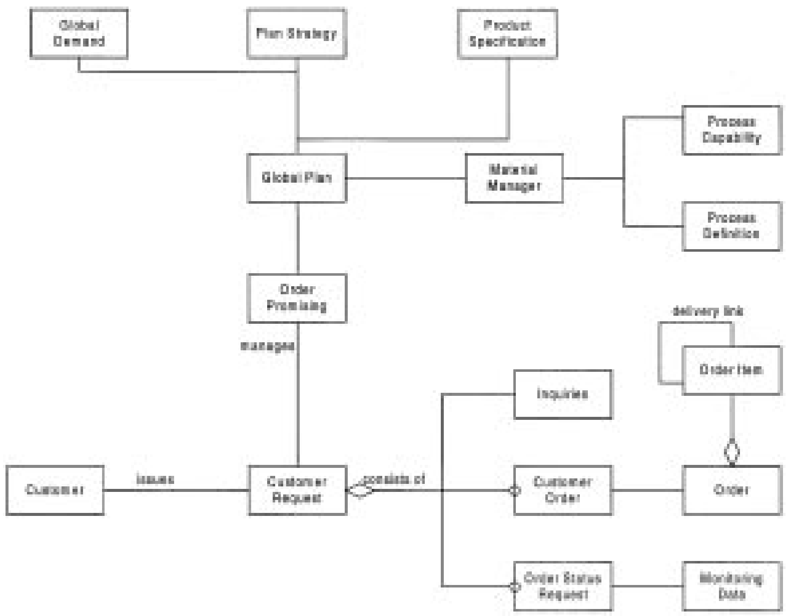

Fig. 8. Object model of the PPC-VE global planning feature.

related start and finish dates for the various units of the VE).

Figure 9 displays the information flow between the main functionalities identified in the module. Basically, the module interacts with customers (on-line transactions) and with a set of static and dynamic data, namely technical data (product information and process routing) and the overall production plan for the VE. When a customer makes an inquiry, several options may be considered: e.g. there is only a query (without reservation), or the query is followed by a reservation, or a full delivery is planned for the ''best'' date that can be offered (in alternative, partial deliveries may be considered).

The system should allow the customer to receive parts of the total requested order items at different time periods if the request cannot be totally fulfilled within one period, or if it cannot be satisfied within the requested period. These procedures trigger the Rough Planning functionality, based on a rough capacity model of the VE. Its output is a Rough Global Plan (RGP). This RGP has to be checked against the capacity constraints (RCCP—Rough Cut Capacity Planning). The purpose of RCCP is to evaluate the RGP in order to determine the existence of critical manufacturing facilities that are potential bottlenecks in the flow of production. This rough capacity model is based on a network of nodes that correspond to processing shop-floors, logistic stages and stocking nodes. For each node, we need to consider the overall capacity for each product group. It is also necessary to know the manufacturing technology sequences.

The RGP is updated every time the order entry component makes a request for the allocation of a customer order that can not be assigned to the available ATP.

The Order Promise procedure can be briefly stated as follows:

Algorithm Order_Promise:
Step 1: Input customer request;
Step 2: Using Insert_Order algorithm try to allocate the order into the current plan;
Step 3: It the result of the previous step is successful, jump to step 4. If not, trigger the rough planning procedure;
Step 4: Prepare a quotation and send an offer to customer;
Step 5: End.

The Insert_Order algorithm tries to insert the customer request into the current production plan. To do that, this algorithm checks the availability of ATP (for the single period and the cumulative value) and tries to satisfy the request within the period considered. If it is not possible to satisfy the request totally or partially, and if there is enough cumulative ATP, the algorithm tries to allocate the order in the previous period, according to a just-in-time policy. The algorithm to efficiently perform the product allocation uses Recursivity.

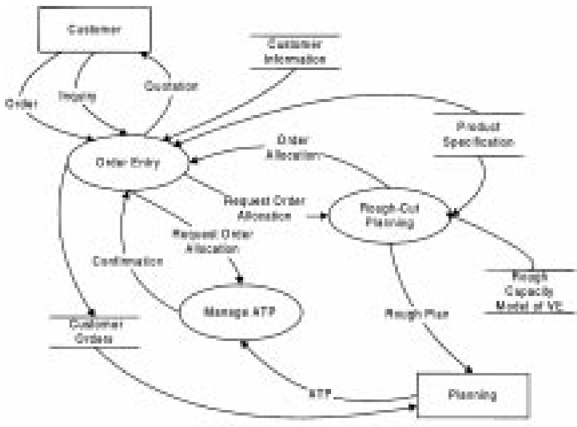

Fig. 9. Overall functional model of the Order Promise feature.

Algorithm Insert_Order:
Step 1: Initialization;
Step 2: If there is enough atp quantity for the period, then update backlog in that period and update the atp, return OK;
Step 3: For the period under consideration, and taking into account the cumulative atp, if there is enough quantity, then call the Insert_Order algorithm with previous time interval data, update backlog in that period and update the atp, return OK;
Step 4: return IMPOSSIBLE;
Step 5: end.

4.2.1. *A more detailed specification*

The Order Promise module should be easily configurable and should have a modular structure in order to maintain its adaptability to future requirements.

The architecture should allow several users to work simultaneously. In order to have this capability, the Order Promise system should consist of a server and several clients eventually spread around the world.

Customer requests are entered into the system using the Order Promise Clients. Since orders may be entered simultaneously, they have to be assigned priorities before the system tries to allocate any available to promise quantities or triggering the rough planning procedure.

Sequencing procedures for ordering customer orders are performed using marketing priorities such as customer tiers or user defined priority rules (e.g., the order with highest priority is processed first, or among orders with equal priority, the one that arrived at the server first is chosen—First Come First Served rule).

Another important requirement is a consistent integration and co-operation with other information (legacy) systems, namely the Business System of the VE.

However, the development of a system to fulfil these requirements and to work with increasingly distributed organisations (in order to respond to the complexity of their business operations) goes beyond traditional client-server technology. We have therefore considered an infrastructure that can support the new emerging paradigm that brings together client-server and object-oriented technologies: the Distributed Object Computing. The use of a distributed object-oriented architecture (CORBA standard) provides several benefits that make it easier to integrate applications into a distributed system (Otte, 1996).

Our development approach encompasses the modeling of the system according to the Object Modeling Technique (OMT) (Rumbaugh, 1991) and the SEMATECH CIM Framework for Enterprise Modeling (Sematech, 1996). Hopefully this approach will lead to significant benefits in terms of modularity, reusability, and flexibility.

Figures 10, 11, and 12 present a partial specification model of the Order Promise module, according to the OMT methodology the overall functional model, the object model, and the dynamic model.

4.2.2. *On models and algorithms*

The main purpose of the Local Capacity Models is to provide a capacity checked answer to customer inquiries throughout the Virtual Enterprise. Obviously each unit that belongs to the VE is singular and has its own specificity. The role of each capacity model is exactly to capture this singularity, providing an interface mechanism with the higher level Rough Planner, in order to provide a planning tool for the entire Virtual Enterprise. Therefore the main functionality of each rough capacity model is to:

- Represent each site capacities in a software model easy to interface;
- Evaluate customer inquiries through a centralized Rough Planner;
- Insert any new local order in the capacity model and pass it to the local scheduler.

The system architecture was designed in order to accommodate different algorithm implementations and instances. These instances can range from simple forward and backward strategies to queuing theory based procedures or local search heuristics. Currently, we are successfully testing and evaluating several of these approaches. Some of these approaches have offered very promising results on specific implementations such as a dynamic bottleneck detection algorithm and queuing theory capacity checking.

The decision-makers should always play a very important role in controlling the automatic procedures, and in helping the construction of acceptable plans. It is basically this concern that leads to the design of the system viewed as a Decision Support System (DSS), where algorithms and resolution methods are hidden from the user, and where the interface plays a major role in promoting a highly interactive utilization of computer based systems. In this context, graphical displays should be considered a major component of a DSS, as they may strongly contribute to enhancing the decision-making processes.

It should be noted that the user plays a major role in the process of configuring, tuning and evaluating each of the Local Capacity Models. This is possible through specific graphical interfaces (GUI). Mainly a first GUI is concerned with the static configuration of the model, namely with the definition of several of the algorithm parameters and the definition of the level of data aggregation used in the construction of the model. A second GUI is used dynamically during run-time as a monitoring tool of the behavior of the capacity model and as a fine tuning mechanism of that model.

5. Conclusion and further work

This paper was written around three major points: some organizational issues of BPR in SC virtual

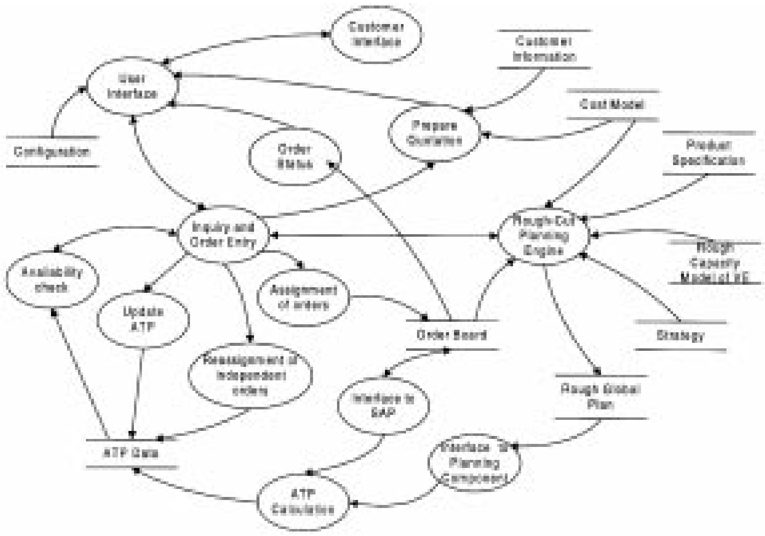

Fig. 10. Order Promise overall functional model.

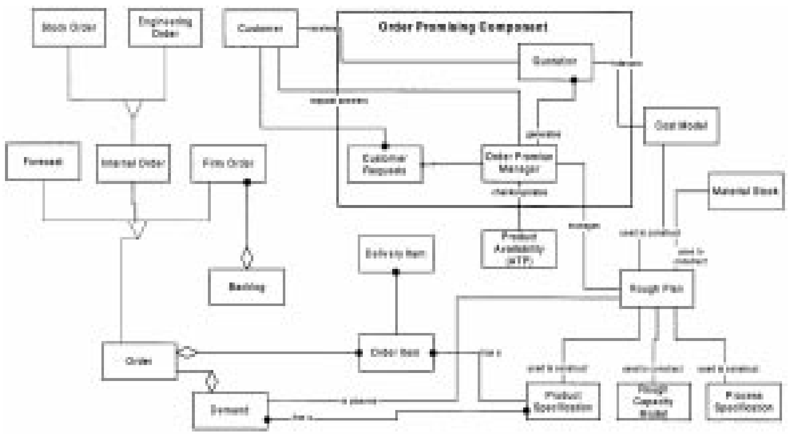

Fig. 11. Order Promise object model.

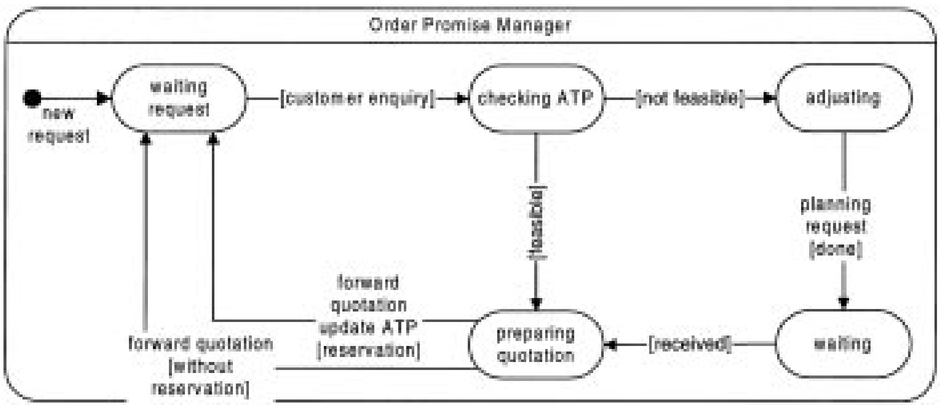

Fig. 12. Order Promise dynamic model.

enterprises, the development of a planning and control system based on the use of ontologies, and the order promise feature of this system.

For the first point, the configurability with respect to labour division, the co-operation within the virtual enterprise environment and the support to agility in virtual enterprises were derived as the general organizational requirements for the distributed planning and control system. These requirements must be operationalized in the system design through adequate functional architectures and user interaction techniques. These issues are not dealt here and will be the subject of a forthcoming paper.

Regarding the second point, the preliminary experience reported in this paper shows that the use of an informal and specifically created ontology has a great potential for mediating the development of large, complex software systems, by providing a platform for agreement on the language to be used inside the project, and also as a way to structure the concepts to be used in the design. This approach was applied to a large R&D trans-national project, involving partners with different academic and industrial cultures, aiming at designing a planning, scheduling and control system for the Virtual Enterprise (VE). Significant improvements are being obtained by using this approach, particularly in the requirements identification, system specification and system design phases. The development of an ontology is a complex and time consuming task, that is dynamically evolving over time. The work done is far from having reached a stable and consolidated outcome. Further work is needed throughout the project, as well as the continuous improvement of the approach described in this paper.

We have also focused on the design of an Order Promise module intended to be used as part of a broader Decision Support System for production and operations planning of a Virtual Enterprise. Even if the system is particularly tailored for the semiconductor industry, we believe it will be easily adapted to other multi-site companies, organized as networks of different units, namely, plants, logistic centers and storage facilities, this being one of our intentions for further work. The system aims at helping the planners to improve the efficiency, precision, and reliability of customer due date calculation, and is intended to be a multi-site planning tool to co-ordinate local activities across the virtual enterprise network. Quick response to customer needs and to unpredictable changes in production conditions is considered in practice a major factor for success. As it was based on Object Oriented Technologies, we believe that the design is flexible and modular, allowing for an easy integration with legacy systems, and for the incorporation of particular ''customized'' models and algorithms. This may be a very important feature, particularly because VE are in general very complex production systems, with heterogeneous management software applications and difficult to integrate ''information islands''.

Notes

1. This work was partially financed by the European Union, through the ESPRIT project E 20544, X-CITTIC, 1996/1999—A Planning and Control System for Semiconductor Virtual Enterprises. The project involved three industrial companies on the semiconductor sector (GEC Plessey Semiconductors, TEMIC, ALCATEL-MIETEC), one software company (Nimble), and three academic institutions (Imperial College—UK, INESC Porto—Portugal, Fraunhofer Gesellschaft IPA—Germany).
2. This critical link is covered by state-of-the-art systems such as SAP r/3 in the ''Forecasting and SOP (Sales & Operations Planning)'' module. They advertise: ''SOP represents the link between sales planning and manufacturing and is fully integrated with the Sales Information System and Master Planning''.
3. An example of mediation in a broader techno-organizational context is reported in (Soares and Mendonça, 1996).

References

APICS. (1995) APICS Dictionary, 8th Edition American Production and Inventory Control Society, Inc.

Atherton, L. F. and Atherton, R. W. (1995) *Wafer Fabrication Factory Performance and Analysis*, Kluwer Academic Publishers.

Bradshaw, J. M., Boose, J. H. and Shema, D. B. (1992) Steps Toward Sharable Ontologies for Design Rationale. *AAAI-92 Design Rationale Capture and Use Workshop*, San Jose, CA, July.

Browne, J., Sackett, P. and Wortmann, H. (1994) Industry Requirements and Associated Research Issues in the

Extended Enterprise. *European Workshop on Integrated Manufacturing Systems Engineering*, IMSE'94, 12–14, Grenoble.

Chen, D. and Doumeingts, G. (1996) The GRAI-GIM reference model, architecture and methodology. *Architectures for Enterprise Integration*, P. Bernus, L. Nemes and T. Williams (eds), Chapman & Hall, London.

Ching, C., Holsapple, C. W. and Whinston, A. B. (1993) Modeling Network Organizations. A Basis for Exploring Computer Support Coordination Possibilities. *Journal of Organizational Computing*, **3**(3), 279–300.

EIL (Enterprise Integration Laboratory). (1995) The Integrated Supply Chain Management Project. http// www.ie.toronto ca/EIL/eil.html).

Feireira, J. P. and Mendoncça, J. M. (1995) Modeling and Simulation of Manufacturing and Information Aspects of the Extended Enterprise. *Proceedings of the International Conference on Improving Manufacturing Performance in a Distributed Enterprise. Advanced Systems and Tools*, Edinburgh, U.K.

Fraser, J. and Macintosh, A. (1994) *Enterprise State of the Art Survey—Part 3—Enterprise Modeling Methods*, Ent/DE/3/1 0, University of Edinburgh.

Gruber, T. R. (1993) A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition*, **2**, 199–220.

Guarino, N. and Giaretta, P. (1995) *Ontologies and Knowledge Bases Towards a Terminological Clarification, Towards Very Large Knowledge Bases*, IOS Press, Amsterdam.

Guarino, Nicola Formal Ontology, Conceptual Analysis and Knowledge Representation. To appear in *International Journal of Human and Computer Studies*, edited by N. Guarino and R. Poli.

Guimaraes, T. and Chair, J. (1994) *Assessing Determinants of BPR Implementation Success*, Institute for Technology Management, University of Tenessee.

Higgins, P., Roy, P. L. and Tierney, L. (1996) *Manufacturing Planning and Control Beyond MRP II*. Chapman & Hall, London.

Leachman, R. C. (1993) Modeling Techniques for Automated Production Planning in the Semiconductor Industry. In *Optimization in Industry*, T. A. Ciriani and R. C. Leachman (eds), John Wiley & Sons Ltd, New York.

Leachman, R. C., Liu, C. and Raar, D. J. (1996) IMPReSS. An Automated Production-Planning and Delivery-Quotation System at Harris Corporation—Semiconductor Sector *INTERFACES*, 26 1 January-February. 6–37.

Otte, R., Patrick, P. and Roy, M. (1996) *Understanding CORBA (Common Object Request Brocker Architecture)* Prentice Hall, New York.

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F. and Lorensen, W. (1991) *Object-Oriented Modeling and Design*, Prentice Hall, New York.

Sematech, (1996) *CIM Application Framework Specification*, 1.3. SEMATECH, Austin, Texas.

Soares, A. L., Sousa, J. P., Azevedo, A. L. and Bastos, J. A. (1996) Virtual Enterprise Ontology—Version 1.0. INESC-UESP.

Soares, A. L. and Mendonça, J. M. (1996) Multiple-Perspective Knowledge Representation in Techno-Organizational Development Processes, in *Manufacturing Agility and Hybrid Automation-I*, Koubek and Karwowski (eds), IEA Press, Louisville, Kentucky, USA.

Tate, A. (1995) *Towards a Plan Ontology*, Technical Report AIAI—The University of Edinburgh.

Uschold, M. and Gruninger, M. (1996b) Ontologies Principles, Methods and Applications. *Knowledge Engineering Review*, **11**(2), 93–136.

Uschold, M. and King, M. (1995) *Towards a Methodology for Building Ontologies*. Technical Report AIAI-TR-183, The University of Edinburgh.

Uschold, M., King, M., Moralee, S. and Zorgios, Y. (1996) *The Enterprise Ontology.* Technical Report AIAI-TR-195, The University of Edinburgh. *http://www.aiai.ed.ac.uk./ ~ entprise/enterprise/*.

Vollmann, T. E., Berry, W. L. and Whybark, D. C. (1997) *Manufacturing Planning And Control Systems*, Irwin/McGraw-Hill, New York.