Planning and Management of Large, Distributed Systems and Projects

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Abstract: *Enterprises which are distributed in space and/or which are composed as a temporary joint venture of legally different units recently often called virtual (extended) enterprises. Planning, design and operation (management) goals and requirements of such firms are generally different from those of single, centralised enterprises. The basic feature of a virtua) enterprise is that the co-operating units of it keep their independence during the life-cycle of the co-operation – what is well regulated by the rules of the given conglomerate. On the other hand that several basic functionalities and goals are the same for all types of distributed, large, complex organisations, which are the targets of our recent study. The evolution of some web-based manufacturing design/planning and operation system philosophies can be followed through the works presented in this paper. We intend to give software solutions for design, planning and operation (management) of complex, networked organisations represented as nodes of networks.*

Keywords: extended/virtual enterprise, supply chain, enterprise resource planning, www, management, SME

1 Introduction

Supply Chain Management (SCM) focuses on globalization and information management tools, which integrate procurement, operations, and logistics from raw materials to customer satisfaction. Future managers are prepared to add product value, increase quality, reduce costs, and increase profits by addressing the needs and performance of several things, as: supplier relations, supplier selection, purchasing negotiations, operations, transportation, inventory, warehousing, benchmarking, third-party vendors, electronic commerce, recycling, supply chain electronic software, customer relations, etc. Globalisation underscored the need for supply chain professionals who seek a variety of experiences, who are committed to life long learning, and who want to capitalise on ever-changing technology.

Today the world-wide globalisation and the appearance of virtual require more than only SCM for some tasks of a given enterprise. Due to the physically and logically distributed character of the co-operating units (workshops, plants, enterprises, etc.), taking advantage of the existence of Internet (intranet, extranet, etc.), web-based solutions are suggested.

These type of solutions are targeted by different projects world wide. There are no plans for really general solutions, and it is hard even to imagine them. As far as the authors are concerned there are two EU projects (FLUENT and WHALES, see [1,2]) to provide the “best” solutions. [1] gives “beyond SCM” workflow/supply chain solutions for distributed (mainly SME) organizations dealing with manufacturing, services, maintenance, etc. The main target firms of [2] are the distributed, multi-site, multi-firm, powerful organizations (and SMEs), and the goal is to manage complex, one-of a kind products and projects, manufacturing and management as well.

2 Management of complex logistic flows

The results of our R&D efforts provide new IT solutions for managing *complex logistic flows*, occurring in distributed *manufacturing networks* with multiple plants and co-operating firms. Networks of this kind are gaining relevance and diffusion, under the impulse of the following main factors:

- emerging virtual/extended enterprise paradigms
- pull-oriented production models, like Just-In-Time, requiring synchronisation of internal and external flows
- lean/agile manufacturing models, based on horizontal, goal-oriented process chains
- evolving market conditions, calling for business globalisation and decentralisation of manufacturing facilities.

In response to these changes, the newly developed solution and software provide manufacturing firms with advanced IT tools for logistics decision-making, thus enhancing their capability to operate in a distributed production environment.

Our objective is to enhance the firms’ capability to operate in a distributed manufacturing network. This kind of organization has been attracting great interest from the industrial community world-wide, under the impulse of innovative paradigms and evolving market conditions:

- Much attention is paid to the concepts of *virtual/extended enterprise*, intended as a network of autonomous firms that co-operate in achieving common business goals. When applied to manufacturing, these models imply changes and extensions to the firms’ interaction with the external world with a consequent strong impact on logistics decision-making [7].
- Advanced “*pull*” techniques, like Kanban, emphasise the importance of smoothing and synchronisation of production tasks at the shop-floor level. A critical success factor is to reach equivalent timeliness and co-ordination with processes outside the factory.

- *Lean/agile manufacturing* models propose the shift to a more process-oriented enterprise structure, where value-adding functions are highlighted and involved into transient, goal-driven process chains. To succeed, this approach requires the same flexibility in the management of business partners, and improved control along the entire supply chain [8].
- Even in a traditional organisations the complexity of logistics decision-making is now increased by factors such as: market globalisation, decentralised manufacturing facilities, extended range of suppliers, highest emphasis on total quality issues and customer satisfaction [9, 10].

In these conditions, traditional logistics functions like sales and purchase are left alone to face problems far beyond their intended roles. Current Enterprise Resource Planning (ERP) systems can be of little help, only supporting the administration of conventional customer-supplier relationships with basic services like ordering, invoicing and inventory. These systems are clearly insufficient to cope with the new manufacturing scenario, based on decentralised and flat organisation models in conflict with the ERP foundations of:

* *hierarchic organisation*, with strict planning rules and pre-determined chain of responsibility

* *embedding of business processes* into the application code; this makes it impossible to manage complex logistics flows, involving business partners,

* *centralised data management* based on *company-specific* standards; this prevents full integration with other firms' information systems,.

Problems deriving from these evident limitations often induce large companies to assimilate their closest suppliers and sub-contractors, at least from the information system point of view. On the one side, this solution can find resistance from the involved partners and, in most cases, it results in makeshift systems with very low flexibility. On the other side, for the partners it means strong renounces in terms of decisional autonomy and, if they are SMEs, the additional costs of an over-sized ERP system to comply with t customer standards.

To overcome these limits, major ERP producers are developing supply-chain management add-ons on top of their production management solutions, often through partnerships with SCP producers. Great diffusion of these systems is foreseen in the future, as testified by the activation of large supply-chain planning projects in leading industries world-wide. In spite of their technological content, current SCP systems are still bound to state-of-the-art ERP software, with consequent significant limitations:

- *Centralised planning;* as ERP add-ons, SCP systems simply extend traditional MPS and MRP planning with new functionalities, such as distribution and transportation planning, and improved performance, thanks to memory-resident algorithms.
- *Manufacturing vs. logistics orientation;* even though an attempt is made at managing the complexity of enterprise networks, this is still done from a manufacturing perspective

- *Pre-defined organisation model;* the supply chain organisation and accountability structure is coded into the application software, and hence can be hardly adapted to the different partnership models found in the real world.
- *High implementation costs,* due to the complexity of SCP integration with the existing organisation and information system. Ad hoc links must be developed for each data source, either inside or outside the enterprise, in order to feed the SCP static models. This poses technical problems of data reliability and consistency, and still greater organisational problems of data ownership and maintenance responsibility.

In spite of the increasing market interest, originated by the actual end-users difficulties and by the ERP functional deficiencies, SCP solutions appear still as sophisticated planning engines for isolated, high-power decision makers. Tactical decisions and day-to-day co-ordination between trading partners are still based on informal communication or point-to-point integration realised, e.g., through batch EDI transfers.

3 A novel supply network/flow control model

Traditional SCM implementations refer to a linear, standardised and relatively stable view of the supply chain: "*Supply Chain Management is about managing the flow of products and services and the associated information, across the whole business system to maximise value to the end consumer.*" (Price Waterhouse [11])

The interpretation given by SCP vendors to this definition is often reductive. The "whole business system" is a row of four to five actors (depending on whether electronic commerce issues are addressed or not) interacting with each other in pairs.

The resulting SCM solutions are product suites including several independent tools, each designed to optimise a single link in this pre-defined sequence. For the whole picture to work, it is assumed that separate optimisation of each link leads to overall performance improvements.

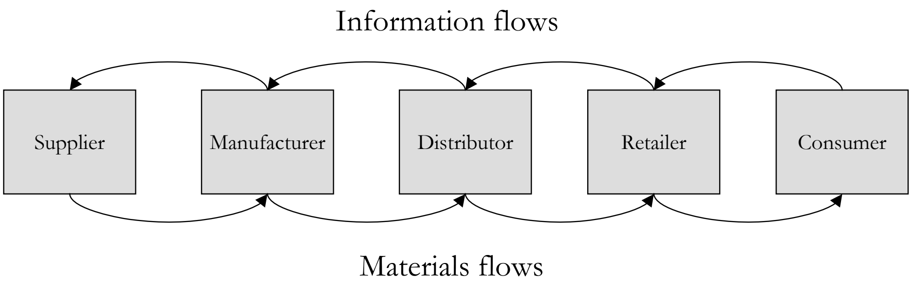

Figure 1: Traditional supply-chain representation

Recent analyses have pointed out the potential failure behind this logic, especially where revenue increase is pursued instead of cost reduction:

- Cost reduction leads to: standardisation and simplification of supply chain and its operation; minimisation of integration costs; definition of "functional silos" independent of each other.
- Increasing revenues means to take advantage of diversification and differentiation, exploiting changes in demand and supply. This means making more money thanks to the supply chain ability to reconfigure itself, to harmonise capacities and to respond quickly as a whole.

To look at the supply chain complexity as a competitive advantage, rather than as a source of costs, means a radical change of perspective in the organisation models supported by SCM tools: *"For a start, the supply "chain" is really not a chain at all - it is a complicated web of relationships between demand and supply. The concurrent and multidimensional nature of these relationships creates a complex fabric woven step by step."*(Gartner Group [12])

The logical architecture of our network is given in Fig. 2., where circles including three bars represent nodes equipped with the new system, and empty circles represent other nodes acting as customers, suppliers or subcontractors. Nodes of the latter type can only take part as executors in logistic flows controlled by the flow management nodes. The reason is that these nodes lack the network-level vision and decision support tools to actively participate in the planning and co-ordination of supply flows.

Each *node* is perceived by the other nodes as an autonomous source of: (i) information on the node and the goods it supplies and consumes (Knowledge level); (ii) demand/availability signals and allocation decisions (Planning level); (iii) supply control signals and exceptions (Control level). Independently of ownership and position in holding hierarchies, nodes in the network are modeled as source and destination of logistics flows. To this purpose, each node is attributed a three-tiered structure including: a Flow Collector, that manages incoming logistics flows, a Flow Dispatcher, that manages outgoing flows, and a Flow Processor, responsible for integration with internal production flows.

Co-operation between nodes is realised through *links,* each representing a stable relationship for the exchange of a given product between a "supplier" node Flow Collector and a "receiver" node Flow Dispatcher. The Flow Processor is not directly involved in the link, since our flow control is based on a clear separation of logistics decision-making domains. Internal logistics are managed by each node on its own, and are perceived at the network level only through requirements, events and constraints on external logistics flows.

A link definition fixes the characteristics of supply flows taking place through the link, in terms of:

- data on the supplied product, including shipping, transportation and delivery parameters
- planning policy applied to the link, in terms of planning parameters, planning method, e.g., "push" or "pull", and planning responsibility, e.g., either the supplier or the receiver, or a third node controlling the flow
- workflow model, i.e., the sequence of messages and events characterising the nodes interaction during planning and control of supplies over the link.

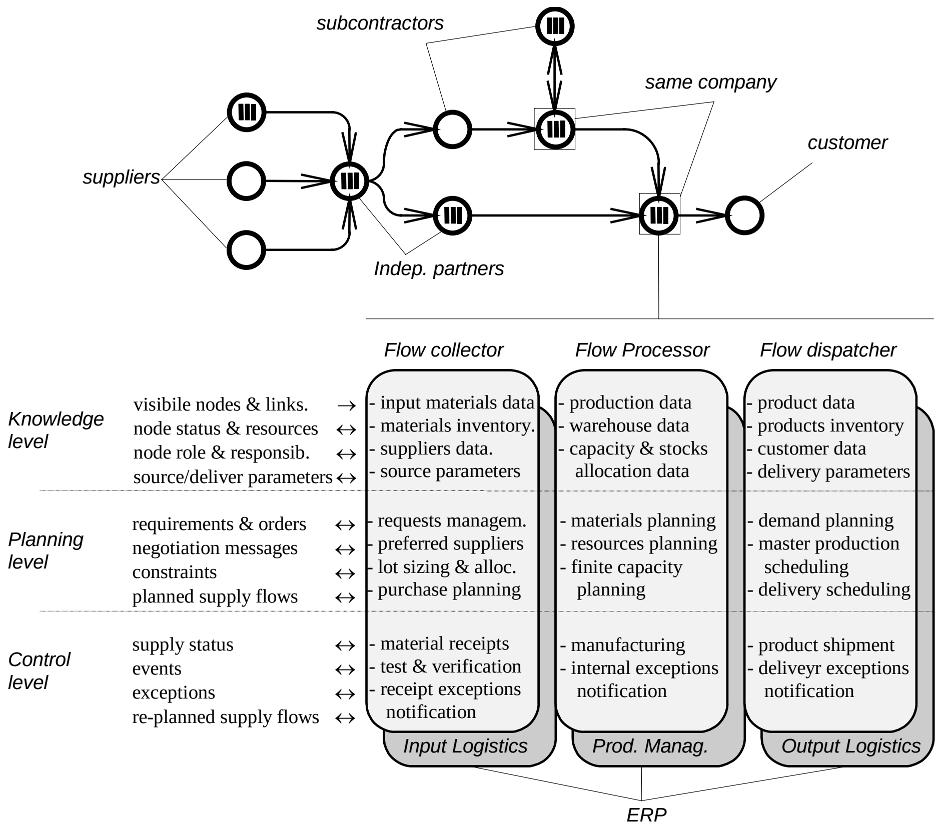

Figure 2: The novel supply network model

In this way, a high degree of generality and flexibility is reached in modelling the variegated network configurations found in the real world. For example, a node can establish “pull” links with a network of suppliers, keeping a centralised control of suppliers selection and orders allocation. The node product can be delivered to a trading partner on the basis of an inventory replenishment agreement, modelled by a “push” flow controlled by the supplier, and to a customer on the basis of a normal “pull” link. Both types of outgoing flows can originate dependent requirements for the above suppliers network.

4 System software requirements and possibilities

To support the above detailed organisation model, each node is provided with innovative software tools designed to fulfil the requirements of a multi-site, multi-enterprise manufacturing network. To fulfil all goals and requirements we provide an advanced IT infrastructure based on the following software components:

- a standard *Communication and Workflow Infrastructure*, for basic data interchange and message services. It can be easily accessed and configured to realise higher level functionalities;
- a high-level *Network Model,* constructed on top of this basic layer to: (i) provide and update a consistent representation of the network from the node point of view; (ii) describe the network physical layout and accountability structure; (iii) adjust the node view and decisional power to network-level changes;
- an *Active Flows Control (AFC)* component, which monitors interaction with nodes in the Network Model to: (i) maintain updated information on active logistics flows; (ii) dispatch relevant messages and events from and to the decisions-support components; (iii) support negotiation with the other nodes;
- a *Performance Measurement System (PMS),* acting in parallel with the AFC to: (i) keep historical recordings of the network activity; (ii) calculate significant performance indicators; (iii) provide multiple performance measures for the different network roles and viewpoints;
- two *Decision Support Systems (DSS),* respectively for input and output flows management, that: (i) process internal and external demands; (ii) allow flow planning based on AFC and PMS input, according to the node role and policy; (iii) react to exceptions and negotiation messages from other nodes;

an *Interface with Enterprise Resource Planning (ERP)* that allows transparent interaction with the node local production management, in order to: (i) supply aggregate capacity and stocks information to the Network Model; (ii) exchange requirements and status information with the DSSs; (iii) maintain traceability between incoming and outgoing flows.

5 Project management issues

5.1 Supporting large engineering projects

The objective of our work in this chapter is to provide a planning and management infrastructure for complex, distributed, multi-site, multi-enterprise organizations working on large scale engineering projects, characterized by huge investments in both materials and human resources and by concurrent, disparate activities (manufacturing, design and services) as well. Managing projects of this kind means dealing with several problems at the same time:

- Complexity of scope, in terms of time and resources employed, and variety of activities to be planned, synchronized and monitored;
- Distributed organization, spanning through several companies and involving a multiplicity of actors and competencies;
- One-of-a-kind design, increasing planning complexity, hard to apply product and process standardization;
- Geographic distribution of project activities, sometimes in unprepared or hostile environments;

- Strict time constraints, with complex milestones and dangerous critical-path dependencies;
- Contingency risks, due to the high planning uncertainty and difficult re-alignment of activities;
- Revenue-loss risks, due to difficulties in budgeting and high contingency costs.

Concerning the research state of the art, we can identify two main directions pursued in the last years by many projects:

- On the one side, standards and systems are sought for product and process data modeling and interchange, and to support distributed design in concurrent and co-operative engineering environments. This category of projects focuses on the "what", i.e., on the contents specifications for a product or project, rather than on the "how" and "when" that are typical project management concerns. References to some of these projects are in [3 and 4].
- On the other side, virtual enterprises are studied as evolving organisms, investigating environmental, legal and socio-economic conditions for the creation of enterprise networks. Considerably less effort has been directed to the analysis of the planning and monitoring problems characterizing such networks, and to how co-operation can be sustained and managed on a daily basis. References to some of these projects are in [5 and 6].

As an innovative system for project management in complex and distributed organizations, the system implements the following general features:

- *Provides a unified and generalized representation* of project activities and related artifacts, comprising all material and immaterial work items (e.g., products, knowledge, design documents in different stages) that need to be organized in complex projects. *Supports distributed organization models*, crossing hierarchies and company boundaries*;* to be general and commercially exploitable, the system does not rely on any pre-defined organization schema, but supports a case-by-case definition of links between companies, organizational units and employees involved in each project.
- *Provides a scalable and flexible co-operation environment*. The system provides a project network infrastructure accessible to every node (company or organization unit) independently of its size and information system. It supports nodes and individuals in readjusting their role and interface toward the network (for example to reflect changes in the node internal organization, or to make new resources available to any project).
- *Integrates and distributes relevant information* across the project network. Data maintained by each node and related to a specific project is given a generalized representation and shared with the other project participants through a web-based environment according to visibility and consistency rules mirroring the project organization model and management responsibilities.
- *Supports decision-making* in the project ideation, definition and deployment phases. This means to select potential partners on the basis of their past performance, cost and capabilities, to generate detailed plans considering both

activities' timing, equipment and materials availability, and to find substitute resources for a running activity, etc.

- *Manages and synchronizes the flow of decisions and events* in the project network. The system manages the distributed workflow associated to a project e.g. circulating planning proposals among the partners, integrating multiple decision threads in a consistent and transparent fashion, and dispatching monitored exceptions to the responsible actor(s) for contingency management.
- *Integrates with local management and planning systems*. It means to safeguard the nodes' autonomy and IT investments. The system shall not interfere with node internal procedures and management tools, as ERP, PPC, Human Resources, stand-alone Project Planning and budgeting packages. Instead, proper interfaces are designed and implemented for real-time information exchange between these systems and our new management system network infrastructure.

Such projects are rarely carried out within the scope of a single organization. More often the prime contractor, typically a large company with adequate know-how, references and financial resources to sustain the project, outsources specific components and services to smaller firms through several forms of sub-contracting. This way SMEs are often involved.

The previously listed general features answer the following problems, too:

- High direct and indirect costs of basic resources;
- Complex and hierarchical organizations grown up in times of unchallenged and stable demands (e.g., markets protected by local governments);
- Low operative margins, putting short-term activities and contingency management ahead of technology and business process improvements;
- Cultural and organizational obstacles to apply "virtual enterprise" partnership models;
- Low flexibility that, paired with complexity, makes it almost impossible to prepare reliable plans and project budgets.

As stated earlier the prime contractors in large-scale projects are typically big companies with proper financial resources and assets. Nevertheless, this does not prevent our system to be extremely significant to SME users that can be involved as nodes (e.g. subcontractors for provision of services and components, to develop entire engineering packages, etc.) in a large project network.

A good project control/management software assists in project planning and deployment thanks to a software infrastructure producing the following measurable results on the end-users' business:

- Improved planning and budgeting, monitoring, cost and risk assessment
- Effective contingency management, higher flexibility and efficiency

6 System software environment issues

To achieve the above improvements requires dealing with different enterprise functions and information sources, supported by heterogeneous and poorly integrated software applications, as:

- Enterprise Resources Planning systems (ERP) (as SAP, Baan, etc.) represent the companies' administration backbone, and provide basic transactions for bids and contracts management, job order stages and costs reporting, billing and invoicing;
- Production Planning and Control (PPC) and Warehousing systems, often sold as ERP components, support materials management and long- to short-term production planning;
- Project planning tools provide graphical editing of GANNT and PERT project diagrams, along with on-line display of resources workload and activities timing;
- Human Resources (HR) packages support company organization management, identifying key project roles, skills and positions, as well as project personnel costs and timetables.

None of these systems by itself covers the full spectrum of project management requirements, that in complex organizations range from financial planning and cost analysis, to human resources recruiting and assignment, to procurement and allocation of manufacturing resources and materials. Moreover, none of these systems provides a data and communication infrastructure for the whole project network, i.e. to the multi-site, multi-company organization created to fulfil specific project objectives. As a temporary and goal-oriented structure, although it can last years and absorb large turnover shares, the project network presents typical "virtual enterprise" properties that make it impossible to map it on traditional, enterprise-centric information systems.

7 Innovative features of the project management

State-of-the-art software applications offer only partial responses to the needs, being still too much dependent on given, specific industrial sectors, organization models or ERP platforms, and approaching project management with a solution- rather than with a problem-oriented approach. They are focused on specific tools or technology applications to optimize a single aspect of project lifecycle management:

- *ERP packages' Management extensions*
- *Project Management applications*
- *Data Interchange and Workflow infrastructures*

The resulting system accommodates the needs of project networks independently of the industrial sector, thanks to its general and adaptable design, that comes from features like:

- *Distributed project management environment*
- *Decentralized architecture and accountability structure*
- *Powerful project and network data model*
- *Project representation*
- *Flexible decision-support tools*

8 The main system components

The system architecture has been designed to match the project wide application scope, the complexity of technical objectives, the variety and extent of business cases to be analysed and implemented at pilot users' sites. Each of these topics raises different categories of problems, requiring specific competencies along with conventional project management and software development activities. For this reason the work has been subdivided into two thematic areas

R: Requirements - A&D: Analysis and Design - Im: Implementation, T&D: Test and Deployment, BCA: Business Cases Analysis - EP: Experiment Preparation EI: Experiment Implementation, RA: Results'Assessment.

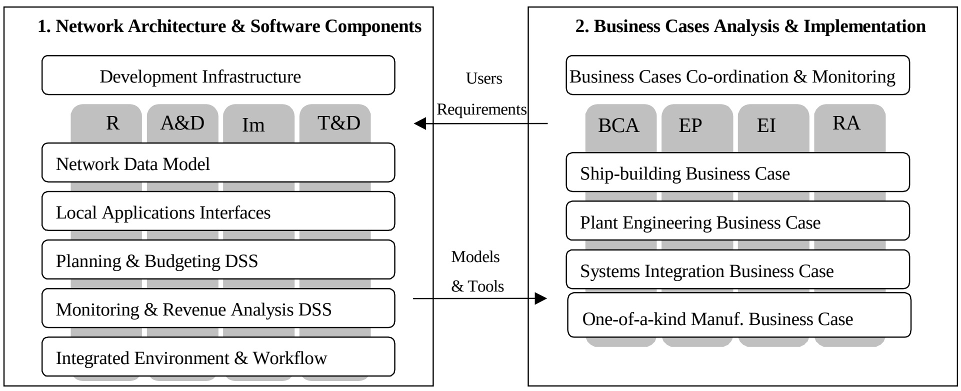

Figure 3: Project management system architecture

The Network Data Model is closely connected of the following three layers:

- The *Work Network Structure (WNS)*
- The *Work Accountability Structure (WAS)*
- The *Work Breakdown Structure (WBS)*

To support the outlined organization model the system network is provided with **innovative software tools**:

- *Web-based Project Environment, Workflow Management System*.
- *Network Data Mode, Local Applications Interfaces*
- Decis*ion Support Sub-systems*
    - *Project Planning & Budgeting to*
    - *Project Monitoring & Revenue Analysis*

8.1 Business Cases Analysis, Implementation and Evaluation

The objective of the four business cases is to provide reference requirements, realistic applications on the field, and measures of the system benefits by applying our management model and tools and software on real-world projects carried out by pilot users. The system user companies have been selected to represent various types of engineering and service networks in different countries, thus providing a significant selection of business cases for requirements analysis and experimentation of the proposed approach (shipbuilding, engineering industry, plant repair and maintenance services and software project management).

We selected outward-focused modeling and benchmarking tools to comply with the system network organization model (e.g., standards oriented to supply-chain organizations [14]).

Recently all four pilot cases are making the experimentation with the software tools and means and the results seem to be remarkable, however some more months are necessary to the appropriate evaluation.

To assist evaluation:

- the metrics defined and measured in preliminary business cases analysis will be measured again by the end of the experiments at the selected industrial sites,
- a comparison will be made between the initial values of the performance metrics and the final ones, and conclusions will be derived from that comparison.

This way the assessment of the benefits will be quite straightforward to show that the new tools and working software are useful at real users' sites of four different European countries. Each of the four cases, depending on the scope and industrial sector, needed a specific configuration of system modules to be implemented in order to carry out the experimentation work. The installations proved that the solutions are general enough to be easily implemented

9 Conclusions

The implementation of our logistics flow management/supply chain approach represents a significant step forward on state-of-the-art logistics management techniques for the end-users. On the one side, in traditional enterprise practice the focus is on bilateral supply relations with each individual customer and supplier, with scant and informal co-operation possibilities and no supply-chain visibility. On the other side, multi-site planning extensions offered by major ERP and SCP vendors are still based on a centralised approach, lacking on-line integration and synchronisation with the other network actors. In this scenario we provide considerable benefits in terms of improved network visibility, better co-ordination and real-time control of materials flows.

Feasibility of the above improvements, along with the costs and time required for achieving them, are assessed through experimentation of the software system on selected user firms. The validation phase was successfully finished on four pilot cases in different industrial sectors: machine-tool industry, equipment production, textile industry and naval industry.

Experimentation was done on the basic flow management components, supporting network modelling, data-integration and workflow, in parallel with design and development of the decision-support components. Now the software is finished and it is commercially available.

The web-based management software provides a planning and management infrastructure for complex distributed organizations working on large scale engineering projects, characterized by huge investments in both materials and human resources and by concurrent, disparate activities – manufacturing, design and services as well. The first experiments are running successfully at all the four different pilot sites and will prove all advantages detailed in this paper.

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