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An integrated approach to implement Project Management Information Systems within the Extended Enterprise

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Abstract

Project Management Information Systems (PMIS) are software applications that help managers track projects from their conception to their execution. They provide them with pertinent information and collaborative tools. Currently, most businesses use disconnected instruments which are not designed for managing complex projects. Increases in complexity, both due to the extent of scope and the fact that the users who contribute to the decision making process are physically separated, have led to initiatives that deal with cooperation, teamwork and continuous improvement. This work presents an integrated approach to improve PMIS applicability within the Extended Enterprise. The study regards the definition and the building of a management framework where planning, scheduling, and communicating are made immediate and effective by the adoption of common standards, shared communication and appropriate software tools for the management of whole Supply Chains. The proposed approach has been successfully applied within the shipbuilding industry.

Keywords: Supply Chain Event Management; Project management; Extended Enterprise; PMIS

1. Introduction

Project Management Information Systems (PMIS) have grown to a great extent over the last decades and have become comprehensive systems that can be used to sustain the whole life-cycle of complex projects (Ahlemann, 2009). They are software applications that allow individuals or teams to track projects from their conception to their execution, providing project managers and other team members with pertinent information such as the scheduling of resources, budget management, supplier management, time management, task assignments, quality control, documentation and collaborative tools. The goal of PMIS is therefore to boost efficiency by making the development cycle more visible as long as all users are able to track specific tasks and can have a better understanding of how the project is going on. A key improvement is enabling a coherent flow of information between project managers and team members, which significantly helps them to keep people on task and up-to-date. All these aspects are mandatory for the "agile" supply chain, that needs quick responses to shifts in design, supply, production and delivery.

At present PMIS are shifting from single-project management systems to distributed, cooperative multi-projects planning applications with resource leveling capabilities (Pollack-Johnson and Liberatore, 1998). Surveys still confirm that only approximately 20% of available installations refer to multi-project programs. Recent tendencies clearly show that all kinds of industries are beginning to exploit PMIS to deal with a number of multifaceted project management aspects. In particular, PMIS can help practitioners to detect latent issues before they occur, meet deadlines, and collaborate more easily and at a greater extent (Raymond and Bergeron, 2008). The potential gain in efficiency can lead to significant cost savings and an increased return on investment both for small and large businesses. In brief, PMIS are

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intended to assist managers and practitioners in defining and completing projects, keeping within the available budgets, respecting deadlines and, last but not least, collaborating. They also keep involved people informed, assuring that they know what the others are doing at any given time and allowing appropriate countermeasures in the case of failures or delays. This lets project managers successfully delegate tasks, monitor progress and assess the overall risk. Finally, they help managers create working profiles and work-packages to assign the right task to the right person by means of an effective resource management.

The PMIS industry is presently dominated by a number of leading software representatives, such as Microsoft, Oracle and Metier Management Systems (a former Lockheed company), and a number of small independent companies. Demand has remained steady for years but, as companies are increasingly turning to enhanced technical solutions, it is supposed to grow up significantly in the near future. In particular, PMIS are believed to evolve towards a more integrated project lifecycle management and the extensive adoption of web-based or cloud computing tools (McCullen, 2009; Tarantilis et al., 2008).

A noticeable aspect in this context regards the data management feature. At present, most firms use different tools, such as spreadsheets and paper based data collections, which are definitely not designed for managing the evolution of complex projects. A good number of project managers use PMIS, but most of them are yet unaware of the potential benefits they could bring in. This is mainly due to a lack of an understanding of what such software really is and how it can influence projects from their conception to their completion (Archibald, 1992). In some cases managers are dissatisfied (Caniëls and Bakens, 2012) as they still have problems when used in a multi-projects and strongly collaborative environment.

The progressive affirmation of the "agile" thinking and the increase in project complexity has led to initiatives that deal even more with cooperation, teamwork and continuous improvement. Attention is therefore shifting towards the need to manage the flow of activities throughout the whole life cycle and, in particular, those that actually add value (Alshawi and Ingirige, 2003). This evidenced a number of important problems. As an example, the lack of consistency in the flow of information between individuals and/or teams generally determines additional expenditures for reworking. This is both due to inconsistent information or information that is not received in time by the right individual or team. In general this often occurs when designs are changed frequently but communication of changes is not timely and successful. At the same time, the whole supply chain is negatively affected by the lack of integration and ordering, purchasing and invoicing often go late. The case study presented in this paper focuses specifically on PMIS for shipbuilding. However, there are similarities between the shipbuilding industry and the construction industry that make the work relevant to both. In particular, both industries share a common tendency to issue hard copy documentation for recording purposes. This makes communication and coordination even more complicated and burdensome due to the necessity of completing whole cycles of amendments, revisions, confirmations and acknowledgments (Alshawi and Ingirige, 2003). These aspects are further worsened by the fact that most of the available IT solutions only focus on specific tasks, resulting in a wide spread of disconnected applications that prevent a smooth flow of information between the various players involved in the management process. This is, instead, a fundamental aspect of the management process itself, as communication consumes up to 75–90% of project managers' time (Scanlin, 1998) and can be seen as the root cause of most project failures (Biggs, 1997).

The present work presents an integrated solution that tries to give answers to most of the above mentioned issues within inter-organizational processes or, in other words, the Extended Enterprise (Dyer, 2000). In particular, the study regards the definition and the building of a management framework where planning, scheduling, communicating and sharing are made immediate and effective by the use of common standards, shared communication and appropriate software tools. This is done by adopting the Supply Chain Event Management (SCEM) paradigm (Stadtler and Kilger, 2002) as the kernel of a modular application where a Control Tower (CT) application handles, collects and addresses messages and event-triggered procedures (Butner, 2006), a PMIS plans and schedules activities, tracks their execution and levels resources overallocations, and a Product Data Management (PDM) manages designs and documents to assure that the correct release is used when needed. The approach has been chosen as is known that inter-organizational processes take place within tricky environments, exposed to failures and disturbance factors, that make them rarely execute as scheduled (Otto, 2003). The SCEM can be used to identify, as an early warning system, the existing variations between the original plans and their execution, considering the huge number of processes, the constraints and the actors in the supply chain and the continuous necessity of eliciting corrective actions, according to predefined rules.

The proposed integrated system and the corresponding and valuable implementation process have been successfully tested on the inter-organizational processes that characterize the luxury shipbuilding industry and allow a number of interesting outcomes:

- reduction of errors and reworks, by assuring that current releases of drawings and documents are used;
- time saving in the query and approval process (drawing management);
- time saving in the real-time control of activities;
- improvement of communications;
- enhancement in the planning and execution of projects;
- building of a collaborative environment where all involved actors can perform on-line interactions.

2. PMIS — features, strength and drawbacks

There are numerous different PMIS available on the market that can be used by any industry with respect to the scope of their projects and to their specific necessities. Also, some companies can purchase specifically tailored solutions. Therefore, depending upon the company and the type of projects they will be addressed to, PMIS can vary significantly

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from one another. However, it is important to note that all projects include several basic elements (Project Management Institute, 2008; Turner, 2009) and that these elements become key requisites of any PMIS:

- Scope, that is the goal of the project and includes all tasks required to complete it;
- Resource allocation, to define teams and individual assignments along with materials;
- Time;
- Deliverables;
- Assignments;
- Risk management, to deal with uncertainty and control the project flow effectively;
- Monitoring;
- Quality control.

Each task of the project life cycle must constantly be tracked to have a project completed successfully and on time. This means that scope, time and costs constraints (Project Management Institute, 2008) have been respected as planned or adequately reviewed if necessary. Most companies use a number of different tools, ranging from relational databases to spreadsheets and, in certain cases, simple paper-based documents. Moreover, the members of a single team may not be using the same tools in order to share information on their tasks and timelines (Akram, 2011; Cheng et al., 2003). Spreadsheets and other software applications, for instance, are generally available within organizations and are frequently used to support the communication, plot timelines, define budgets, control resource allocations and work progress. To grant effective communications, files have to be sent and received by e-mail regularly. Issues arise when many actors may modify the spreadsheet contents at the same time and if the communication is not maintained properly. E-mails themselves represent a very common communication channel and are used to send and receive information about deliverables, changes in scope and other important issues regarding the project. Unfortunately, it is common for paper-based messages or e-mail to be received and to go ignored for lengthy periods of time, causing serious delays. Further problems and inefficiencies arise when project managers have to track multiple resources, each dealing with specific deliverables and characterized by defined time and cost constraints. Scattered and fragmentary information results in a significant loss of performance.

Owing to the above mentioned considerations, it is possible to individuate several benefits deriving from the adoption and the correct use of PMIS:

- projects can be managed from within integrated and coherent applications;
- tasks and task assignments can be created, updated and tracked in real-time;
- involved actors have direct and real-time access to all documents regarding the project;
- documents are updated and only last approved releases are made available to them;
- teams and individuals have access to the full list of tasks they have been assigned to;
- tasks are timely updated when modifications to the current scheduling is needed and all actors are immediately informed when this occurs;
- workers can report their progress in a common environment, allowing other team members to easily understand where the project stands in comparison to the project baseline;
- real time completion control gives a justification for the eventual re-scheduling of the project itself;
- individuals are allowed to communicate with one another in real-time. All communications can be logged and tracked from within the software.

At present both small and large firms may adopt project management tools to increase efficiency, productivity and transparency, making the most of a single application which allows them to manage and track their projects. One of the most interesting and valuable aspects is the possibility for the involved managers to act proactively on tasks if resources are behind schedule, increasing the chances that the project will be completed on time and profitably. This is particularly true for companies that run multiple projects at the same time. Additionally, PMIS become essential when teams are made up of people who are dispersed across multiple locations, as it provides them with access to a centralized information database that reflects real-time updates. In brief, they can be effective if any of the following statements apply:

- employees frequently work on multiple projects simultaneously;
- projects are usually completed after their deadlines;
- re-scheduling and adjustments are frequent due to poor planning or budgetary constraints;
- projects are often suspended for long time to allow project managers to redefine the scopes or to search for new funding;
- budgets are often exceeded;
- team members find it difficult to track their assigned tasks and deadlines;
- employees complete their tasks, but are unable to start new ones because they cannot determine which tasks have yet to be completed. This is a common issue when communication is incomplete or lacking and PMIS can help solving it (Cheng et al., 2003; Project Management Institute, 2008);
- resources are often overbooked, leading to delays or budget extensions;
- miscommunication leads to delays and causes employees to work on the wrong tasks;
- project managers cannot take advantage of a centralized database containing the essential documents.

PMIS are currently available both as a stand-alone and cloud-based solutions. Stand-alone applications are generally hosted on centralized servers. These solutions make it easier for team members to collaborate and they also offer highly standardized interfaces and very fast response times for users. However, they can be very expensive and may be unaffordable for most small businesses. Cloud-based solutions, on the

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contrary, are more effective (above all with respect to costs) for small businesses due to the fact that they are maintained by third-party workforce on remote servers. In both cases, the most significant features that they offer at present may be summarized as follows:

- budget tracking: this allows to define and update all aspects related to budgets;
- schedules: individual and group timelines can be used to track deadlines for all assigned tasks;
- time tracking;
- task assignments: project managers can assign tasks to project members or teams;
- resource allocation: this allows to manage the resources required for the planned projects;
- risk management: team members should concentrate on the potential risks which may occur and their consequences;
- templates: appropriate project templates can be used as the basis for new projects.

Project timelines can be updated by project managers and can be accessed by all project members, usually in the form of Gantt Charts, to provide them with a coherent and updated perspective on the project. They offer the opportunity to monitor the time and the money amounts that have been assigned to a task or an entire project in order to compare the actual progress to the planned one. This, in turn, represents a valuable tool to gather data for performing the well-known Earned Value Analysis (EVA), as explained in Project Management Institute (2008).

It is noteworthy that the cost of a solution should not be the driving factor behind choosing a PMIS package. Other considerations must be kept in mind and these mainly refer to the issues that generally arise within inter-organizational processes or, in other words, within the Extended Enterprise (Dyer, 2000). In particular, these new scenarios push communication requirements, data interchange capabilities and the cooperative real-time planning and monitoring of activities up to the limit. PMIS, as independent and stand-alone software applications may not fit the new challenges that they are expected to. Therefore, some topics that should be carefully considered and assessed regard the following aspects:

- web-enabled project management;
- web-based resource allocation and tracking;
- software compatibility and data interchange within inter-organizational systems;
- interaction with the existing ERP systems and material requirement planning features.

Further, when the number of resources grows up significantly the real-time tracking activity may become almost unfeasible if the job is not committed to each resource individually. Owing to these considerations, the integration of a PMIS with a SCEM seems to be a promising tool to make the most of both applications.

3. The Extended Enterprise and Supply Chain Event Management

Forward-thinking organizations well understand that they are “no more islands unto themselves”. Networks represent the ultimate means to reach competitive advantage, increasing revenues while reducing the overall costs (Ross et al., 2006; Zook and Allen, 2001). These networks are made of customers, suppliers and partners and allow to develop new and fertile profit centers. In particular, partnership is mandatory to enable the rapid exchange of information in those areas where information is money. The recent evolution of economic structures has been characterized by the gradual shift from standard industrial enterprises (hierarchies) to smart networks and, in the most advanced cases, to collaborative markets. The latter actually represents the Extended Enterprise and is characterized by the following features (IBM, 2006):

- it allows to get products to the market rapidly and efficiently with a supply chain integration solution;
- it connects both large and small trading partners efficiently and effectively, integrating different internal and external processes and technologies;
- it strengthens supply-chain visibility;
- it gives a near real-time view of the whole supply-chain, allowing rapid adjustments to processes and infrastructures whether needed.

In brief, the Extended Enterprise is a “loosely coupled, self-organizing network of firms that combine their economic output to provide product and service offerings to the market” (Farrell, 2008).

It is remarkable that Extended Enterprise is a more descriptive term than supply chain, as it introduces different types and degrees and durability of relationships among the involved actors. These can be represented by contracts, as in partnerships, alliances or trade agreements, or by open market exchange. In particular it has gained even more importance as firms tend to become even more specialized and inter-connected, global markets are replacing the local ones, and processes are undergoing significant standardization. The latter aspect allows companies to obtain most of the previously built-in business functions as external services. Owing to this they can focus their resources on those activities that provide them the greatest rate of return.

This new scenario introduces new issues and severe challenges. Indeed, inter-organizational processes take place within tricky environments, exposed to failures and disturbance factors, that make them rarely execute as scheduled. At present this is a significant weakness of a standard PMIS and to overcome these limitations a new tool has been introduced to help firms during the implementation and the management process.

As Otto correctly stated (Otto, 2003) SCEM can be seen at the same time as a management concept, a software application and a software component. In their common meaning they manage a particular class of events, namely those that are related to the “management and transformational and transfer processes”.

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When referring to a SCEM as a management concept the goal is that of identifying all possible deviations from schedules, minimizing their impact early before they may disrupt the customer satisfaction and the operational efficiency. In general, all operating processes will start off time-phased requirements for all the necessary activities. Within the Extended Enterprise this originates a network of sequentially interdependent processes that are difficult to track and monitor, leading to lateness and, whether this exceeds a defined threshold, endangering the ability of meeting the customer expectations. A SCEM may help the managers and the workers by automatically triggering a sequence of actions that range from the simple raising of alerts and warnings, to the re-scheduling of milestones and the consequent communication to all the involved actors. It appears evident, from the above, that events are associated to milestones for which status values are expected and wait to be activated. Therefore, if the process goes smoothly and no warning is required the event is not triggered at all. On the contrary, when the deviation exceeds a pre-defined value, the event calls the corresponding event-handler (the latter, usually makes use of a set of pre-defined rules to solve the issue). An interesting feature is here represented by the fact that the SCEM not only is able to automatically manage the events, but also eliminates the delay that generally occurs between the event triggering and the starting of the corresponding corrective actions. At present, this feature is not present in the available PMIS. In brief, SCEM may help managers to reduce the idle times and, last but not least, to record, manage and share out the know-how deriving from the precious lessons learned. The precondition to successfully manage events within a supply chain or the Extended Enterprise is to have visibility (Kemmeter and Knickle, 2002). This means that all the information needed for the event management engine to work properly must be accessible (both in time and space) from within the whole network. Also, information must be up to date and coherent. When the SCEM is seen as a software application two core aspects are the processes and the activities. Processes are sequences of synchronized activities geared towards a well defined goal. When sequentially interdependent activities lose their synchronization the whole process lose efficiency. Here the SCEM is expected to allow a permanent event-driven re-scheduling. This means that it can only work properly if the process is well defined in terms of timelines, milestones and the corresponding events.

This clearly indicates that PMIS, SCEM and PDM should be viewed as a whole, as long as the blending of their features provides answers to all the above mentioned requirements. Indeed:

1) the SCEM deals with processes and all the operating processes will start off time-phased requirements for all the necessary activities;
2) time-phased requirements will be effectively managed by the PMIS, which is the deputed application;
3) significant milestone activities will be linked to events and these, in turn, will activate re-scheduling and re-synchronization processes;
4) this will initiate a real-time bi-directional dialogue between the SCEM and the PMIS;
5) up to date information is a key factor for a successful implementation and can be managed by means of the PDM software.

Moving to the Extended Enterprise requires an intensive use of new and affordable tools for the *e-business* and the *e-information*, to support, control and monitor the safe and rapid exchange of data between the various players within the whole process and dispersed over several production sites. Without these tools, migration is almost unfeasible, unmanageable if not simply inconceivable. The creation of a "concurrent business environment" requires a dramatic increase in the capacities of the available information systems. Access both to applications and the corporate data at any time, from any place and by any means represents a significant challenge and researches in the field are moving towards the development of systems that are capable of managing huge amounts of documents and information. Besides, the necessity of creating service networks and basic infrastructure capable of allowing a comprehensive connectivity to all the players in the Extended Enterprise (Butner, 2006) has emerged in recent years.

The migration to this new type of integrated organizations requires an in-depth analysis and the complete redesign of the involved business processes. At the same time this enforces the adoption of new tools, that can be adapted to the existing management systems of the individual partners or that broaden their capabilities, to achieve the full compatibility. The key features of such systems can be summarized as follows:

- full management of the flow of information;
- remote access by any actor, allowing safe, effective and efficient data sharing;
- planning, scheduling and control capabilities;
- built-in control systems based on appropriate observation points (the "Control Tower") that can monitor the proper execution of the required activities.

4. A web-enabled PMIS for the extended enterprise

From the observations reported in the previous paragraphs and considering the following aspects:

- the organization and the management of many shipbuilding companies have remained unchanged for many years and are very far from achieving the basic concepts of the Extended Enterprise;
- the absence of information systems specifically designed to support the creation of the Extended Enterprise in shipbuilding;
- the importance and the growing need for integration within the shipbuilding network;
- the absence of readily-available software applications that integrate planning and scheduling with real-time event-driven control systems and the knowledge management.

The authors propose a new combined approach that integrates a PMIS, with enhanced planning and scheduling capabilities,

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within a SCEM system able to deal with the cited shipbuilding industry issues. The solution comprises (*i*) a Control Tower (CT) application that handles, collects and addresses messages and event-triggered procedures, (*ii*) a PMIS that plans and schedules activities, controls and tracks their execution and levels resources overallocations, and (*iii*) a Product Data Management (PDM) that manages designs and documents to assure the correct release is used when needed. As shown in Fig. 1, the proposed approach and the consequent software system consist of a number of interconnected layers and applications.

Shared data are maintained within a Technical DB and an ERP system that are centralized and common to the various partners of the considered Supply Chain. In the middle, a new layer has been inserted, where a set of brand new applications has been provided to exhaustively cover all the management areas. Summarizing, the involved applications are:

- a PMIS, to plan and schedule the projects activities;
- a PDM, constituted by an Accuracy Management (AM) and an Engineering Data Management (EDM) applications, to deal with documents and the shared know-how, both with respect to processes and technical specifications and to designs and modifications (actually, this constitutes the PDM application);
- a Control Tower (CT), used to monitor and manage events and event-handlers and to broadcast messages among the different actors (an example is reported in Fig. 2, where the shipyard and a supplier share the knowledge of a technical modification. The CT delivers the right warning messages and, based on predefined rules, waits for the answer at given times).

The integrated system has been actually defined and built within and with the valuable help of a local shipyard. From the methodological point of view the first step of the proposed approach required an in-depth knowledge of the involved processes. This was obtained by means of a Business Process Reengineering (BPR) activity (Guha et al., 1993) with respect to the most significant processes and involved both sub-contractors and a considerable number of current suppliers. The step, that represents one of the most valuable contributions of the implementation process and has been recorded as a standard operating procedure, was intended to:

- simplify and re-engineer the processes (in particular, design, supply and production) with the aim of making them more effective and efficient;
- define and optimize the operating rules in order to provide the technical requirements for the development or the adaptation of the IT tools;
- define and/or individuate the appropriate additional control points to prevent all possible deviations from schedules, minimizing their impact early before they may disrupt customer satisfaction and operational efficiency;
- define the workflows that underlie the functioning of the information systems.

In brief, the BPR led to the definition of the "as is" and the "to be" conceptual maps of the mentioned processes and allowed the identification of a number of potential issues to be corrected and optimized by the SCEM system (Woung Woong and Yoon Ki, 2011). In particular, the most valuable outcomes of the analysis can be summarized as follows:

- availability of the conceptual maps, written in a graphical format by means of the Business Process Modeling Notation (BPMN) (Ko et al., 2009), of the significant processes in the design and construction of a ship;
- identification of the corresponding inputs and outputs (an example is reported in Fig. 3, dealing with the planning and the execution of building tasks within the shipyard);
- availability of the matrix of responsibilities, where "who does what" is clearly identified and defined for each step of the process (documents, responsibilities, methods, timing, objectives, constraints, and critical control points);
- full visibility (business visibility) of the process;
- definition of the control points that are necessary to ensure, at all times, the process status monitoring, its criticality and the degree of accomplishment of its objectives;
- full integration and widespread communication among the various partners.

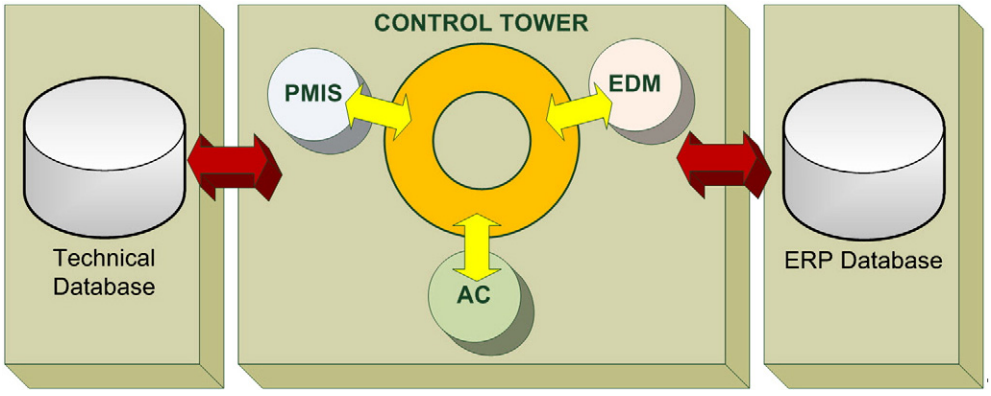

Fig. 1. The application model.

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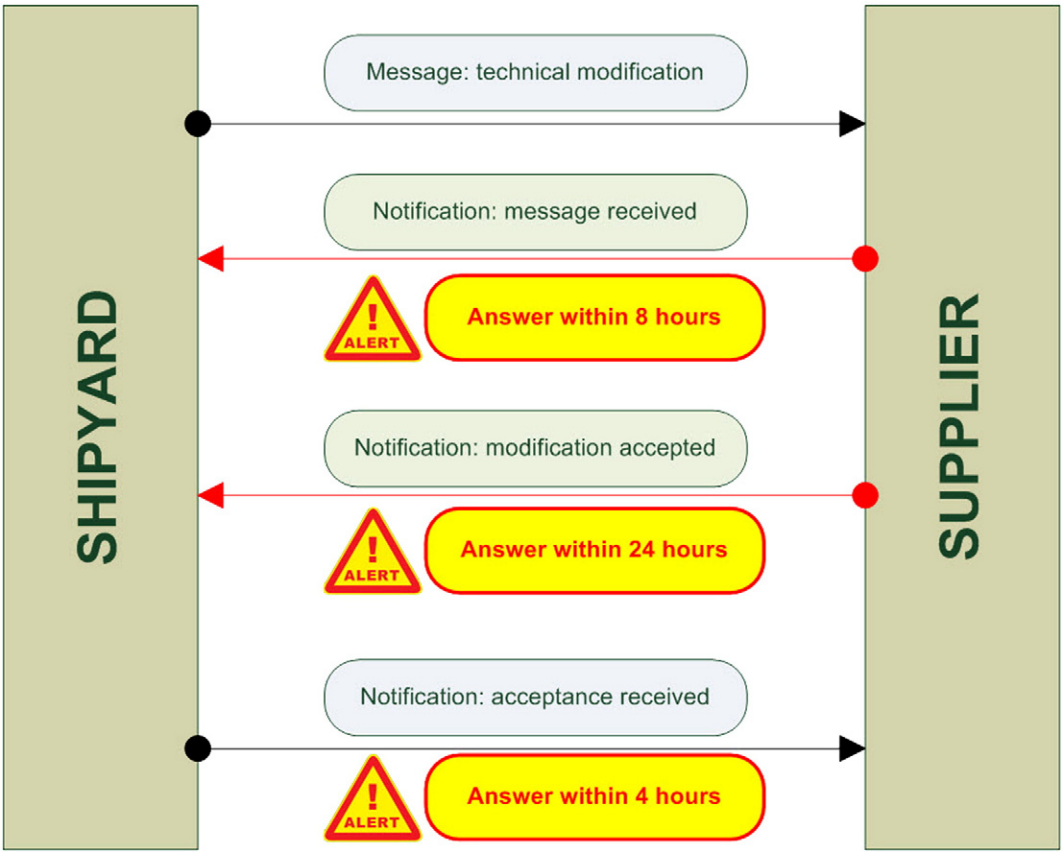

Fig. 2. The Control Tower alert system.

The adoption of BPMN and, consequently, of a Business Process Modeling System (BPMS) (among the many available at present. See, for instance, Ko et al., 2009), represents a valuable advantage as changes within processes can be easily captured and managed over time, while they occur, without the necessity of a complete revision of the framework. Besides, this allows separating the processes from the rules, making the improvement and the maintenance of the software tools even easier. In the last decade BPMS have been used jointly with web services, (service-oriented architecture framework) and together they provide a fitting technical foundation for making business processes accessible within enterprises and across enterprises (Leymann, 2002). Such information systems deal with the definition, management, customization and assessment of tasks evolving from business processes as well as from organizational structures and can be used efficiently to control the workflow in an organization, to transfer data, and to integrate legacy information systems. In effect, research in this field is characterized, for many years, by the attempt of "applying information systems to heterogeneous and distributed environments" (Karagiannis, 1995) like those involved in a generic Extended Enterprise.

The introduction of the concept of Extended Enterprise in the shipbuilding requires therefore that numerous companies (often highly specialized in their specific activities, such as, for example, the suppliers of electronic sub-systems or the shipwrights, but characterized by a wide variety of informatics skills and competences) will actively and strictly cooperate. This necessarily introduced a further step. Indeed, in such context it becomes mandatory to build an appropriate knowledge management system, able to host the expertise and the independent knowledge of each partner. A particularly complex problem to be faced here regards the interfacing of the pre-existing software systems and the communication requirements among the various data sources and exposes the various actors to the risk of late information. Experience shows that often the technical changes or the improvements that occur during the production stage (usually these derive from specific customers requirements) are not reported at all to the Technical Office. This dramatically impacts on the planning and scheduling of the activities, since it usually ends in a significant number of reworks or, in the worst cases, in the complete re-scheduling of the project. In the shipbuilding industry, where the hard copy of documents is often required, this makes communication and coordination even more complicated and burdensome due to the necessity of completing a whole cycle of amendments, revisions, confirmations and acknowledgments. In brief, a standard PMIS greatly suffer from this situation and in many cases the planning and scheduling outcomes results obsolete and unreliable as soon as they are deployed. As an example, a good number of corrective actions, resulting in the identification of an error in the design, are activated directly at the production level and are solved directly, without "bothering" to create adequate notice to all those involved in the process. Often this is not due to simple

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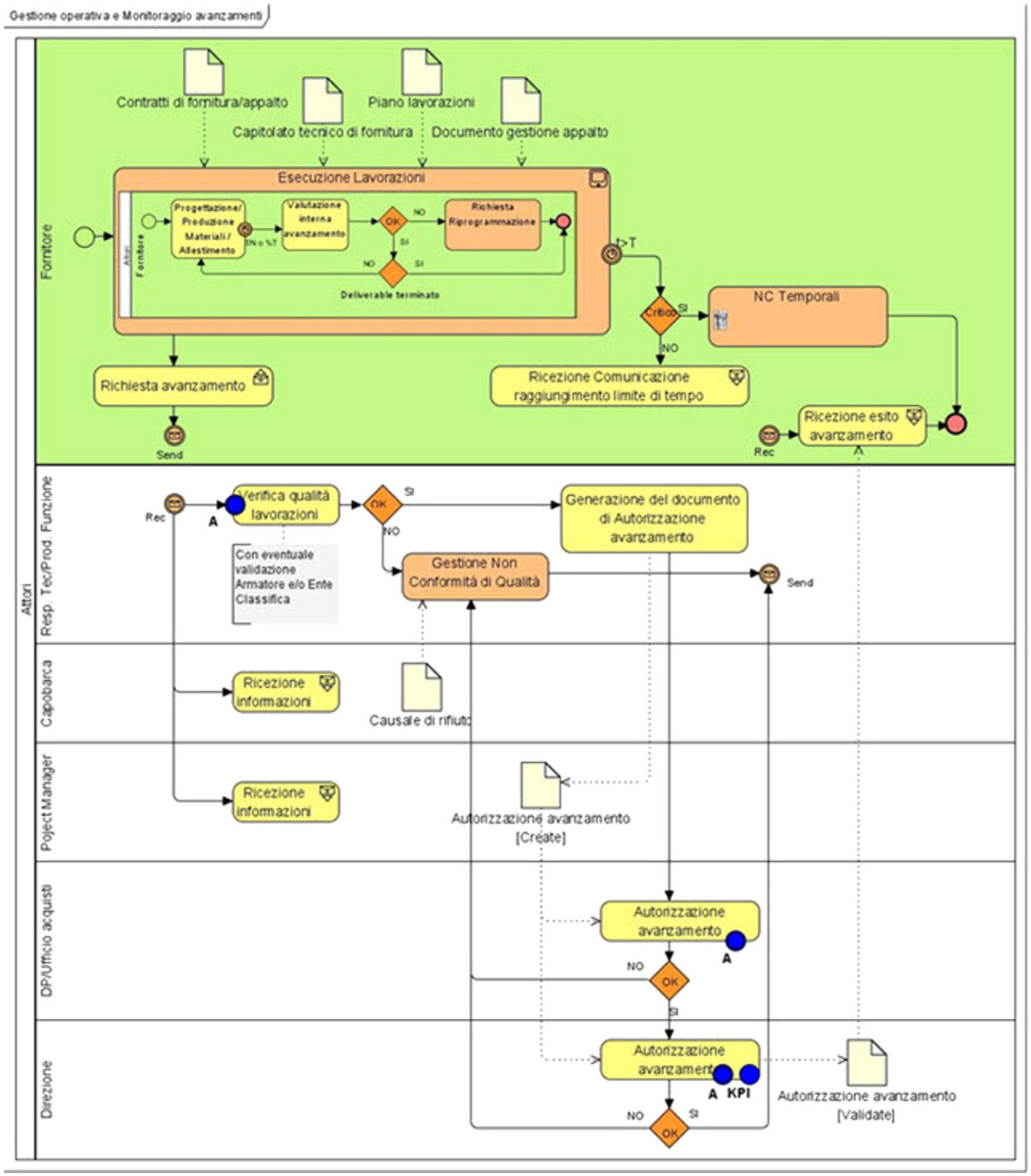

Fig. 3. Process mapping with BPMN.

negligence, but must be ascribed to the lack of adequate communication tools. Keeping this in mind, the AC module that has been introduced within the PMIS system allows to:

- detect the problems faced by companies and by the working teams during production, design, management;
- record the solution proposals that are advanced by the technical staff of each supplier;
- notify the presence of the problem and its current solution to the Technical Office;
- agree with the Technical Office on the feasibility of the proposed solution or get an alternative one;

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- identify and alert all the possible processes on which the change will impact;
- activate the update process on all the linked technical documentation;
- collect all the project documentation in relation to the reported problem;
- manage the received documentation, according to pre-defined criteria;
- facilitate the retrieval of a specific document (drawings, specifications, procedures) in a simple and intuitive manner.

The two stages described above finally allowed the definition and the building of a prototypic PMIS specifically designed for the Extended Enterprise. It is noteworthy that the decision of developing a new planning software was mainly due to strict budget constraints. Indeed, some available (and known) commercial applications could fit adequately the necessities of the project, but their cost represented a major obstacle and led to the final decision of developing a new prototype. This is an important aspect, since it clarifies that the most important contribution of the present work resides in the integration of the above mentioned systems and in the methodological approach and is almost independent from the software applications supporting it, provided that they grant the required functionalities. In particular, the proposed PMIS module is characterized by the following features:

- enhanced resource management, with particular attention to suppliers and sub-contractors;
- finite capacity scheduling capabilities;
- interaction between the PMIS and the ERP with respect to the material resources;
- ability to consider incompatibilities among contemporary activities;
- complete interaction with the event-driven SCEM, with the aim of allowing the broadcasting of early warning alerts and messages (usually related to delays and re-scheduling necessities) to all the involved actors (Fig. 4).

A web-based application allows each actor to control and track the assigned tasks from remote, while the CT continuously monitors the status of the activities with respect to their deadlines and provides to activate the correct event-handlers, for instance when delays occur (Fig. 5).

At the same time, finite capacity scheduling is a necessary feature since the software has to deal with multi project planning and this may lead to significant resource overallocations. Along with this, the prototype has been provided with basic Material Requirement Planning capabilities, with the aim of avoiding delays and material unavailability or to help detect risks before the beginning of the scheduled activities.

In the shipbuilding industry some activities are carried out within confined environments and cannot be completed at the same time mainly due to safety issues. The standard PMIS can deal with this feature by inserting precedence constraints among activities or by using overallocated virtual resources. Unfortunately this makes the finite capacity scheduling process even more troublesome and lengthy (Kastor and Sirakoulis, 2009). These considerations led to the introduction of the incompatibility constraints among tasks and significantly improved the leveling performance of the PMIS.

Technically speaking the application has been developed using Object Oriented Programming techniques and is constituted by several classes that interact with one another (Fig. 6) and with a Relational Database by means of the Open Data Base Connectivity (ODBC) standard Application Programming Interface (API). Each class represents a logical entity and owns attributes and methods that fully represent and manage projects, tasks, resources and all complimentary items. In particular the most notable classes are the following:

- Multi-project main class;
- Project class;
- Task class;
- Resource class;
- Assignment class.

The multi-project main class is the highest class and it holds all the others. Its purpose is to create a common environment where planning, scheduling and leveling take place such that resources and their corresponding assignments can be easily monitored and adjusted over time. The objects deriving from this class are able to query the owned objects with the aim of creating reports and validating the current schedule. The project class represents in turn a single project and is characterized by methods that help the PMIS to evaluate durations and costs and to build the technical constraints among the tasks. Tasks, obviously, represent the single activities that constitute each project and are by far the most complex class available within the PMIS. In fact, they are able to schedule themselves with respect to their allocations, to the current constraints and to the available calendars. Besides, they are capable of evaluating the overall costs (resources and materials) and identifying the eventual overallocations that may make the scheduling unfeasible. The resource class allows creating both working and material resources: the former ones determine the duration and the eventual allocation issues, while the latter ones are used to evaluate the material requirements. Finally, the assignment class is a complex class that interacts with tasks and resources and allows linking them within the schedule.

The schedule feasibility is guaranteed by a complex resource-leveling procedure, based on a genetic algorithm derived from the one proposed by Hegazy (1999), that resolves incompatibilities and overallocations. This is accomplished by means of re-scheduling functions that are activated on tasks based on priorities and constraints, both in forward scheduling and backward scheduling. The overall performance of the algorithm confirms the outcomes of the original work of Hegazy both with respect to Microsoft Project and Oracle Primavera. Moreover, since this procedure may be lengthy and cumbersome due to the number of concurrent tasks, the possibility of scheduling over limited periods of time ("time windows") has been provided. Besides, this is fully justified by the fact that long term scheduling is

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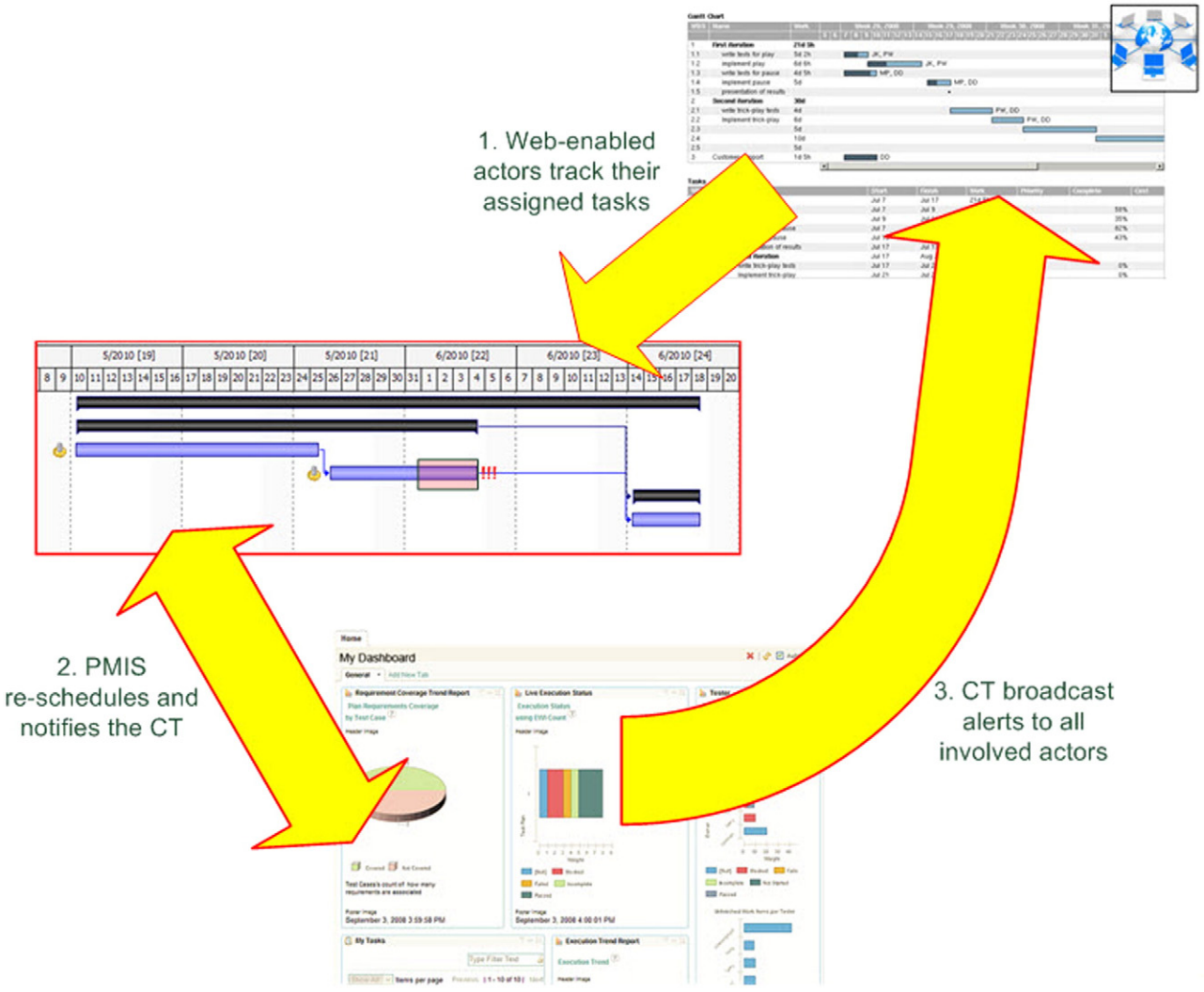

Fig. 4. The task tracking and control system.

generally unreliable due to the continuous necessity of adjusting tasks durations and the corresponding resource allocations.

The adoption of the ODBC API is intended to make the framework independent from the actual database systems available. Indeed, data can be read and written into many different databases by means of standard routines. This feature is mandatory since, as already stated in the previous paragraphs, firms are actually using many different software applications to manage their vital facts.

The tool is greatly beneficial in that it:

- ensures the proper modeling of the typical processes of shipbuilding orders;
- enables the optimal management of resources and of feasibility constraints in order to ensure a timely control of the production capacity in a multi-project environment;
- communicates with the remaining modules of the SCEM, in particular to ensure the timely updating of the shared knowledge database and to broadcast the occurrence of important events;
- allows the punctual control of the production advancement at all stages of the building process and at different levels of aggregation, according to the characteristics and necessities of the users and their skills;
- gives full visibility of all processes to all the involved actors within the Extended Enterprise, enhancing the understanding of the processes themselves and making it easier to detect and isolate issues at an early stage.

To sum up, the whole framework is based on the detailed mapping of the vital processes by means of the BPMS. Appropriate web services manage the execution flow and the data exchange. Whenever a process requires the planning and the scheduling of its tasks and the allocation of resources, the PMIS is used to generate feasible schedules and to punctually control and track their execution. Since this requires the intervention of several actors across the Extended Enterprise, a web service enabled event-driven CT has been provided with the aim of managing and dispatching messages, alerts and information and to ensure that the important events are not ignored or delayed.

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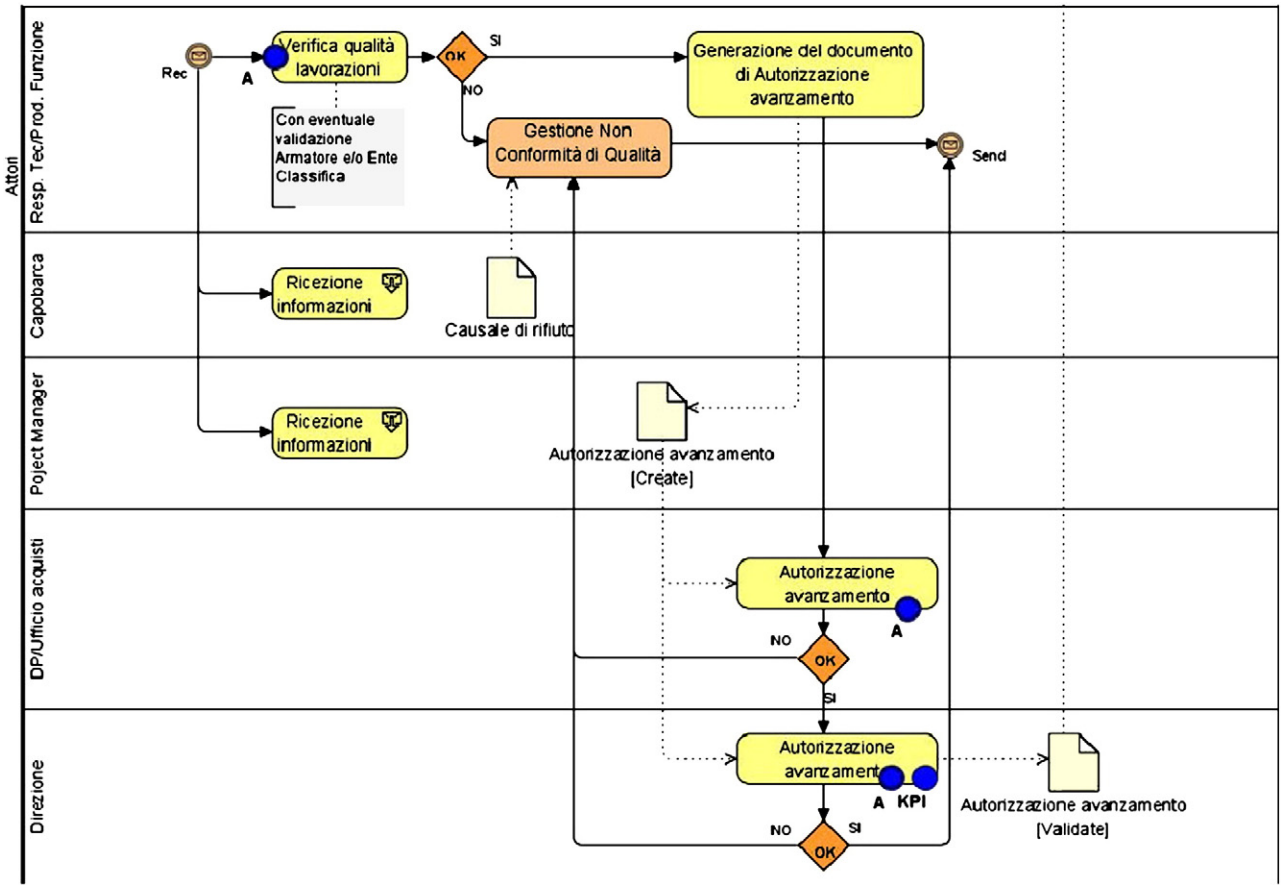

Fig. 5. Warnings and messages broadcasted to all the involved actors.

The supply chain is consequently fully supported by the integrated SCEM software. This represents a key feature of the proposed system and differentiates the proposed application from standard PMIS, as the event-driven approach grants that critical messages are dispatched when needed, avoiding both the loss of information or its excess. Besides, thanks to the use of the BPMS tools, it is easy to modify the events database, with the possibility of extending or enhancing the application if necessary. If the scheduling, the execution, the control and the tracking of the tasks require documents and/or other related information, the web-enabled AC system is able to broadcast them in real-time across the Extended Enterprise, assuring that the correct release is made available for the users at any time and in any place.

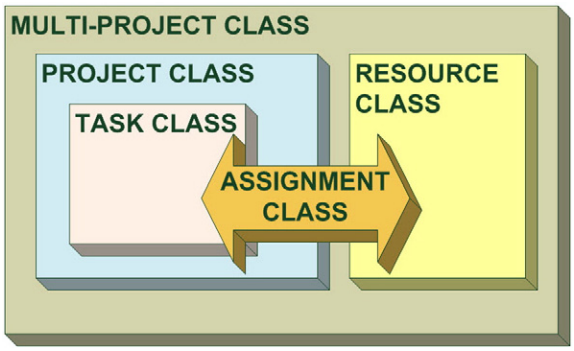

Fig. 6. The PMIS OOP classes.

5. Conclusions

The present work has proposed the definition of an integrated approach and a modified PMIS application for the Extended Enterprise. It combines a finite capacity planning software with a knowledge management tool and an event-driven control system, that makes extensive use of web-based and collaborative technologies. The result is a management framework where planning, scheduling, communicating and sharing are immediate and effective. This is done by adopting the SCEM paradigm as the kernel of a modular application where a Control Tower application handles, collects and addresses messages and event-triggered procedures, a PMIS plans and schedules activities, tracking their execution and leveling resources overallocations, and a Product Data Management (PDM) manages designs and documents to assure the correct release is used when needed.

The approach has been chosen as it is known that inter-organizational processes take place within awkward environments, exposed to failures and disturbance factors, that make them perform hardly ever as planned. The SCEM can be used to identify, as an early warning system, the existing discrepancies between the original plans and their execution, considering the

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huge number of processes, constraints and actors in the supply chain and the continuous necessity of eliciting corrective actions according to predefined rules. The proposed integrated system has been successfully tested on the inter-organizational processes characterizing the luxury shipbuilding industry. It allows a number of interesting outcomes, such as the reduction of errors and reworks, by assuring that current releases of drawings and documents are used, a significant time saving in the query and approval process, the overall improvement of communications among the various involved actors, the enhancement in the planning and execution of projects, the building of a collaborative environment where all involved actors can perform on-line interactions.

In brief, such an approach can give full visibility of all processes within the Extended Enterprise, enhancing the understanding of the processes themselves and making it easier to detect and isolate issues at an early stage. This represents a key feature and differentiates the proposed application from standard PMIS as the event-driven approach grants that critical messages are dispatched when needed, avoiding both the loss of information or its excess. Besides, thanks to the use of BPMS tools, it is easy to modify the events database, with the possibility of extending or enhancing the application if necessary.

Further work may follow with the aim of getting deeper into the integration of such tools with the available ERP systems (with respect to the management data) and the EDM systems (with respect to the technical data). Currently, the problem of planning and scheduling in manufacturing environments and implementing workflow management systems at the same time and on the same information system still remains almost uncharted.

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