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A Computer Simulation Game for Learning Product Lifecycle Planning Through the Engineer-To-Order Case*

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In this paper we present a computer-supported simulation game intended for teaching the planning aspects of Product Lifecycle Management (PLM). The game deals with product lifecycle planning dynamics in the Engineer-To-Order (ETO) industry. The ETO environment that serves as the working case allows the eliciting of important PLM concepts: unified product development multi-project planning and manufacturing planning, links between PLM software and ERP systems, and emphasis on the PLM holistic approach. The game is designed as a series of group sessions in which the different planning decisions appear progressively so that in the last session a complete lifecycle planning problem is completed. The sessions act as a series of practical cases encouraging group discussions. The computer system consists of two main components: a discrete event simulator and a planning decision support system. The simulator guides the game and stochastically generates the different events that cause the need for planning decisions in the working case. The planning decision support system makes it possible to emulate the resolution of the day-to-day tasks.

Keywords: product lifecycle planning; computer simulation games; engineer-to-order

INTRODUCTION

GROWING INTEREST AROUSED by the emergence of Product Lifecycle Management (PLM) as a holistic business concept to manage the entire product lifecycle [1–2] led to corresponding demand of 'entry-level professionals who are PLM-proficient at the time of the hire' [3]. This trend, in turn, is reflected in the increasing presence of PLM in engineering education programmes. Consequently, there is a demand for appropriate educational approaches to teach this recent paradigm. While PLM encompasses a wide range of topics, one important issue is the planning aspect of product lifecycle. In this paper, we present an educational tool aimed at teaching the planning aspects of PLM. The tool adopts simulation games, which have been proved effective in management education [4].

We consider simulation games to be a valuable resource in PLM education even though more applications have been done in management education. There is a long, diverse history of simulation games in the field of management [5–6]. Actually, simulation games for management education have become increasingly relevant in the last decades, and it is becoming apparent that they will continue to gain importance in the forthcoming higher engineering education scenarios. Underlying this circumstance is the fact that constructivist learning theories fit particularly well in engineering education, due to the practical, problem-solving nature of the disciplines involved [7]. Recently, there has been a renewed interest by different authors, Shank [8] among them, in the 'learning by doing' paradigm, formulated by pioneer John Dewey (1859–1952). Taking advantage of this learning philosophy, case method and simulation games emerge as the main pedagogical resources in management education [9]. In fact, both resources are closely related since a simulation game is 'essentially a case study, but with the participants on the inside' [10].

Chang and Miller present a redesign of a PLM curriculum based on the industry-demanding workforce profile. They refer to previous works by other authors which add to their own experience in the sense that 'one major concern the authors picked up from early PLM adopters was that the new graduates right out of school often do not have proper training to consider a problem from different angles' [11]. They propose to complement the basic PLM courses, which focus on product development technologies, with a course that stresses how computer simulation can be used to support engineering decision-making processes. This course also includes a module on project management as it is considered a basic background for PLM graduates.

Following the same approach, we present below

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a computer supported simulation game that is intended to constitute a complementing module of a Product Lifecycle Management (PLM) course. The game deals with product lifecycle planning dynamics in the framework of PLM. Although the planning function does not receive the necessary attention by PLM software, Schuh *et al.* explain that it is because production planning is a function traditionally covered by ERP systems [12]. Yet, ERP is an important and essential component of PLM [1, 12–13]. Jin *et al.* point out the importance of combining PLM with project management techniques in an integrated enterprise approach [14] whereas Ershov *et al.* underline the importance of project scheduling in PLM systems [15].

The environment that serves as the working case is the Engineer-To-Order (ETO) industry, which is characterized by products covering the commonly known lifecycle phases. This particularity allows for the elicitation of some key concepts in PLM: unified product development multi-project planning and manufacturing planning, links between PLM software and ERP systems, emphasis on the PLM holistic approach.

ENGINEERING-TO-ORDER CASE

The ETO industry is characterized by the concurrence of both project management and production management features [16–17]. According to the APICS dictionary, ETO companies deal with 'products whose customer specifications require unique engineering design, significant customization, or new purchased materials. Each customer order results in a unique set of part numbers, bills of material, and routings' [18]. PLM is particularly useful in ETO companies. In fact, one of the paradigmatic ETO industries is the aerospace sector, which, along with the automotive sector, is one of the main industries using PLM technologies [13, 19]. In this section, we describe first the main features of the ETO companies from the management point of view and then analyze the benefits of using the ETO case for PLM education.

ETO characterization

A thorough analysis of the literature on the problematic management aspects of the ETO companies—such as [15–16, 20] among others—yields four main critical features:

1) Produce to order. Customers, frequently engineering companies, order products—unique products most of the time—for which there is no stock and no process planning, though requiring a customized treatment.
   - There is a bidding/quotation stage, before the order contract. After signing the contract, there is an engineering stage, before manufacturing, where drawings, bill of materials, manufacturing process definition and material requirements are issued.
   - Raw materials are specific for each order, which prevents a stable supply policy from being established.
   - Subcontracting becomes common practice.
   - As projects differ from one to another, there are not enough expertise and data to estimate activity durations, adding to the uncertainty regarding raw material lead-times.
   - The particularities of each product makes it difficult to have a bill of material based production management, and hence the use of MRP (Material Requirements /Manufacturing Resources Planning) systems.
2) Demand uncertainty. There is a high uncertainty regarding new orders, added to the high variability in the complexity and total lead-time of the projects.
   - The traditional demand forecast techniques cannot be used, making medium/long term planning even more difficult.
   - 'The sooner the better' execution policy appears due to the inability to foresee what should be produced in the short/medium term.
3) Project structure. Orders are handled following the traditional project structure as precedence networks.
   - Traditional project management techniques might be advisable for use in manufacturing planning tasks. However, as manufacturing takes place in a shop floor designed as a job-shop, competence becomes a major aspect for the manufacturing resources.
   - There is a matrix organisational structure based on the assignment of Project Managers with cross-functional responsibilities over the functional units (particularly, Engineering and Production).
4) Part of a bigger project. Orders are usually, but not necessarily, part of a bigger engineering project.
   - Because orders are planned within the bigger project (the customer), there is a demand when it comes to achieving the deadlines and quality. Furthermore, changes in due dates or technical requirements are quite common.
   - Regarding the information system, being part of a bigger engineering project implies some particular requirements. Such a system must provide proper interfaces with the main stakeholders: customers, suppliers and subcontractors.

PLM in ETO environments

The PLM framework proposed by Saaksvuori and Immonen [1] can be applied in order to understand the rationale behind the relationship between PLM and ETO environments. The mentioned framework distinguishes between the product process—product development, productizing, product design maintenance and marketing—and the order-delivery process—fulfilment of customer's orders—as depicted on left side of Fig. 1.

In the ETO companies the new product introduction (NPI) process becomes the group of engineering phases required by each customer order. The right side of Fig. 1 shows an illustrative adaptation applicable to the ETO case, which also includes the supporting IT systems. The linkage between product process and order-delivery process (arrow line), which is characteristic of ETO environments, enables the elicitation of some interrelated PLM important concepts, as mentioned in the introduction.

- From the planning point of view, the product process encompasses the utilization of multi-project management techniques in the management of the portfolio of product development projects [21], while the order-delivery process encompasses the utilization of sales and manufacturing planning techniques. The connection between the product process and the order-delivery process leads to a unification of product development planning and manufacturing planning. The evolution of the technical data of the product throughout the lifecycle brings along the evolution of the product planning data.
- From the systems integration point of view, the ETO case elicits the connection between PLM software and ERP systems. Saaksvuori and Immonen point that 'traditionally, PLM systems have been used in the product development process, just as ERP systems have been used in the production process' [1]. This circumstance is depicted in the model of Fig. 1, with the evolving proportions of PLM software vs. ERP system along the lifecycle. The fact that every ETO product crosses the boundaries between PLM and ERP underlines the necessary integration of both systems and the data involved in the integration. Product lifecycle planning constitutes an integrating force [22] and product structure (BOM) is an essential data linkage [23–24].
- From the PLM global view, product lifecycle planning of the ETO environments helps to emphasize its holistic approach to the management of a product. From the quotation stage, all product lifecycle phases are globally considered. Stark (among other authors) stresses the holistic approach as one of the most important characteristics of PLM [2]. Ncube and Crispo base their proposal of applying the Gestalt principles to the learning of PLM concepts on the importance of the holistic view of PLM [25].

Regarding the product lifecycle, the connection between product process and order-delivery process implies the coexistence of projects that are in at least three different definition stages (after which they will be manufactured and delivered to customer) [26]: roughly defined projects in the quotation phase; projects after design and prior to process planning; and totally defined projects after the process planning. Three main planning decisions for each project arise:

- Order quotation. The engineering departments have to determine a rough definition of the project network and estimate the approximate durations and costs of the resulting activities. The planning department has to provide a feasible due date for the project.
- Aggregated planning. After the contract has been signed, the engineering department refines the initial rough project network and the planning department has to establish an initial plan for each aggregated activity of the project.
- Detailed scheduling. Finally, the process planning department decomposes each aggregated activity into a network of detailed operations. The low-level planning includes not only the scheduling of such operations, but the rescheduling caused by different shop disruptions such as machine breakdowns or material supply delays.

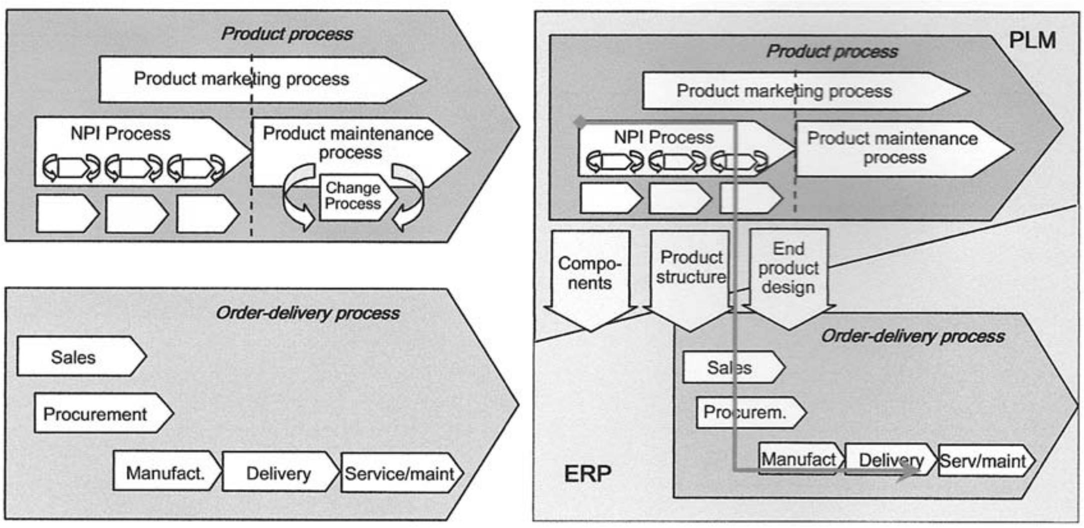

Fig. 1. Product process and order-delivery process [1].

SIMULATION GAME

Basing his work on different references [27–29], Ruohomäki provides good insight into the concept of simulation games for educational purposes [30] which are presented according to their twofold nature, simulation and game: simulation is a working representation of reality and may be an abstracted, simplified or accelerated model of a process; a game is played when one or more players compete or cooperate for payoffs according to a set of rules [27]. Besides, a game means a setting in which participants make choices, implement those choices and receive consequences of those choices in an effort to achieve given objectives [28] and the players, either real or simulated, operate in an environment which can be either real or simulated [29]. A simulation game combines the features of a game (competition, cooperation, rules, participants, roles) with those of a simulation (incorporation of critical features of reality) [27]. One possible definition of simulation games is that of Kriz: 'the simulation of the effects of decisions made by actors assuming roles that are interrelated with a system of rules and with explicit references to resources that realistically symbolize the existing infrastructure and available resources' [31].

There is no accepted taxonomy of simulation games and many criteria can be employed in order to classify them [32–33]. As Riis *et al.* explain they can be classified according to dimensions such as its pedagogical purpose, the kind of decision-making roles, the subject area, the general or company specific purpose, the effort and duration, whether they are computer based or manual, the target group, the advancement of time, and others [33]. Riis organizes his compilation book, following the dimension of the kind of decision-making roles and thus distinguishing between: single decision maker, decision centre and multi-functional interplay [4]. Taking production management games as an example, a single decision maker game would be a dispatcher scheduling game, where an individual has to assign tasks to resources in order to satisfy a given demand while trying to minimize the production costs; in a planning decision centre game, there would be a team working together on a complex planning task; in a multi-functional interplay game different players would be assigned to the functions involved in production management, such as purchasing, production planning and manufacturing.

Zülch and Rinn have remarked, as a principle classification, the separation into socially-oriented and computer-supported simulation games [34]. Socially-oriented simulation games concentrate mainly on the interaction between participants while solving given tasks; most of these games are multi-functional and aimed at creating awareness and understanding [32], and their success relies heavily upon the professional and social skills of the trainer [34]. In computer-supported simulation games, the idea is to use the computer as a substitution for the real world, thus making the participants face real world problems. They have to react to situations generated by the software, taking into account the players' inputs. The software also shows the effects of the decisions made, i.e. what would have happened if the decision had been carried out in reality. This way, decisions can be taken without any risk, either for the participant or for the system. This kind of simulation games requires extensive development efforts, consequently, they usually focus on very specific tasks.

The game described in this paper can be classified as a decision-centre and computer-supported production management simulation game. Regarding the decision-centre dynamics, the game adds a very interesting feature: the sessions are planned and conducted as case studies. The complex ETO environment described in the above section constitutes the working case. The idea behind the game is to simulate the day-to-day planning tasks, with a computer simulator generating a list of the possible planning events stochastically, and provide a decision support system for helping to resolve the tasks in a discussion group. The game is conceived as a series of group sessions, basically organized as an initial presentation by the instructor followed by a group discussion. The different planning decisions appear progressively such that in the last session a complete lifecycle planning problem is completed. As a result, the sessions act as a series of practical cases encouraging group discussions, thus leading to a combination of the two main 'learning by doing' educational resources. A small group of students facing a simulated real life problem with the aid of computers is particularly beneficial for engineering students to develop the necessary problem-solving and teamwork skills [35].

THE COMPUTER SYSTEM

The core of the simulation game, which is a computer system that integrates both the simulator of events—called EtoSim—and the planning decision support system, is described below. Figure 2 shows the architecture of the system with the database serving to communicate the different modules.

EtoSim

The simulation module, intended to be used by the instructor of the game, stochastically generates the data of the different game sessions and stores them in a database. It is a discrete event simulator [36], aimed at emulating the dynamics of the ETO planning environment. Thus, the first step in the development of the simulator is to model such an environment, particularly the events that take place. The UML use case diagram of Fig. 3 shows the interactions of the different actors and

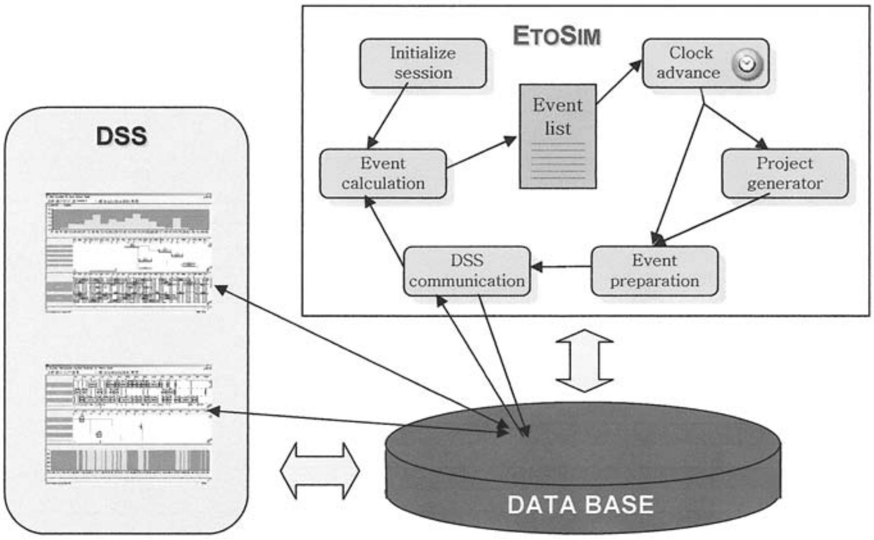

Fig. 2. Computer system architecture.

the planning system. Taking the use case model as a reference we can identify and classify the events of the target system in three categories:

1) Project life-cycle events. These are the events linked to the lifecycle of the projects. As pointed out in the above section, in the ETO environments projects coexist in three different definition stages. The corresponding transition events are:
   - New project arrival. This event refers to the situation of the company entering into a new quotation process. From the planning point of view, there is a request for a plausible project due date in order to bid or to participate in a tendering process. The input data consist of a rough project network determined by the engineering department.
   - Project contracted. A specific project has already been contracted so eventually it will load the shop; consequently, it should be considered in the aggregated planning. The rough project network will be substituted by that provided by the engineering department.
   - Project defined. The process-planning department has completed the definition of a project, so it can be scheduled jointly with the other projects.
2) Regular events. Periodically, it is necessary to make plans and schedules for all the projects, taking into account the most recent information available. The corresponding events are those concerning the medium-term and the short-term respectively:
   - New aggregated production planning. Typically, one or twice a month, aggregate production planning must be done. It consists in taking decisions concerning the assignment of temporal windows to each activity, and the defining of the medium-term capacity variances, via extra shifts or temporal contracting. Subcontracting decisions are also taken at this time.
   - New production scheduling. More frequently than aggregated planning, typically once a week, it is necessary to determine which operation must be performed, in which machine and at what time.
3) Shop-disruption events. Unexpected events happen in the day-to-day routine, some of them invalidating the current schedule and making it necessary to reschedule part of the operations at least.
   - Machine breakdowns. A temporal reassignment of the operations is needed, with the cascading consequences for the operations whose precedence is affected. The same refers to the absenteeism of a critical human resource.
   - Supply delays. If a number of operations are affected, a new schedule considering the new material arrival date must be made.
   - Activity over-duration. Depending on the consequences of the delay, over-duration may also imply rescheduling.

With regard to its internal architecture, the ETO simulator is a computer tool made up of several modules (see Fig. 2), aimed at defining the simulation session, generating the event list, advancing the simulation clock, generating the project and event data, and communicating with the decision support system through a database. All these modules are integrated into a computer application, which has a GUI (Graphical User Interface) that makes the tool suitable for the simulation game purposes.

When the user (the instructor) starts the ETO simulator, an initial screen presents him with the option of opening a previous simulation session or creating a new one. This second option leads the user to the screen shown in Fig. 4, allowing him/

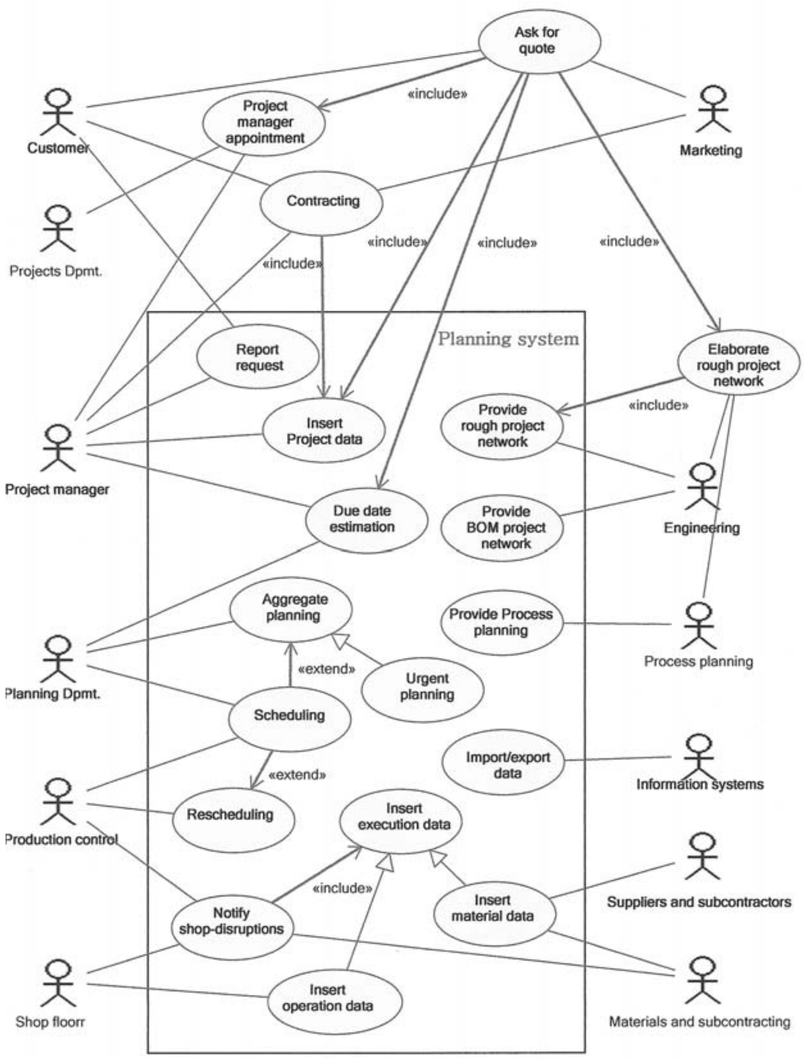

Fig. 3. Use case diagram of the planning system.

her to specify the desired simulation parameters. In the first tab, the general parameters are set. First, a reference session is selected, which serves to establish the default values. Then the random seed to be used—which makes it possible to reproduce a sequence of events exactly—and the mean time between events are specified. In the third place, two possibilities are offered to the user: defining the expected ratios that will follow the three shop-disruption events (those in Fig. 4) and the new project event—from which the other lifecycle events are derived— or treating these events independently, by defining their main occurrence parameters, i.e. probability of delay of each activity, days between resource breakdowns, probability of each material delay, and days between successive projects. The first option is pedagogically oriented to control a session, so that the events take place in the desired proportion (it is also possible to force one event to occur or to skip another); the second is more oriented to a realistic simulation of an ETO environment. In a simulation game, typically the first option will be chosen, as the sessions become more enriching and controlled if the desired events occur, but advanced concepts can be shown with the realistic option.

The other tabs of the screen in Fig. 4 allow specification of the different simulation parameters associated with the four events of the general tab (shop-disruption, new project). There are similar options for the three shop-disruption events, enabling the user to specify the statistical distributions, along with their corresponding parameters (mean, deviation . . .), to be used in the generation of the respective events: how long an activity exceeds its duration, how long a machine breakdown takes, how long material is delayed. Finally, the project tab gathers all the options related to the generation of the most complex event: the arrival of a new project. To generate a pseudo-random hierarchical project network that resembles a real one, the simulator integrates a complex independent module, HierGen, described in [37], which offers the possibility of specifying parameters as

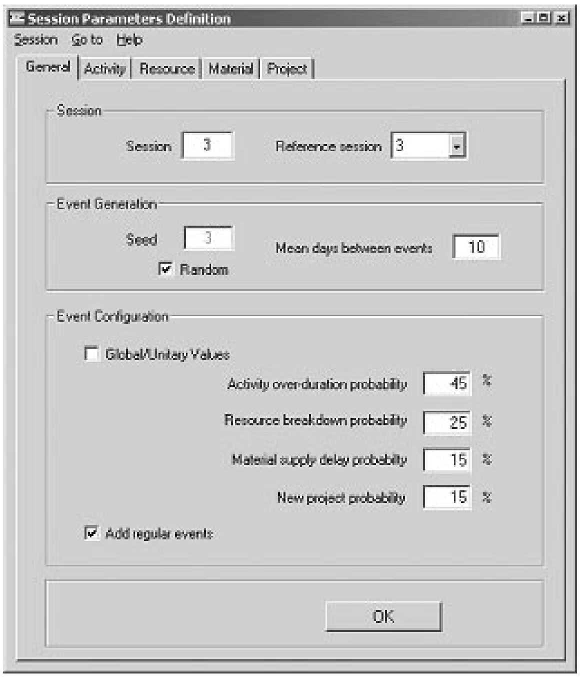

Fig. 4. Parameter definition screen of EtoSim.

the statistical distributions from which to draw the expected number of activities, the length of those activities, the expected precedence relations, etc.

Once the parameter definition of the session is completed, the initial state of the simulation and the event list are generated. The simulation is conceived as a series of states. A state is created as a result of the execution of an event; it consists of the pair plan/schedule after that event and will be valid until the next one. The initial state of a session is created as a copy of the reference session state. Therefore, it is possible to have several reference sessions and to use one or another depending on the objectives of the game. With the initial session established, the event generator determines the initial event list of the simulation.

The list is presented to the user in chronological order. The simulator offers the possibility of skipping some events (as the events are generated stochastically it is possible to prefer altering the proposed list). The first event of the list is then executed, which means that the clock will advance to the instant of that event. For the sake of usability, a simplification is made: it is assumed that what has happened in the interval between events is exactly what was scheduled (in the case of the first event it is the schedule of the initial state, and in subsequent events, the schedule is determined with the decision support planning tool). Thus, the clock module acts also as an execution data collector module, registering the operations that have been carried out in the database. Then the communication module takes control. This module waits until the user finishes the resolution of the event (as explained below). When the user gives the control to EtoSim again, the communication module checks whether a new pair plan/schedule has been defined and establishes the new state of the simulation.

Planning Decision Support System

When the ETO simulator informs the user of a new event and its characteristics (activity, resource or material involved, duration . . .), the role of the planning decision group commences. The group is provided with a computer tool which is a real-sized prototype of planning system, i.e. it is almost fully functional planning software capable of dealing with real-size production problems. The computer decision support system is primarily made up of two functional modules: one for quotation planning and aggregated planning, and the other for detailed scheduling. An additional module allows the monitoring of project planning and execution through the Internet. The modules are hierarchically integrated through a database system, which also communicates with the event-driven simulator. The two basic modules share a number of characteristics, as they are conceived in a similar way:

- The planning and scheduling algorithms follow a very similar logic, utilizing the same algorithmic engine, which is based on Constraint Programming techniques as described in [38–39]. The main differences stem from the level of aggregation of the data. The planning level is associated with medium-term decisions, and deals with days/months, aggregated activities and aggregated resources (groupings of similar resources). The scheduling level is associated with short-term decisions, and deals with hours/days, detailed operations and individual resources.
- The GUI has a very similar design, thus making it easier to learn how to use the tools. Both GUIs present the plans/schedules in the same way, as a four-framed screen, including (see Fig. 5): a resource Gantt chart, with the time-information of the activities to be carried out in each individual/aggregated resource; a multi-project Gantt chart, showing the planned/scheduled precedence networks of all projects; a load chart, representing the workload of each individual/aggregated resource; and a properties-results page, summing all the information regarding the parameters selected to create the plan/schedule and the results obtained by the algorithm. The creation of plans/schedules is also accomplished in a very similar manner. There is a creation wizard that presents three successive dialog boxes: the first dialog box contains general parameters of the algorithm such as the objective function to be optimized (earliness-tardiness, inventory cost . . .), the heuristic priority rule to guide the search (earliest due date, least remaining work . . .), and the search time of the algorithm; in the second dialog box the capacity and subcontracting options are

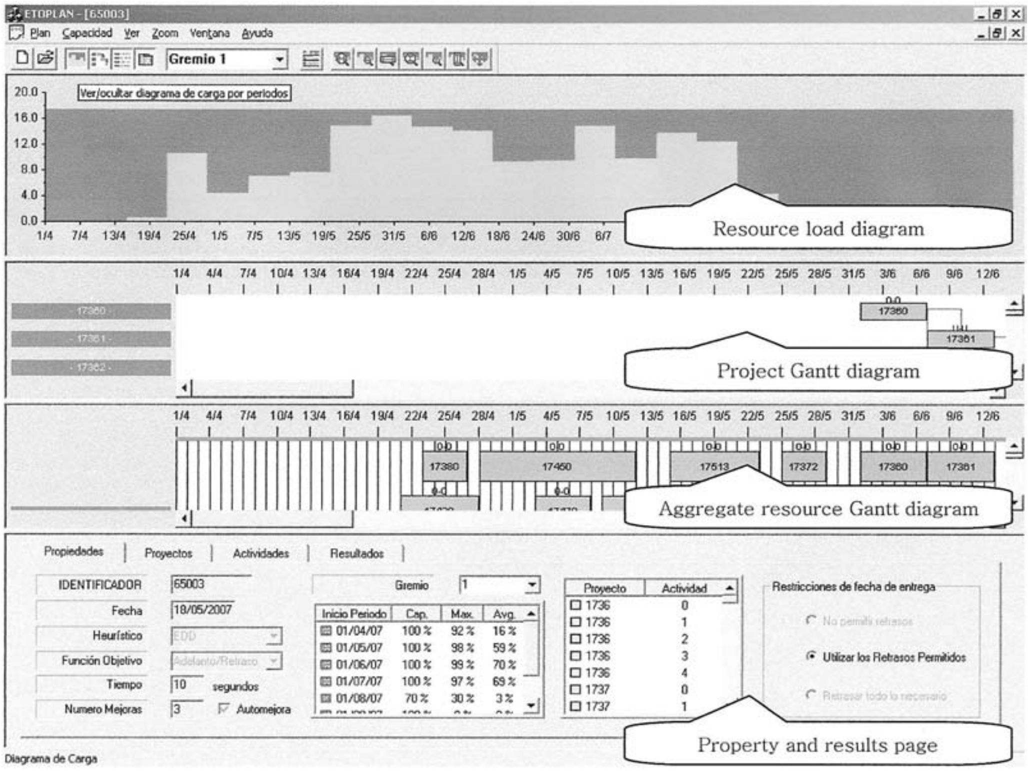

Fig. 5. Planning module main screen.

selected; in the third, the flexibility to the project delays is established (to require all the projects to be finished on time, to allow some slack, to allow as much delay as necessary).

- The way the decision is supported is also similar. The user creates a plan/schedule, analyses the result, and tries to change some specifications made in the creation. The tool makes it easy to change the active plan/schedule. Once a plan/schedule is satisfactory, the user marks it as 'firm', which means that it is set as the current plan/schedule of the simulation state.

With regard to the main differences between the planning and schedule modules:

- First of all, the planning module supports the due date estimation process, providing three alternate options: critical path method coefficient, in which the critical path is calculated and multiplied by a user specified coefficient; planning the new project along with the contracted ones, but imposing the constraint of not allowing extra delays in the current plan; and planning the new project with the others and with no extra constraints.
- The main functional difference is in the capacity definition. In the planning level, the capacity is defined as a monthly percentage relative to the nominal capacity of each aggregated resource (for instance, an aggregated resource profile would be 125% of its nominal capacity in April, 110% in May and 100% the remaining months; in the example of Fig. 5 all the periods of resource 1 are defined with a capacity of 100% except for August which is set to 70%). In the scheduling level, the capacity is defined as shift profiles (for instance, working two eight-hour shifts from Monday to Friday, one shift on Saturday and none on Sunday). In the resource Gantt diagram of the schedule module shifts are depicted with a colour code in the temporal axis. Figure 6 shows the definition of a resource breakdown. In the upper diagram Resource 1 works a double 8-hour shift from Monday to Friday and a single shift on Saturday. Green colour means the resource is free, blue colour means the resource is busy and beige colour means the resource is out of working shift. We define a breakdown from 19 May to 2 June and reschedule with the aid of the scheduling module. The result is the lower diagram in which the shift bar appears beige in the breakdown period and, consequently, none activity is scheduled causing a delay in the initial schedule.

Finally, the planning system includes a web module intended for customer or project manager use. This module is executed at the suggestion of the instructor, with the purpose of underlining the relationship with the mentioned actors. Customer needs frequent updates of the project status, actual and planned. The module allows for the generation of a brief report, including a Gantt diagram, which is generated in execution time and taking advantage of GanttProject libraries [40]. The user connects through a web browser to a specific web page and—after a user/password validation—the

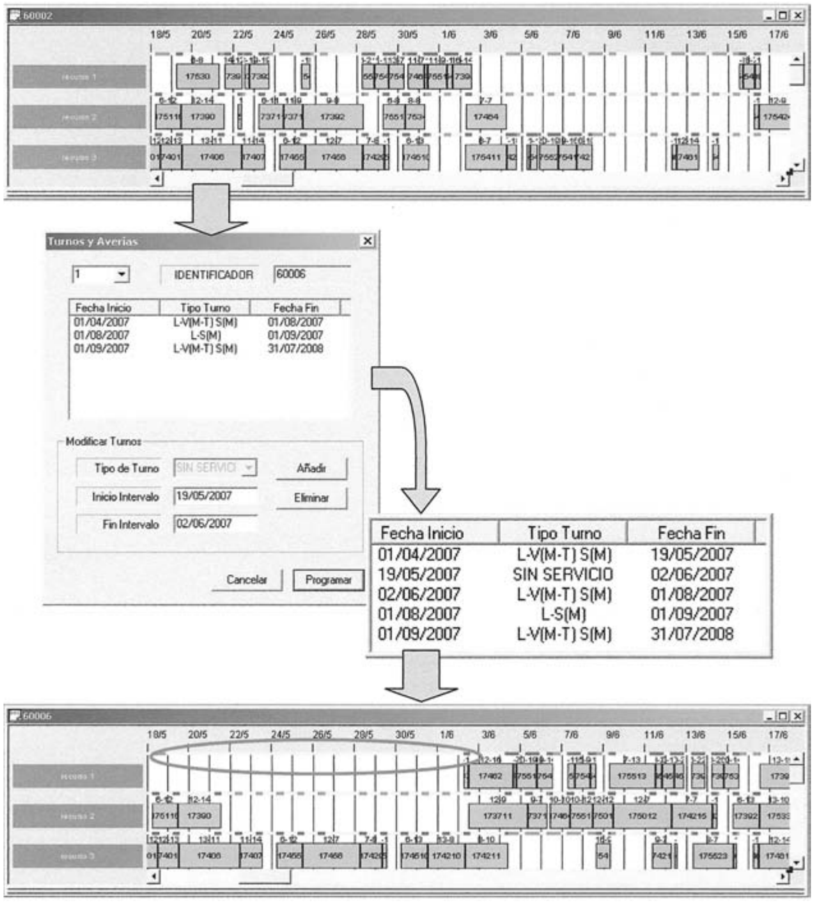

Fig. 6. Resource breakdown example with scheduling module.

module generates the requested report. Figure 7 shows an example of a project report and the corresponding Gantt chart.

SIMULATION GAME EXPERIENCE

To test the game, we conducted an experiment with eight students from the Industrial Engineering degree programme who had already taken introductory production management and project management courses. The game was carried out through five 4-hour group sessions, as part of a 6-credit course. The contents of the sessions were briefly the following:

1) Session 1. The session began with an introduction to the game followed by a presentation of the multi-project manufacturing case, emphasizing the positioning of project lifecycle within the framework of PLM. In the second part of the session we carried out a group discussion aimed at gaining insight into the case, using the characterization of the ETO industry included in section 3 (manufacture to order, demand uncertainty, project structure, part of a bigger project) as a guide (for example: 'The products are manufactured to order: how does it influence on BOM management?').
2) Session 2. The first part consisted in a description of the planning module and a short presentation of the simulator EtoSim. Then, a new EtoSim session was created, choosing the new aggregated production planning event to be executed. The new plan was elaborated in a group session, with the students suggesting several changes in the capacity and subcontracting options. The decisions regarding the changes were reached jointly by the students with the guidance of the instructor. Issues concerning data exchange with subcontractors were highlighted.
3) Session 3. With the same structure of Session 2, the first part of Session 3 included a description of the scheduling module. The EtoSim session was continued, choosing the new production scheduling event, which led to a group discussion. The new schedule elaboration was followed by the resolution of a machine breakdown event.
4) Session 4. In the first part we made a presentation of the due date estimation options as provided by the planning module. Then, we continued with the EtoSim session, picking the new project arrival event. The group proceeded to estimate a due date for the new project. In the last part of the session we reviewed the concepts learned so far, going

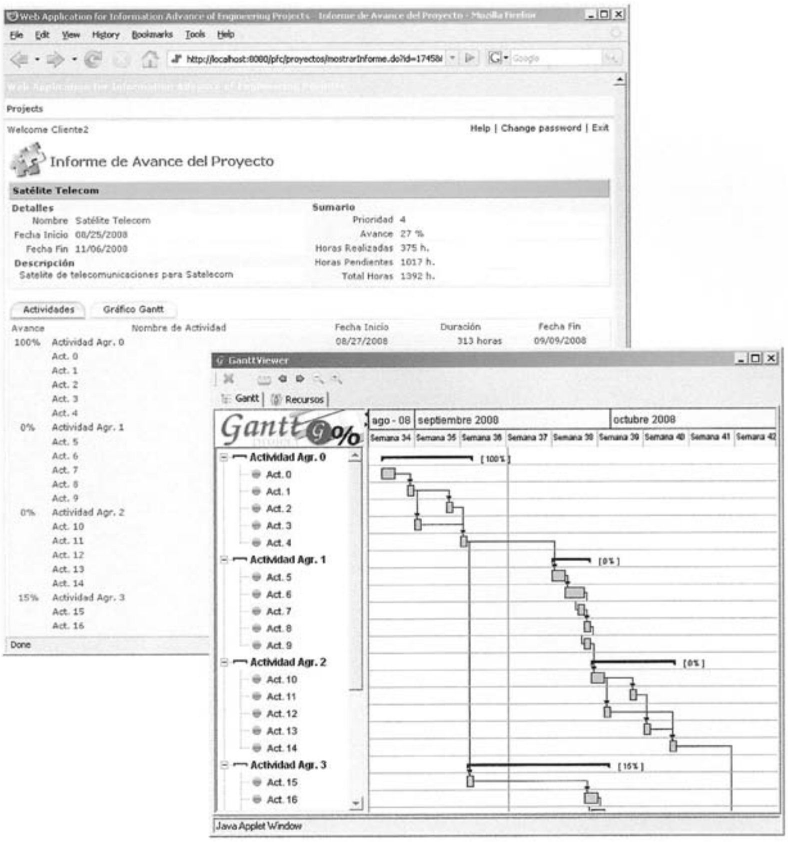

Fig. 7. Example of a project report generated by web module.

back to the project lifecycle and PLM scheme presented in Session 1. The session finished with a group analysis on the evolution of the project network throughout the lifecycle.

5) Session 5. In the last session we created a new EtoSim session with the purpose of covering a complete project lifecycle, from the due date estimation to the manufacturing execution. We reduced the indications given to the group, which worked almost autonomously.

After the five group sessions, each of the students participated in a 2-hour cam-recorded individual session. This session served as an evaluation of the knowledge acquired in the group sessions. The results were very positive, with all the students being able to comment and solve a given planning situation. As a means of game assessment students also answered some questions regarding their personal opinion. The answers showed students' great interest and motivation. Specifically, by the end of the game the students showed the following abilities:

- They were aware of the importance of information integration and the necessity of a holistic lifecycle management approach.
- They were able to solve real-sized planning situations through the use of advanced planning and scheduling techniques. Argue about the appropriateness of modifying resource capacities, subcontracting, schedule extra shifts . . . Interpret planning indicators (weighted/mean delays, weighted/mean earliness . . .).
- They were able to associate each lifecycle stage with the basic product information managed (input and output data) and with the proper information aggregation level, as well as the typical software applications used. Understand the evolution of the project networks throughout the lifecycle.
- They were familiar with the technical interactions (inputs and outputs, data exchange) and management relationships (precedence, requirements, typical complaints . . .) across the enterprise's functional areas involved in the product lifecycle.
- They were familiar with the supply chain stakeholders' (suppliers, subcontractors, customers) technical interactions (inputs and outputs, data exchange) and management interactions (demands, complaints . . .), as well as the consequences of delays in all the product lifecycle stages.

CONCLUSIONS

The planning aspect of product lifecycle is an important issue of Product Lifecycle Management (PLM). The learning of product lifecycle planning dynamics can be greatly enhanced by using computer-based and decision-centre simulation games, as they exploit the intrinsic connection and synergies of both case method and simulation games. The combination of a simulator which generates a set of events that take place in the engineer-to-order case, and a planning decision support system that makes it possible to emulate the resolution of the day-to-day tasks, appears to be quite beneficial for teaching all the concepts concerning the planning system.

By following product lifecycle from quotation to delivery, the students deepen the relationships and interdependences amongst the different functional areas of the company such as marketing, engineering, process planning, procurement and manufacturing; likewise, they become familiar with the relationships and data interchange across the supply chain (suppliers, subcontractors and customers). Students acquire valuable knowledge regarding the evolution of the information that accompanies each stage of product lifecycle, which elicits the linkages between PLM software and ERP systems. There is also an elicitation of the necessity and advantages of a holistic management approach to product lifecycle.

Experimentation with eight industrial engineering students shows that satisfactory results can be achieved with a minimum of 20-hour group sessions plus an individual evaluation.

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